Evaluation of a Simulator Training Program with Driving-Specific Feedback for Older Drivers

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Abstract

Older adults over the age of 65 continue to be the fastest growing segment of the population when it comes to driving. Driving a vehicle is complex and many older adult drivers see their safety being affected as they are at a higher risk of motor vehicle crashes, especially while maneuvering intersections as drivers tend to engage in less frequent scanning behaviours in these situations. There exist numerous ways to increase the life expectancy of safe driving, notably through a virtually simulated driving environment. However, one key factor in the acquisition of safe driving behaviours relies on the nature of the feedback provided while being trained in a simulated environment. Therefore, the current study sought to further reduce this gap by providing two types of live feedback (i.e., simulator or instructor feedback) at intersections during simulator training and to determine its impact on scanning behaviours and overall driving performance. A total of 61 participants aged 65 years and older were randomly assigned to one of three conditions: 1) Control Group (CG); 2) Instructor Feedback Training group (SIT); and 3) Simulator-Automated Training group (SAT). All participants completed a combination of cognitive (e.g., Montreal Cognitive Assessment) and visual (e.g., Pelli Robson Contrast Sensitivity; Peripheral Motion Contrast Threshold) baseline measures. The primary outcomes were the number of scanning errors at intersections and global driving errors on the road and in the simulator which were captured by video and coded by multiple blinded and independent raters. Results indicated that automated feedback and instructor feedback contributed significantly towards decreasing scanning errors both during simulated and on-road drives in comparison to the control group. However, the generalizability of feedback towards global driving behaviours was mixed, with mostly insignificant findings except for decreases in general observation errors on the road. The results of this study highlight the importance and relevance of individualized training methods for improving targeted driving behaviours in older adult drivers.

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Chapter 1: Introduction

The older adult population, defined as individuals over the age of 65, has been steadily increasing over the last decades and was reported to occupy approximately 18.8% of the Canadian population in 2022 (Statistics Canada, 2022). This number is projected to increase to numbers between 21-30% by 2068 (Statistics Canada, 2022). The shift to older adulthood is an adjustment to many, especially since it is accompanied by numerous other transitions, such as those of social and health statuses. For example, many individuals' employment status' shift as they transition to older adulthood, and many utilize this number as a standard when planning their retirement. This is supported by reports which stated 64.6 years of age as the average age of retirement in 2022 (Statistics Canada, 2022).

As individuals age, they become more susceptible to physical and cognitive ailments, and many are therefore subject to changes in health status, such as dementia or other degenerative disorders. Regardless of the nature of the ailment, older adulthood can be accompanied by cognitive impairments (i.e., memory, reasoning, judgment, communication, visual perception, attention, etc.), behavioural impairments (i.e., motivation, emotion regulation, social behaviour) and functional impairments (i.e., loss of motor function; Chapman, Williams, Strine, Anda & Moore, 2006). However, with the ongoing development of technology and specialized medical treatments, there has been an increase in longevity, whereby people with a variety of conditions can live much longer than before. In fact, between 2018-2020, Canadians could have expected a life expectancy of 81.97 years on average at birth, comparatively to that of 75.43 years between 1980-1982 (Statistics Canada, 2022).

It can be assumed that this increase in longevity can lead to increases in other areas of living, such as driving, in which individuals are expected to drive longer than ever before. In Canada, driving is the main means of transportation for most of the population and it is inherently linked to one's sense of independence, autonomy and identity (King et al., 2011; Rosenbloom, 1993). The benefits of driving are widespread and have been documented through research as a cultural practice essential to activities of daily living, such as acquiring and accessing basic needs like food and shelter (Redshaw, 2017). Driving also acts as a facilitator for pleasurable activities as well as accessing social activities and family connections (Steg & Gifford, 2005) and is associated with psychological benefits such as a sense of independence, and freedom and can contribute to the reduction of stress and anxiety (Liddle et al., 2014). Other benefits include the widespread access to a variety of environments, such as employment and healthcare, among others. Older adults are certainly not exempt from these benefits and heavily rely on and prefer personal transportation over other means to access their mobility needs (Gormley & O'Neill, 2019). This is especially important for older adults living in rural communities where transportation alternatives are typically limited. Data from the AAA LongROAD study highlights that older adults from rural areas rated the importance of driving as being more elevated in the prospect of future potential driving cessation (Strogatz et al., 2020).

Needless to say, driving is also directly related to a person's quality of life, impacting areas of both physical and psychological health as well as life satisfaction, self-reliance, freedom and independence (Carp, 1988; Cohen-Mansfield, Dakheel-Ali, & Frank, 2010; Dickerson et al., 2007; Owsley, 2002). Preserving these outcomes in older adulthood is especially relevant when considering advances and supports for the aging in place movement. This movement has been generally defined as the desire to remain in one's home as they age, which has been linked to well-being, a positive sense of control and independence (Fox-Grage, Coleman, & Freiman, 2006; Sabia, 2008; Wiles et al., 2012). In order for one to successfully age in place, certain factors are required, one of which is unsurprisingly related to transportation (Dickerson et al., 2007). While alternative options for transportation do exist in most communities, older adults nonetheless heavily rely on and prefer driving as their primary means of transportation (Webber, Porter & Menec, 2010). Therefore, the lack of adequate transportation would result in a person's inability to access essential items and activities of daily living, as highlighted previously, leading to unsuccessful aging in place and consequently affecting the person's physical and psychological well-being.

Driving holds an especially important role in an individual's life, so much so, that the act of ceasing to drive, commonly referred to as driving cessation, is linked with the onset of negative outcomes such as deteriorating health, weaker social connections, increased frustration and loss of independence (Adler & Rotunda, 2009; Pellerito, 2009; Sanford et al., 2020). These impacts are typically felt across any age group but more commonly impact older adults due to the physical and cognitive changes that they face which force them to cease driving. Often enough, the decision to cease driving does not come from the driver themselves, but rather from their caregiver/spouse or family physician. Regardless of who addresses this topic, making decisions regarding driving cessation can be extremely stressful. The impacts of driving cessation have been felt recently alongside the apparition of the COVID-19 pandemic which confined many individuals in their homes for extended periods of time. The many mandatory confinements forcibly led to the premature and temporary driving cessation of many individuals, as evidenced by reports showing drastic reductions in driving activity and traffic volumes (Apple, 2020; Clarke, 2020; Google LLC, 2020) and consequently led to many adverse effects, namely endangering the physical and emotional health of the older adult population (Abootalebi et al., 2021). A longitudinal study which followed older adults' driving behaviour since 2017 was able to compare their driving behaviour before and after the onset of the pandemic and reported that older adults went on significantly fewer and shorter trips and reduced their number of days driving (Roe et al., 2021). Regardless of the underlying nature leading to driving cessation, it remains that the impacts are influential on the well-being of many. The key now lies in determining whether there is a way to provide early intervention to address age related driving declines before they are faced with the daunting ultimatum of giving up their license. However, we must first better understand the nature of changes in aging and how they pertain to driving before intervening.

Normative changes in aging and their effect on driving

Driving is a complex activity and requires the combination of motor, visual and cognitive skills. Among others, driving requires accurate detection and quick processing of multiple relevant driving cues, all of which are essential to optimize timely driving reactions and decision-making. In 2021, over 26 million people held a valid driver’s licence across Canada; the age group of drivers over 65 years old occupied the largest portion of drivers, totalling to approximately 20% of the driving population (Statistics Canada, 2021). This represents a considerable increase since 2011 when they were reported to occupy approximately 15% of the total licensed population (Statistics Canada, 2011). While aging is not a contraindication to driving, the increased prevalence of illnesses or the natural changes commonly associated with aging coupled with the increase in longevity results in more cognitively and physically impaired older adults on the roads, consequently raising potential danger and safety concerns (Ayuso, Sanchez et al., 2020). Examining the normal age-related changes across a multitude of areas of functioning can help us understand the exact nature of driving deficits in the older adult population which results in these concerns.

Cognitive changes

Unsurprisingly, aging is often accompanied by numerous predictable normative (Harada, Natelson & Triebel, 2013; Lezak, Howieson & Bigler, 2012; Salthouse, 2010) and non-normative (i.e., dementia; Carr, 2000) cognitive changes. While many of these changes are a normative process of aging, they nonetheless represent a change in functioning and can therefore impact activities of daily living, such as driving (Anstey & Wood, 2013; Cuenen et al., 2016; Salthouse, 2019; Wagner et al., 2011). Specifically, declines in processing speed are well documented in the literature (Brunce & Macready 2005; Raz, 2000; Salthouse, 2010). This slowness in processing information has been suggested to impact additional areas of cognitive functioning, such as memory, fluid abilities (i.e., processing and transforming new information) and crystallized abilities (i.e., cumulative skills and memories from past acquired knowledge; Finkel & Pedersen, 2004). Numerous studies document the relationship between processing speed with better lane keeping and car following behaviours (Andrews & Westerman, 2012; Bunce et al., 2012), as well as consistent speed maintenance and reactions times (Bélanger et al., 2015). Irrespective of processing speed, deficits in certain memory abilities such as working memory, retrieval of information and learning are documented while other aspects of memory such as procedural, and immediate memory seem to be stable in older adulthood (Buckner, 2004; Chai et al., 2018; Lezak et al., 2012; Verhaeghen et al., 2003). Strong memory has been linked with better lane-keeping behaviour and car following across all ages (Bunce et al., 2012). Additional affected cognitive skills in aging include declines in executive functioning (i.e., decision-making, problem solving, multitasking; Lezak et al., 2012; Paraskevoudi et al. 2018), diminished capacity for numeracy (ability to understand numbers and mathematical concepts; Best et al., 2022) and visuospatial processing (Lezak et al., 2012). Better results on visuospatial tasks have been linked with safer overall driving (Andrews & Westerman, 2012; Michaels et al., 2017), better lane keeping behaviour on the road (Ledger et al., 2019; Sun et al., 2018), and fewer crashes across all ages (Michaels et al., 2017). Moreover, a recent meta-analysis which examined the impacts of cognitive functioning on the driving performance of older adults in comparison to younger adults concluded that, irrespective of age, domains of cognitive function such as executive function, attention and dual task ability are associated with driving performance (Depestele, 2020). However, older adults were found to perform worse on cognitive and driving tasks than younger adults, suggesting the presence of an age-related decline in cognitive and driving performance. More specifically, older adults were noted to adopt more defensive driving habits such as maintaining slower speeds to compensate for higher task demands in complex driving situations. They also demonstrated larger variability in their driving (i.e., lane-keeping behaviour, distance to lead car). The domain of attention also sees changes during aging, most notably during complex attentional tasks such as divided attention (i.e., ability to simultaneously pay attention to multiple tasks), selective attention (i.e., ability to pay attention to certain information and disregard others, and sustained attention (Bigler, 2012; Commodari & Guarnera, 2008; Lufi & Haimov, 2018; Murman, 2015; Vallesi et al., 2021). A recent study by Balzarotti and colleagues (2022) examined the change of driving-related cognitive abilities in a sample of older adult drivers undergoing an assessment for driving fitness over time and found that selective attention decreased significantly between their two measurement points (between 1-4 years).

Overall, while some associations between cognitive aging and driving performance can be inferred, it does not imply causation. It also remains that older adults most affected in driving are typically those who suffer from clinically significant cognitive changes (Anstey et al., 2017; Barco et al., 2015; Carr, 2010).

Physiological changes

Physiological and health-related changes are a commonly cited cause for driving cessation (Adler & Ruttunda, 2006; Ragland et al., 2004). These changes include medication use as well as changes in health status, physical fitness and senses. In the realm of vision, changes in visual acuity, contrast sensitivity and visual fields, which are common in aging, have been associated with adverse driving outcomes (Owsley & McGwin, 2010). Specifically, a recent study on visual acuity demonstrated that drivers with higher visual acuity were able to perceive other vehicles and pedestrians sooner and were thus able to respond and react quicker than drivers with lower visual acuity, regardless of age (Selander, Thorslund & Henriksson, 2021). Visual acuity, along with poor contrast sensitivity and peripheral vision have also been linked with less driving mobility (Emerson, Johnson & Dawson, 2012; Freeman, et al., 2005). Conversely, drivers with better contrast sensitivity were associated with fewer safety critical events (i.e., harsh breaking, turning and acceleration; Feng et al., 2021). A systematic review by Nguyen and colleagues (2023) examined the impact of visual impairment on on-road driving performance. While they were unable to conduct a meta-analysis due to large variability in outcome measures, they were nonetheless able to conclude that a wide range of visual problems (i.e., visual acuity, contrast sensitivity, visual field, glare sensitivity or specific eye conditions) negatively affect a multitude of driving performance measures. These findings were in part supported by a previous study by Wood (2022), but they specified that motion sensitivity, contrast sensitivity and useful field of view were more strongly associated with driving performance than visual acuity and visual fields.

Physical functioning, described as the ability to perform and complete basic activities of daily living, has commonly been examined in the context of driving mobility. Specifically, driving mobility is typically comprised of driving space (i.e., zone driven beyond one's home), driving exposure (i.e., such as driving at night), driving frequency (i.e., number of trips per week), and driving distance (i.e., miles driven per week). A longitudinal study on the association between physical fitness and driving mobility revealed that several markers of physical functioning were associated with certain outcomes in driving mobility; grip strength was associated with driving space and number of miles driven; number of steps and self-reported physical function was associated with driving exposure and driving frequency (Phillips et al., 2016). Additional studies corroborated Philips et al.'s findings and concluded that a specific measure of physical functioning such as the lower extremity physical performance task, is positively associated with driving exposure and driving cessation (Ng et al., 2020) and is inversely associated with restricted driving space (Mielenz et al., 2017). However, they failed to find any association between this measure and crash risk. Additionally, a reduced range of neck motion, which is important for environment scanning and lane changing has been linked with unsafe driving (Lacherez et al., 2014).

Self-perception changes

Discourses regarding societal perceptions of older adults' driving competencies have been at the centre of research and media for several years (Davies & Patel, 2005; Glasgow & Blakely, 2000; Parker et al., 2001; Rothe, 2020). A tendency to disregard idiosyncratic differences and view and treat older drivers as a single homogenous group has been observed. This was notably the case with studies examining stereotypes which revealed that younger drivers often perceived older drivers as being a homogenous group, wherein any unsafe or risky driving maneuvers by a single older adult were considered as being typical or expected of all older drivers (Joanisse, Gagnon & Voloaca, 2012; Lambert et al., 2013). These studies also reported general stereotype themes of perceiving older adults as being overly cautious, uncomfortable behind the wheel and being too slow. A follow-up study also confirmed that older drivers were additionally attributed a positive stereotype of being “cautious” drivers (Selwyn, 2014). Older adult drivers themselves also hold self-perceptions of their driving abilities which can affect their driving behaviours. More specifically, older drivers were reported to rate themselves as being more skilled compared to when they were younger but added experiencing challenges with maintaining their speed, sensitivity to glare and requiring additional time to interpret road information such as road signs (Musselwhite & Haddad, 2010). Similar conclusions were reported in Huang and colleagues’ (2020) systematic review which examined how older adults self-perceive their driving abilities. Their findings revealed that older adults tend to not only perceive their driving abilities as being better compared to their younger age but also in comparison to objective driving ability evaluations (Huang et al., 2020). It is important to note that stereotypes and self-perceptions do not necessarily equate to objectively measured behaviours on the road. To this effect, there are mixed findings on the impact of self-perception and stereotype factors on older adults’ actual driving, with many studies failing to provide any empirical evidence in support while others simply concluded that some older adults were not affected by stereotypes (Davies & Patel, 2005; Gaymar, Chauveau & Cohen, 2022; Huang et al., 2020; Parker et al., 2001). This mismatch could potentially be explained by the fact that the self-perceptions may not be accurate due to a self-presentation bias (Horswill et al., 2013). On the other hand, a study conducted by Lambert and colleagues (2016) demonstrated that older adults with reduced working memory capacity (i.e., ability to ignore distractions and maintain task goals) under stereotype threat experienced longer break reaction times and maintained longer distances to vehicles in front of them during a simulated driving task. Similar findings were concluded in the most recent study by Brelet and colleagues (2016) in which older drivers under stereotype threat often saw their ability to self regulate in strategic ways be hindered. While it is important to be cautious in not further projecting these stereotypes, it is also important to recognize the normative changes that happen in older adulthood and how these can relate to driving performance and risks for this population.

Driving outcomes in older adults

Common and normal issues within aging across prevalent areas of functioning and how they may globally pertain to driving were presented in the previous section. This section details common impacts on driving outcomes in older adults. However, it is first important to understand and define a driving outcome, as this term in the literature can refer to an amalgamation of different measures and terminology. Specifically, a distinction between two common themes of driving outcomes can be made: driving safety and driving performance. Both have been closely examined with older adults in light of the normative cognitive, physiological and perceptual changes that they face, which have been previously discussed. Driving safety typically refers to crash risk or crash rate while driving performance is defined as a driver's behaviour which encompasses strategic behaviours (e.g., route and lane choice), tactical behaviours (e.g., following, approaching, lane changes), situation awareness (e.g., scanning the road environment, head movements), and operational behaviours (i.e., vehicle control, signalling, steering; Li et al., 2019; Michon, 1985). While these refer to separate measurable outcomes, it is not recommended to delineate them rigidly from each other as driving performance can often be a precursor for driving safety (Shechtman et al., 2007).

A growing body of research has been dedicated to examining the driving safety of older adult drivers, especially in how it pertains to crash involvement and crash risk, also known as motor-vehicle collisions (MVCs). While older adults tend to drive less than younger adults (Karali et al. 2016), they nonetheless accounted for the most fatalities in motor vehicle accidents in 2021, accounting for approximately 21% of the total fatalities (Statistics Canada, 2021). Further, recent reports indicate that approximately 1 in 5 individuals over the age of 65 deceased following a crash, a data that seems to overrepresent this age group given the proportion of older adult drivers on the roads (Transportation Canada, 2021). However, while these statistics pose concern for the safety of all road users, it is important to be cautious in their interpretation by recognizing that these statistics reflect fatality only and cannot attest to a driver's accountability in the crash or their performance on the road. Likewise, this also does not equate that more older drivers means more car crashes. Interestingly, recent reports have demonstrated a downwards trend in the total number of fatalities since 2011 (Transport Canada, 2021). However, these overall statistics nevertheless attest to the fragile nature of older adulthood which leaves them more susceptible to serious injuries and fatalities (Alhomaidat et al., 2020; Eberhard, 2008). While these statistics are to be interpreted prudently, there nonetheless exists some evidence to suggest the presence of some deficits in older adulthood which increase their risk. Additional statistics from 2020 show that older adults had the highest percentage of fatalities because of distracted or inattentive driving, accounting for 24.9% of total fatalities (Transport Canada, 2020).

Studies have found that declines in physical, perceptual, and cognitive abilities, such as those previously discussed, are associated with an increased risk of driving accidents (Brayne et al., 2000; Hole, 2007; Lundberg et al., 1998). More specifically, in comparison to younger drivers, older adult drivers tend to perceive a greater mental workload from driving which makes it more difficult to attend to a multitude of demands, therefore resulting in increased difficulty controlling their vehicle (Bélanger, Gagnon, & Yamin, 2010; Cantin et al., 2009). Not only are older adults involved in more MVCs that occur in good driving conditions (i.e., during the day and with good weather), but they also account for a larger proportion of MVCs which involve at least one other vehicle (Coughlin & D’Ambrosio, 2012). A recent study has found a positive relationship between the age of older adult drivers and the severity of a crash, with drivers over the age of 75 being more at risk than their counterparts between the ages of 65-75 (Ayuso, Sanchez & Santolino, 2020), which can potentially be attributed to their greater physical fragility and cognitive decline (Noh & Yoon, 2017; Regev et al., 2018). Additional differences based on road environment have been observed, with a greater crash risk being present in rural areas than in urban areas (Horne & Reyner, 1999; Zwerling et al., 2005). Conversely, Canadian statistics show that there is a greater number of collisions in urban areas, but rural collisions result in greater fatalities (Transport Canada, 2021); which may in part be due to the reduced availability of emergency services in these regions.

Although these findings can pose concerns for older adults and all-road users, it is nonetheless important to recognize that not all older adult drivers pose risks on the road, with many being able to sustain safe driving for many decades. It is also important to make distinctions between drivers who are over 65 years old, and those who are 80 years old and over since the cognitive, physical, and perceptual impacts in both ranges can vary significantly. Nonetheless, these issues remain relevant, especially when considering the impact of intervention strategies which could improve driver and overall road safety.

Intersections

It is critical to recognize that safety risks are not uniquely attributable to deficits on the driver's part, but rather occur because of the interaction between a driver's ability and the road environment itself. This is especially the case when examining drivers' behaviours at intersections, which have long been documented as particularly challenging situations to navigate. Intersections are defined as points where two roads intersect (i.e., cross or T intersections), and can be comprised of signalized/controlled (i.e., controlled by a traffic signal or road sign) and non-signalized/uncontrolled (i.e., not controlled by traffic signals or road sign) intersections. These road points are further complicated by their high traffic density and their many points of potential conflict with other road users, whether they be drivers, pedestrians, or cyclists, which leave minimal reaction time to respond. Approximately 30% of reported fatalities and 40% of reported serious injuries have occurred at intersections across the entire Canadian population (Transport Canada, 2020). These road points are thought to be especially challenging for older adult drivers to navigate (Romoser et al., 2013) and older drivers are more likely to commit an improper action leading to an intersection crash than other drivers (Transport Canada, 2020). In fact, after the age of 75, the risk of intersection crashes is said to dramatically increase (Clarke et al., 2010; Lombardi et al., 2017; Yamani et al., 2016). Indeed, many of the reported MVCs that involve older adult drivers have occurred at intersections (Langford & Koppela, 2006; McGwin & Brown, 1999), many of which can be attributable to errors related to difficulties merging into traffic, failure to yield the right of way, improper lane changes, and improper entry or execution of a left turn (Braitman et al., 2007; Cicchino & McCart, 2015; Clarke et al., 2010; Davis et al., 2018; Hakamies-Blonqvist, 1993; Langford et al., 2006; Vichitvanichphong et al., 2015). Similar conclusions were found at stop sign controlled intersections where older drivers displayed difficulty in the execution of left and right turns which was at the source of their crash involvement (Romoser et al., 2013, Wang & Qin, 2015). Similarly, a recent study which examined the liability for crashes at stop sign controlled intersections revealed that older drivers were less likely to be liable for a crash when crossing straight but were 2 to 92 times more likely to be liable when executing a turn or a lane change (Alhomaidat et al., 2022).

To safely maneuver through an intersection, drivers must actively scan their environment for potential hazards, which include vulnerable road users (i.e., pedestrians and cyclists). However, since intersections are typically a dynamic and constantly changing environments, they usually warrant rescanning to increase certainty of the state of a driver's surrounding environment. Scanning behaviour refers to a person's ability to observe important segments of a driving environment, using either lateral head or eye movements or a combination of both (Cicchino & McCartt, 2015). While peripheral vision can be useful in detecting some hazards, a larger movement, ideally the combination of eye and head movement, referred to as gaze, would be necessary to bring an object or hazard into clear sight to be detected (Bowers et al., 2019; Savage et al., 2020). Numerous studies to date have demonstrated that older adults partake in less scanning behaviours compared to their younger counterparts (Bao & Boyle, 2009; Bowers et al., 2019; Romoser & Fisher, 2009; Romoser et al., 2013; Yamani et al., 2016) and account for the most frequent errors leading to older adult crashes during intersections (Braitman et al., 2007; Cicchino & McCartt, 2015). Some of these studies investigated scanning behaviours as a function of primary glances (i.e., eye movement to either periphery when approaching an intersection) and secondary glances (i.e., eye movements towards latent hazards once driving through the intersection). Their results suggest that older drivers executed significantly fewer secondary glances compared to younger drivers (Romoser & Fisher, 2009; Yamani et al., 2015). However, many of these studies used different metrics to quantify scanning behaviours, some of which relied exclusively on eye movements (Romoser et al., 2013), others on head movements (Bao & Boyle, 2009; Bowers et al., 2019), and some using a combination of both (Kito et al., 1989; Romoser & Fisher, 2009). A study by Savage and colleagues (2020) sought to better quantify scanning behaviour to acquire a more accurate understanding of whether the reported age effects were a result of age-related differences in eye or head movements. They did so by evaluating these behaviours on a driving simulated task while following a lead car. Participants were categorized according to the type of guidance they received, whether it was from a GPS or a lead car. Gaze scans were operationalized in terms of two primary components: eye-only scans (i.e., predominantly eye movement only), and head+eye scans (i.e., contained both eye and head movements). Their findings stipulated that the magnitude of scans by older adult drivers was inferior to those of younger drivers (p=.036). Interestingly, their findings also revealed that older adults made fewer head+eye scans (p=.002) but more eye-only scans compared to young drivers (p<.001), which suggests the presence of compensation for lack of neck flexibility which is a common functional limitation in older adults (Bowers et al., 2019; Savage et al., 2020). A small effect of guidance type was found, whereby participants following a lead vehicle had a slightly lower number of scans close to the intersection compared to participants following a GPS (p=.015).

Many hypotheses have been suggested to better understand the challenges that affect scanning behaviours in older adults, and therefore driving. For example, the increased safety risk for older drivers is believed to stem from the relationship between aging and declines in cognitive and sensory abilities which results in insufficient scanning before and during their maneuvers. One of the most common theories relates this deficit to attentional limitations (Angell et al., 2015; Stinchcombe & Gagnon, 2009) since drivers are required to consecutively allocate their attention to many different areas at an intersection. Attentional abilities can significantly decline with age, which manifests itself as a reduced capacity to execute several tasks simultaneously, increased distractibility as well as a reduction of the attentional field of view (Yamani et al., 2016). Coupled with other normative cognitive declines such as slower reaction times and gap choice decision-making for situations of greater complexity, this only continues to add to the mental load that these drivers must manage on the road in a very short time frame (Bao & Boyle, 2008).

Research has also proven that driving behaviour changes as a function of the intersection type. In terms of crash risk, there is evidence which reports that the number of crashes at signalized intersections is more elevated than at non-signalized intersections (Braitman, 2007; NHTSA, 2020; Yamani et al., 2016), with red-light violations comprising the most dangerous threat (Chen, Cao, & Logan, 2012). Other studies have examined aspects such as operational tasks for right turns at intersections (Wu & Xu, 2017), approaching and stopping behaviours at intersections (Hong et al., 2016), cognitive distraction at stop-sign controlled intersections (Liao et al., 2015) and attention allocation at non-signalized intersections (Bao & Boyle, 2009) among many more. A recent study by Girgis and colleagues (2023) examined the allocation of visual attention at urban intersections across all ages. Their study found that drivers waiting to complete a turn were observed to be focusing most of their attention on pedestrians or on leftward traffic when waiting to turn right on a red light. Of particular interest to our study, however, is the applicability of this principle when examining scanning behaviours based on the type of intersection. In particular, a few studies have examined scanning behaviours in either signalized or non-signalized intersections and some have looked at a comparison of the two environments. For the former, results show that older drivers spend more time looking at road lines and markings at signalized intersections (Dukic & Broberg, 2012), while they were noted to observe less at potential threats while turning at non-signalized intersections (Yamani et al., 2016). Research reveals that a there is a significantly higher number of crashes taking place at signalized in comparison to unsignalized intersections (Yamani et al., 2016). There are many hypotheses that can explain this difference in crash risk between both types of intersections. Interestingly, in a simulated study by Liu and Ozguner (2007), they found that drivers spent more time being engaged in decision-making and stopping behaviours at unsignalized compared to signalized intersections which could likely be a contributing factor. Another study conducted by Li and colleagues (2019) investigated differences in visual scanning between signalized and unsignalized intersections in a sample of ten Chinese drivers. They segmented the visual field into 10 areas of interest; forward (FW), near left (NL), near right (NR), far left (FL), far right (FR), rear-view mirror (RM), left view mirror (LVM), right view mirror (RVM), clusters (CL), and others (OT). They reported that drivers were observed to check their left view mirror most frequently when driving straight through signalized rather than non-signalized intersections. In terms of signalized intersections, drivers were found to attend most to the forward, rear-view mirror and left view mirror areas. These results suggest that there are areas in intersections that are subject to more frequent checks than others, possibly leaving place for some hazards to not be detected. However, their results should be interpreted with caution not only given the small sample size, but also in terms of implications since they did not assess how these results could change based on age. Overall, more research is needed to better understand the nature of scanning behaviours conducted at the different types of intersections.

Theoretical considerations for driving in older adulthood

Person Environment Fit Model

Previous evidence in the literature discussed above has highlighted how a driver's personal factors (i.e., age, cognitive, physical, and sensory functioning, etc.) rendered intersections difficult to manage. However, this evidence is not sufficient to properly encompass the interaction between the driver and their environment which is crucial to acquiring a complete understanding of the exact nature of behaviours at intersections. The Person Environment-fit framework (Lawton, 1982) is a psychological framework which posits that human behaviour is a result of the interplay between personal and environmental characteristics – this is where the notion of "fit" comes from. This model states that a person and their environment can mutually influence each other and that this fit dictates a person's motivation, behaviour and overall well-being (Eccles et al., 1997). If a fit is deemed optimal, that means that the person's functioning may be facilitated and vice versa. This framework is fitting in the driving context since it allows for the complexity of the driving environment to be taken into consideration. When applied to this environment, this model suggests that road and traffic conditions can influence an older driver's ability to drive safely. In the instance where the demands of the environment, referred to as "environmental press," are too great, it can lead to maladaptation and potentially lead to safety concerns. This is especially relevant for intersections since these segments are known as road points with increased structural complexity and high traffic concentration. Lawton defined the individual's ability to cope with environmental press as a skill set comprised of sensory motor functioning, biological health, and cognition among others, which are all relevant domains for optimal and safe driving. Therefore, an alternative outcome to be considered is that the driver has inadequate skills, such as deficits in any of these domains, to navigate the environment.

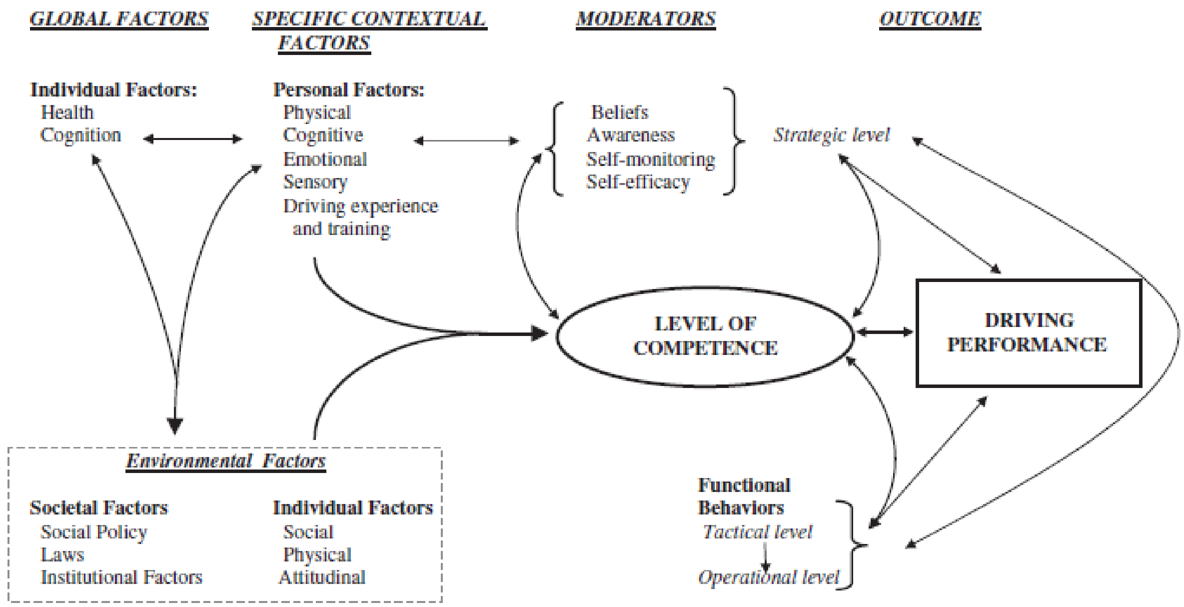
Consequently, a congruent fit between the driving environment (i.e., intersections) and the driver would equate into more adaptive driving behaviours at these road points. From this model, we can therefore infer the need for one of two things to ensure a proper fit: 1) structural changes to diminish the load from the environment (i.e., at intersections) or 2) individual changes to increase a person's capacity to meet the needs of the environment.

Driving as an Everyday Competence (DEC) Model

Similar to Lawson's Person-Environment Fit model, Lindstrom-Forneri and colleagues (2010) built a model directly linked to the driving context and adapted it specifically to older drivers. Their Driving as an Everyday Competence (DEC) model puts at the forefront the assessment of driving competency and level of driving performance. This model (see Figure 1) was critiqued by a panel of experts from the Canadian Driving Research Initiative for Vehicular Safety in the Elderly (CanDRIVE) research team. The version presented in this section is the result of the consensus from this panel of experts. The DEC model defines driving competence as the result of the interaction between the driver and the environment. This variable is considered latent, and therefore not measured, but is subject to fluctuations based on the demands of the environment and on the driver's own functioning (i.e., cognitive, psychological, sensory, and motor) in that particular environment. Driving performance, on the other hand, is defined as the actual actions that drivers commit on the road and is moderated by the individual's awareness, beliefs, self-monitoring, and self-restrictions.

Figure 1

Driving as an Everyday Competence model



Note: Adapted from "Driving as an Everyday Competence: A Model of Driving Competence and Behavior," by W. Lindstrom-Forneri, 2010, Clinical Gerontologist, 33(4), 284 (https://doi-org.proxy.bib.uottawa.ca/10.1080/07317115.2010.502106). Copyright 2010 by Taylor & Francis. Reprinted with permission.

The DEC model incorporates global factors which encompass individual factors (i.e., health, cognition) as well as environmental factors (i.e., social policies, stereotypes of aging drivers, community resources). Specific contextual factors within the model are defined as both personal and environmental factors which directly affect and influence driving. The personal factors differ from the individual factors previously described, in so that individual factors reflect broader traits associated with driver`s age cohort/health population, while the personal factors are unique to the individuals themselves. Like Lawson's model, personal factors within this category refer to the physical (i.e., neck rotation, presence of disease, history of falls), cognitive (i.e., processing speed, attention, reaction time, memory, executive functioning), emotional (i.e., anxiety, fear) and sensory (i.e., acuity, contrast sensitivity) abilities as well as the driving experience (i.e., driver knowledge and training) of the driver themselves. The environmental sublevel refers to physical (i.e., road conditions, vehicle equipment, financial factors, structural and dynamic elements of roadways) and social environmental factors (i.e., behaviours of other drivers, available social support, presence of passengers) which can interact with the personal factors and affect driving competence. Certain moderators, such as personal attributes, can modify how the levels of personal factors, environmental factors, and their interaction impact driving competence. The most notable moderators include a driver's beliefs about how personal factors affect their driving abilities, their awareness which acts as a motivator for compensatory behaviour, as well as their self-monitoring and self-regulating abilities in relation to driving. Finally, functional behaviours refer to the specific skills required for driving and include both tactical skills and operational skills (i.e., vehicle control). Therefore, the outcome of the interaction between global factors, specific contextual factors and moderators is the driving performance.

According to this model, assessing one's ability to drive is a complex and multifaceted task with multiple points of intervention. This is especially relevant when applying this model to examine and understand driver performance at intersections. Specifically, we can anticipate impacts at the level of specific contextual factors, notably those at the personal level related to cognitive abilities such as attention (Balzarotti et al., 2022), multitasking, and challenges pertaining to physical abilities, such as range of neck motion (Lacherez et al., 2014). We can additionally observe challenges at the environmental level since intersections are complex road situations to navigate as previously discussed. Certain moderators can also be at play, such as the beliefs and self-awareness in relation to self-perception and stereotypes of older adult drivers which may aid or hinder their ability to navigate complex tasks and maneuvers (Brelet et al., 2016; Lambert et al., 2015).

Many of these points of impact can, however, act as points of intervention, whether it be improving transportation options (e.g., societal factor), improving cognitive ability (e.g., personal factor) and improving awareness (e.g., moderator) among others (Ang et al., 2019), all of which would enable to keep drivers safely on the road for as long as possible. Not all factors can be easily targetable due to political or structural limitations, which would make changing the inherent structure and demands of intersections rather difficult, timely and costly. Although it is difficult, some areas in the United States have adopted an alternative format of intersections known as a Restricted Crossing U-Turn Intersection (RCUT). In relation to this, a recent examination of the eye glancing behaviour and visual workload of drivers at left turns for conventional intersections versus right turns followed by U-turn movements at RCUT intersections was conducted (Zhang et al., 2022). Results from this investigation proposed that drivers making left turns at conventional intersections were more focused on looking at their left and right mirrors and less time looking forward compared to drivers at the RCUT intersections who spent more time looking forward. No effect of age was found. Their results implied that RCUT intersections were effective in reducing the visual workload of drivers and could therefore improve intersection safety (Zhang et al., 2022).

Although this study was successful in finding a positive effect of this type of intersection, it remains extremely difficult and costly to change the road infrastructure of many cities to accommodate such an intersection design. This has thus led many researchers to determine the most feasible and effective point of entry to optimize driving performance. This model suggests many alternatives, many of which revolve around personal factors. In other words, intervening with the drivers themselves, which has been examined through the provision of numerous forms of driver training.

Driving interventions

As discussed above, the models suggest the possibility of intervening directly with older adults as a means of obtaining a better fit with the driving environment and its demands, therefore potentially optimizing functioning. Unsurprisingly, there is a plethora of research dedicated specifically to providing interventions among older drivers with the goals of not only improving their driving performance but also allowing them to continue to share the road safely and prolong their sense of independence, which is crucial for the well-being of many in older adulthood. Predictably, the creation of these training programs has brought along with them questions regarding their effectiveness.

There exist two primary methods of offering interventions to help improve driving behaviours; either through real word driving or simulated driving. Driving interventions that focus on real-world driving typically offer the opportunity for drivers to practise their skills in a real vehicle. Driving simulators, on the other hand, offer the same promise but are rooted in a simulated driving environment. In fact, driving simulators have since long been used to study individual driving performance (Fisher et al., 2011). With the continuous advancement of technology, simulated driving programs have increased in complexity to provide a more accurate representation of real-life driving environments. Compared to traditional pen and paper psychometric tests, driving programs have better face validity in assessing actual driving skills (Desmond & Matthews, 1997; Fisher et al., 2011). Previous research has shown that driving behaviours across simulated platforms are comparable to on-road driving (Bédard et al., 2010; Kaptein, Theeuwes & Van Der Horst, 1996; Lemieux et al., 2014; Meuleners & Fraser, 2015).

These programs also inherently often carry more appeal than real life driving alternatives, as they lack exposure or risk to any dangerous or life-threatening situations that drivers may face on the road (Allen et al., 1990; Ivancic & Hesketh, 2000). This is an asset for older drivers given their increased risk and prevalence for injuries and fatalities on the road. Simulators also allow researchers to standardize and directly control factors that could affect driving performance, such as road traffic and design, route difficulty and weather conditions (Boyle & Lee, 2010; Lee, Cameron, & Lee, 2003; Fisher et al., 2011). These implications for driving interventions will be discussed in some of the sections below.

Physical interventions

Although physical interventions are not typically the primary focus of driver rehabilitation, studies have shown some effectiveness in their application. Marottoli et al. (2007), examined the effect of a physical conditioning program on a sample of 174 physically impaired older adults. Participants were divided into a control group and an active intervention group, with the latter receiving a weekly visit for 12 weeks by a physical therapist to guide them through the program. Participants from the intervention group were conditioned in targeted areas of physical functioning such as upper extremity coordination and hand strength, axial conditioning (e.g., targeting cervical, shoulder, hip, and knee areas), as well as gait and foot abnormalities, while the control group received monthly education modules about house safety, vehicle care and fall prevention from their home. The primary outcome measured changes in on-road driving performance, as well as critical errors as a secondary outcome, both of which were measured at baseline and then at three months post-intervention (Marottoli et al., 2007). They reported that the intervention group scored significantly higher than the control group on their on-road performance ($p < .001$) and committed 37% less critical errors ($p < .001$).

Following this work, Marmeleira and colleagues (2009) examined the effect of a physical exercise program on cognitive, perceptive, and physical abilities related to driving in a sample of 32 older adults following a randomized control design. After baseline assessment, the intervention group completed a 12-week supervised exercise program which targeted aerobic fitness while concurrently asking participants to partake in problem-solving to train cognitive abilities. The targeted outcome measures included measures of visual attention, executive functioning, reaction time and psychomotor performance (Marmeleira, 2009). They reported that the intervention group showed significant improvement in response time (-13%, p = 0.018), reaction time (-11%, p = .018), visual processing speed (-66%, p = .032) and on a psychomotor task (-15%, p = .002) compared to the control group. However, it is important to note that this study utilized a small sample size and did not include any on-road outcome measures. Similarly, Chattha (2010) also sought to investigate this same effect using an RCT with 29 older adults, but their study included driving performance measures which Marmeleira's study did not. More specifically, their outcome measures included data on simulated driving performance, physical functioning as well as cognitive functioning. They found significant intervention effects for some cognitive abilities such as selective attention (p = .001) and visual attention (p = .027) for the intervention group and significantly fewer driving errors on the simulated driving route for the control group (p = .003; Chattha, 2010). However, this study also did not examine the on-road driving performance of older adults.

More recently, a study by Staplin et al. (2021) filled some gaps in the previous literature and sought to examine the impact of a structured exercise program for inactive older adults on their on-road performance as well as on their driving exposure. They conducted a Randomized Control Trial (RCT) with a total of 30 participants split unevenly between a control group (n=10) and an exercise group (n=20), who were exposed to dance elements, weight-bearing, and resistance exercises. The exercise program took place twice a week for a duration of 23 weeks. A baseline of the participants' physical and functional levels was obtained prior to the start of the intervention and outcome measures focused on their driving exposure (i.e., number of trips, driving hours and driving distance) and driving performance on the road, calculated using a total of errors for operational skills, tactical skills, and strategic skills. Their results showed weak effects of the exercise program on driving performance and no effects of the intervention on driving exposure (Staplin et al., 2021).

Overall, there seems to be only moderate evidence regarding the effects of a physical intervention on driving performance. Moreover, none of these studies addressed scanning behaviours, save for some interventions which could address range of neck motion, which is an important aspect for being able to safely navigate intersections. While there are some positive findings, it is especially important to be prudent in their interpretation and applicability due to some important methodological limitations, most notably the absence of specific driving outcome measures as well as the small sample sizes. Future studies should focus on ensuring stricter methodology and measuring driving outcomes directly.

Cognitive interventions

Like some of the physical interventions outlined above, the cognitive training interventions available to date have focused exclusively on seeking to improve cognitive abilities (e.g., speed of processing, memory, reasoning, and visual perception) that are relevant to driving. One such study conducted by Roenker and colleagues (2003) assessed the effect of processing speed training versus simulated training on the on-road driving performance of 104 older adults using an RCT. Participants underwent initial assessment measuring their useful field of view

(UFOV), simulated driving performance, and on-road performance. They were subsequently reassessed using these measures after completing training, 18 months later. Participants were randomly allocated to one of three arms; a control group, a simulated training group (e.g., education-based training from a certified instructor with simulated driving demonstrations) and a speed-of-processing training group (e.g., based on scores on the UFOV). Their results demonstrated that the speed-of-processing training group had significantly less dangerous driving actions ($p < .024$) and scored significantly better on the UFOV ($p < .001$), compared to the simulator training group. However, it is important to note that their raters evaluated driving performance through a rank of categories rather than totalling the driving errors which may not be an accurate measure of change in their on-road performance. A similar but more recent study by Ross and colleagues (2016) also found that the number of speed-of-processing training sessions was associated with driving frequency contrary to their two control groups. However, this study did not include any measure of actual driving performance. A few additional studies have yielded findings in support of the impact of speed of processing on crash risk (Ball et al., 2010), driving cessation (Edwards, Delahunt & Mahncke, 2009) and mobility (Edwards et al., 2009).

Cognitive interventions have also studied the impacts of memory training on driving (Ball et al, 2010; Cuenen et al., 2016; Edwards, Delahunt et al., 2009, Edwards et al., 2009; Ross et al., 2017). Cuenen and colleagues (2016) recruited 56 older adults and randomly assigned them to either a working memory training group, a non-adaptive working memory training group or a control group. The two working memory groups differed only in task difficulty. Outcome measures included measures of cognitive ability (i.e., working memory, inhibition, and attention) as well as driving ability (i.e., speed, lane position, right of way, complete stops, gap acceptance decision and number of crashes), based on their performance on a driving simulator. They showed significantly larger improvements in cognitive ability for the adaptive working memory training group compared to the other two groups. Results for driving ability, notably reactions to stop signs and speed management, were only marginally significant and highest for the adaptive training group. Overall, the supporting evidence of working memory training on driving performance is limited, especially considering the lack of on-road evaluation.

Reasoning has also been studied by a few of the previously mentioned authors (Ball et al, 2010; Jobe et al., 2001; Ross et al., 2017). In particular, Ross and colleagues (2017) conducted a study using data from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) RCT which was previously examined by Jobe & colleagues (2001) as well as by Ball & colleagues (2010). The ACTIVE intervention sought to study the impacts of three training interventions (e.g., a reasoning training group, a speed of processing and a memory training group) on cognitively demanding daily activities related to independent living over a period of ten years (Jobe et al., 2001). As such, driving performance or ability was not specifically measured, nor was it a primary outcome. However, information regarding driving status was collected and used in subsequent studies. In Ball's study, it was discovered that cognitive training enhanced cognitive functioning in all three training groups, suggesting potential implications for risks and rates of motor vehicle collisions (Ball, 2010). Ross's study analyzed the data after the 10-year period, focusing specifically on outcome measures related to driving status, including tracking the duration until participants ceased driving. Their findings indicated that none of the training groups had significant effects on driving cessation according to an intention-to-treat analysis. Nonetheless, their results also showed that participants in the reasoning and speed-of-processing groups experienced a reduced likelihood of ceasing to drive by 55% and 49%, respectively, over the 10-year period (Ross et al., 2017). Booster trainings in the speed of processing group resulted in a 70% reduction over a 10-year period, whereas the booster sessions from the reasoning group did not show an effect. No effect of the memory training group was found. While these results provide some evidence supporting the effectiveness of two cognitive training interventions, it is challenging to attribute the reduced likelihood of driving cessation solely to these interventions. Many other risk factors, such as health, which were not accounted for in the analyses, could influence an individual's ability to continue driving.

Taken together, some positive conclusions can be drawn across most of these studies regarding the effect of cognitive training on driving performance. However, it remains that there are some notable limitations, namely the accuracy of some of the outcome measures used as well as the applicability and generalization of the findings in improving driving-related skills for older adults. Moreover, none of these studies addressed scanning behaviour, which is an important aspect for being able to safely navigate intersections.

Educational interventions

Typically, a common course of action or intervention in driver rehabilitation revolves around educational interventions. Driver education, while not mandatory, is common in Canada. It is a common practice for individuals to register for driving courses when they come of age to acquire both theoretical and practical skills and knowledge in driving. While driver’s education courses are commonly used for the initial obtention of a license, there also exists refresher programs for drivers seeking to review or enhance certain skills after several years or decades of driving. Ensuring that older drivers, especially those who did not receive formal training when they first obtained their licenses, are knowledgeable and informed about current road safety practices could help reduce inappropriate driving habits they may have developed over the years

(Keskinen, 2014).While the benefits of individualized training on the road are paramount, they are not always common or accessible options for older drivers due to their costly nature. In fact, in Ontario, the cost for a driving course averages 600$, or alternatively can range from anywhere between 35-70$ per hour for individual lessons (Drivers Ed, 2022). These price points can be highly unaffordable for many older drivers. It is for these reasons that researchers have sought alternative options to train drivers. Researchers have specifically implemented this notion of refresher courses for older adult drivers to address some of the aforementioned safety issues that can be prevalent in older age. Educational interventions, such as classroom-based training, act as an adaptive resource to improve driving skills and counteract the decline of driving abilities (Robinson et. al., 2015). A well-known example of an educational intervention that has been extensively studied in various research projects is the 55 Alive/Mature Driving Program, developed and offered in Canada. This program focused on topics pertaining to the rules of the road, normal versus hazardous driving environments, vehicle controls as well as age-related changes that affect driving. Many of the available educational interventions in other research projects follow similar formats (Castelluci et al, 2020).

In terms of effectiveness, Marottoli and colleagues (2007) recruited 126 older adult drivers and implemented an education-based intervention aimed at improving driving performance. This program was comprised of two 4 hours of classroom knowledge-based sessions, as well as two 1-hour on-road training sessions focused on common driving errors (e.g., seat position, mirror adjustment, safety belts, stopping distance, lane changes, signalling, turning, etc.). Results demonstrated that performance on a knowledge-based test as well as a road test was higher for the intervention group compared to the control group ($p < .001$). Conversely, abilities related to scanning behaviours were scored as poor or fair across all participants compared to other markers of driving performance such as the use of mirrors, lane changes, braking, acceleration and more (Marottoli, 2007). Previous systematic reviews seem to show no evidence supporting the effects of educational interventions on the reduction of crashes and injuries (Korner-Biternsk, Kua & Van Benthem, 2009; Kua et al., 2007). More recently, Akbari and colleagues (2021) conducted a systematic review that examined seven systematic reviews on the efficacy of driving education in reducing injuries, crash risk, and other negative outcomes such as driving performance, behaviour, and awareness across all age groups. While they found evidence to support improvements in driving performance and self-perceived driving ability, their review found that educational interventions were ineffective at reducing crashes or injuries. They stipulated that many educational interventions focus too narrowly on only certain aspects of driving (i.e., vehicle controls) which may not be at the source of a driver's difficulty. Furthermore, according to their review, most of these interventions primarily provide information without helping drivers gain a better understanding of their own driving behavior (Akbari et al., 2021). An additional systematic review by Castelluci and colleagues (2020) agrees on the benefits of educational programs on self-regulatory practices. However, their review also highlights that many of the studies used self-reported measures as their primary outcome variable and failed to have any objective measures of driving performance. Like Akbari and colleagues, they concluded that an improvement in self-awareness following educational interventions does not necessarily translate into improved driving safety (Castelluci et al., 2020).

Overall, the collective evidence regarding educational interventions leads us to conclude that they are effective for improving some driving behaviour but cannot be directly correlated to reductions in injuries and crashes. Some researchers, such as Nadimi and colleagues (2021) therefore recommend the combination of education and road training to reduce unsafe actions that could lead to these outcomes. There also seems to be little research available examining these impacts specifically on intersections.

Behavioural interventions

With many options available (i.e., cognitive training, simulated training, education courses, etc.), it can be a daunting task to decide how to best approach older adult training. Many of the previous training options were accompanied by numerous limitations and mixed findings which consequently brought up the need for alternative training formats. Behavioural interventions were thus created to focus on supplementing and/or replacing driver education programs with individual driver training on the road or in a simulated driving environment. More specifically, many studies have utilized driving simulators in comparison to alternative training methods (i.e., instructor courses), and have had success in improving many aspects of driving. One such study known as the DriveWise project compared simulator training to cognitive training (Casutt et al., 2014). Results from this study revealed that participants showed improvements in overall driving performance (i.e., driving safety and driving skills) rather than in specific driving behaviours such as intersection scanning or using mirrors during lane changes (Casutt et al., 2014). However, it is important to note that the effectiveness of this training is not entirely conclusive as there was no active control group. Another study previously found that older drivers demonstrated improvements in their driving performance (i.e., reduced number of unsafe driving actions) following two on-road training sessions with a certified driving instructor in comparison to the control group who only received an education session (Sawula et al., 2018).

Behavioral interventions have an advantage over previously offered physical, cognitive, and educational ones because they can specifically examine driving behavior at intersections. However, the literature as it pertains specifically to visual scanning interventions, while prevalent, is limited and could benefit from a more comprehensive examination. In fact, a recent literature review found that, as of 2016, only eight articles focused on training to improve older adults' visual scanning abilities (Lococo & Staplin, 2018). Although limited, most of the available studies showed promise when targeting specific types of driving errors in combination with offering individualized training (Lavallière et al., 2012; Romoser & Fisher, 2009). In their study, Romoser and Fisher (2009) demonstrated that prior to training, older drivers made more scanning errors than their younger counterparts when using a driving simulator. They exposed participants to a pre and post training assessment both on the simulator and on the road. Participants in the passive training group (i.e., lecture-style sessions) attended educational sessions aimed at raising awareness of crash data for older drivers, discussing the effects of functional and cognitive declines on driving, and highlighting examples of high-risk intersections. The active training group underwent the same educational training but also received additional feedback based on their pre-training on-road and simulated drives through video playback. When compared to a passive training group and the control group, participants from the active training group (i.e., customized feedback from a video replay) showed a significant increase in their scanning behaviours both on the simulator and on the road. Their findings were also found to be long-lasting as participants from the active training sustained their scanning behaviours at a 2-year follow-up while no such effect was found in participants from the control group (Romoser, 2013). Similarly, a study by Sawula (2018) recruited 78 older adults and randomly assigned them to one of three training arms: 1) a three-hour education session, 2) the education session and two on-road sessions with a certified instructor, 3) the education session, the on-road training, and a 45-minute simulated training session with feedback. Drivers from instructor groups were given retroactive feedback on global driving behaviour based on their on-road baseline assessment. The main outcome measure of this study was assessed using on-road driving performance, which was recorded and coded by raters. Results indicated that participants from on-road training groups who received individualized feedback made fewer overall driving errors ($p < .001$) with an especially marked reduction in observational errors (i.e., consistently checked blind spots before merging or changing lanes and more consistent in intersection scanning; $p < .001$). There were no observed differences between the group receiving on-road training alone and the group receiving both on-road and simulator training. It is important to note that there was no active training group restricted uniquely to simulator training and thus findings were inconclusive in determining if simulator training is equivalent to on-road training in reducing observational errors.

A follow-up study to Sawula`s was conducted by Gagnon and colleagues (2019) to address some of the methodological limitations and to reexamine the impact of a simulated training intervention on driving safety in older adults. Participants were once again divided among three groups: a control group (e.g., education component), on-road intervention group (e.g., + education component) and simulator intervention group (e.g., education + on-road component). All participants completed a pre-post road test. Participants from the on-road intervention group received two 45-minute training sessions and had the opportunity to review video footage from their on-road pre assessment while the participants from the simulator group received retroactive feedback on their driving performance on the simulator following the completion of a 25 minute drive. They then completed this course a second time to incorporate the feedback received. The results showed a significant effect of group, meaning that the on-road and simulated intervention groups showed significantly less errors than the control group (p = 0.006). No conclusions could once again be obtained regarding the efficacy of simulated training over other forms of intervention given the small proportion of participants that completed the simulated drive.

Lavallière and colleagues (2012) were interested in the reduction of observational errors through simulator training by focusing on the usage of mirror and blind spot-checking. Due to technological restrictions (i.e., use of a single monitor), the research team could not train left and right scanning at intersections and turns and instead resorted to using an LED light on either side of the participant to mimic the presence or absence of a vehicle in the participant's blind spot for lane changes. To achieve their objectives, this study exposed drivers, who had already undergone a refresher course and received feedback on their driving performance, to an on-road assessment before participating in a simulated training program. Moreover, contrary to Romoser and Fisher's (2009) study, Lavallière and colleagues included a control group who also underwent the same refresher course and simulator training but without feedback. In this study, feedback was exclusively given retroactively. Results following the training with feedback concluded an increase in the frequency of blind spot inspections compared to the control group ($p < .001$).

Recently, some studies have posited that technological advances, such as alert systems, can reduce unsafe behaviours without the need for instructor feedback. Shichrur and colleagues (2021) studied the effects of an in-vehicle warning system on the head movements of older adults at intersections. To do so, they recruited a mix of older adult (65+) and old-adult (55-65 years old) drivers for a total of 42 participants and equipped their vehicles with a collision-warning system (CWS) that provided them with potential forward and lane departure warnings. They also had a front-back camera to capture the head movements of participants throughout their drive, which coders used to note scanning behaviours at each intersection. The study was separated into three consecutive phases: 1) the silent phase (no alerts from the CWS); 2) the

CWS phase (alerts were active) and 3) the silent phase to examine for behavioural change. Their findings revealed that scanning behaviours at T-junctions, turns and four-way intersections were improved in phases 2 and 3 compared to phase 1 ($p < 0.01$). Most of the improper head movements were associated with forward four-way intersections, right or left merges and roundabouts to the left. There was no effect of age, suggesting that older adults did not perform less well than old-adult drivers, which is contrary to most of the evidence in the literature. They assume that some differences could have been prevalent had they compared them to a group of young drivers. Moderate positive correlations were also found between improper head movements and CWS in phases 2 and 3 (Shichrur et al., 2021). A similar study utilized visual and auditory alerts specifically at left intersection turns among a group of 49 older drivers (Bakhtiari, 2019). Their scanning behaviour was evaluated using a simulated driving scenario in combination with eye tracker technology. The alerts were given pre-emptively before reaching the intersection to warn of a potential hazard. Results showed that drivers anticipated a significant portion of latent hazards when provided with alerts. Similar conclusions were found for secondary glances at intersections (Shichrur et al., 2021). Based on these results, it is unknown whether the findings are replicable on the road and if they are generalizable to overall observational behaviours rather than uniquely hazard-seeking observations.

Finally, and most recently, the Refreshing Older Adults' Driving Skills (ROADSkills) program evaluated the impact of video-provided feedback on the driving performance of older adults (Sangrar et al., 2022). A total of 80 participants were recruited for the study, and each underwent a baseline assessment that included completing several demographic questionnaires and participating in a recorded on-road evaluation. Several weeks later, participants were invited to watch two 30-minute video recordings that provided voice-over feedback about their driving (intervention group), while the control group watched a generic video on aging in place. The primary outcome was the on-road evaluation, which included errors in vehicle control, procedural mistakes, observational errors, and compliance violations. Secondary outcomes were self-report questionnaires regarding driving behaviour and abilities. Their results indicated that the intervention group made significantly fewer total errors compared to the control group at the follow-up assessment ($p < .001$) and also saw significant differences across multiple error domains such as vehicle control ($p < .01$), observational behaviours ($p < .001$) and compliance errors ($p < .05$). Their findings concord with previous research which utilized video feedback as a means of improving older adults' driving behaviour (Anstey et al., 2018; Gagnon et al., 2019; Sawula et al., 2018). Although the video feedback provided was not exclusive to observational behaviours, they nonetheless saw a reduction in these errors after the intervention.

Self-imposed interventions

While not considered a training program, an additional source of intervention when questions of driving competence come to light, is one imposed on behalf of the driver themselves or their family. Not all older adults, such as those who live with dementia, have the capacity to recognize changes in their physical, cognitive, or psychosocial functioning which may affect their driving. However, individuals who are generally cognitively healthy usually have foresight, or self-awareness, about their limitations. They often voluntarily engage in a process of self-imposed driving restrictions so that their driving abilities may better align with their perception, limitations and/or preferences (Ang et al., 2019). These self-imposed restrictions, known as self-regulatory behaviors, involve changes in a driver's everyday actions or patterns to reduce their exposure to complex driving situations (Dickerson et al., 2007). For example, older drivers experience changes at the strategic level, such as reduced annual mileage (Stutts, 1998), and adopt additional avoidant behaviors like refraining from driving in higher-risk situations, such as at night, during inclement weather conditions, during rush hours, or in unfamiliar areas (Bergen et al., 2017; Davis & Conlon, 2017; De Raedt & Ponjaert-Kristoffersen, 2000; Molnar & Eby 2008; Molnar et al. 2013; Molnar et al., 2018; Naumann et al. 2011; Okonkwo et al. 2008). These findings are further supported by Vivoda and colleagues (2020), who examined initial self-regulated driving behaviors in older adults. Their results showed that the most common first self-regulatory behavior was reducing nighttime driving (58%), followed by avoiding rush hour (26.96%), unfamiliar areas (10.81%), and highways (4.63%). Some of these findings, such as the reduction of nighttime driving may be related to visual declines (Bergen et al., 2017). Interestingly, self-rated vision abilities were linked to nighttime driving, with better self-rated vision associated with a lower likelihood of nighttime self-regulated driving (Vivoda et al., 2020). Additional research suggests that older drivers will further compensate by reducing their annual mileage (Molnar et al., 2015) and will drive at lower speeds, leaving a larger gap between them and the leading car (Andrews & Westerman, 2012; Charlton et al., 2006).

It is believed that adopting some self-regulatory behaviours contribute to driving safety, and more specifically to the reduction of crash risk (Bergen et al., 2017; Charlton et al., 2006), although these findings have been contested by other authors (Owsley et al., 2004; Ross et al., 2009). Nonetheless, self-regulation alone does not seem to be sufficient in ensuring the safety of older drivers, especially to those who lack self-awareness and thus overestimate or underestimate their driving abilities (Wong, Smith & Sullivan, 2012). However, self-awareness, which not only dictates one’s self-regulatory behaviours but also their global driving behaviours could be modified. Looking back at the Driving as an Everyday Competence model, the relevance and interaction of self-awareness with other aspects of the model is apparent. In the model, self-awareness acts as a moderator, and thus has the capacity to act on and potentially alter a driver's performance. Therefore, it is natural to assume that increasing an older driver's self-awareness would consequently have an impact on their driving in some capacity. Interestingly, not many studies have examined the impact of any of the educational, cognitive, or behavioural interventions on self-rated driving ability. A pilot study by Selander and colleagues (2019) specifically targeted this gap by examining the impact of a driving simulator-based intervention on the self-rated driving ability of 21 older adults. Specifically, they incorporated the use of corrective and corrective + rewarding feedback in their training program. Each participant's driving was evaluated and given a score by an expert rater and participants were also asked to rate their drive before and after the intervention. Based on their results, the average difference between the participants' ratings and the expert rating decreased after the training. This was especially the case for those who tended to underestimate their performance. Their findings also highlighted the impact of providing feedback to increase self-awareness in their own behaviours, similar to findings from a previous study which utilized an educational intervention for the same means (Owsley, Stalvey & Philips, 2003). This follows Ackerman and colleagues' (2011) line of thought in which the provision of feedback could facilitate appropriate self-monitoring and consequently lead to self-regulating practices in their driving, which was partly proven in their study but also supported by previous research (Owsley, Stalvey & Phillips, 2003; Tuokko et al., 2007).

Regardless of their impacts, self-regulatory behaviours are often not sufficient to allow for older adults to continue to safely use the road and preserve their independence. The possibility of intervening on self-awareness through the provision of feedback could aid in improving driving ability but warrants a deeper examination.

Chapter 2: Objectives, research questions and relevance of the empirical work

Consistent with the DEC model, research has shown that a plethora of strategies (cognitive, educational, behavioural, etc.) targeting a multitude of personal and environmental factors are available to improve driving performance, some of which are more effective than others. As highlighted in a systematic review by Castelluci and colleagues (2020), mixed training approaches, such as those using either simulator or on-road training are not only the most studied but have also yielded the best findings. Specifically, many training experiments, such as the ones mentioned above, utilize feedback as a decisive factor for improving driving performance. Most studies thus far have incorporated feedback that targets observational behaviours such as intersection scanning and mirror checking before changing lanes and have had success in reducing driving errors. However, the provided feedback from these studies raised two main issues: 1) it was exclusively given in a retrospective manner (i.e., after the drive was completed or at the beginning of the next training session) rather than live, and 2) the provided feedback was given exclusively regarding the driver's on-road performance rather than being given based on their simulated driving (Lavalière et al., 2012; Romoser & Fisher, 2009). Moreover, while there have been individual studies examining the impact of either simulated feedback (Bakhtiari, 2019; Shichrur et al., 2021) or instructor provided feedback (Anstey et al., 2018; Gagnon et al., 2019; Sawula et al., 2018;), no one study has compared the efficacy of both. Therefore, the current study seeks to further reduce these gaps in the literature by developing and assessing the effectiveness of a simulator-based training program to enhance driving performance by providing feedback on scanning behaviours at intersections as driving unfolds and comparing the efficacy of two mechanisms of feedback.

Consistent with the DEC model, we aim to intervene on the specific contextual factors of a driver, namely their driving experience and training in order to induce change in their driving performance. To do so, the goals of the study are threefold: 1) provide live feedback during simulator training, (2) determine whether feedback targeting scanning behaviours can improve both intersection scanning behaviours and/or overall driving performance, and (3) to compare the efficiency of automated feedback provided by the simulator with instructor feedback provided by an instructor.

This project investigates an economical alternative to providing training to the ever-growing aging population. It also plays an important role in aiding the quality of life of older drivers throughout their aging process by keeping them on the road longer and thus preserving their independence and autonomy. By embedding itself in a simulated environment, as opposed to directly on the road, it seeks to give drivers a safe and risk-free environment to improve their driving behaviours, which could improve their and other drivers' safety on the road and ultimately reduce both intersection crashes and overall crash risk. This study was conducted and funded in collaboration with the Ministry of Transportation (MTO) and has been approved by the University of Ottawa's Ethics Committee.

Research questions and hypotheses

The aims of the present study were to test the effects of active simulator training (i.e., feedback regarding scanning behaviours at intersections) on the driving performance in older adults. To do so, the following research questions and hypotheses are presented:

Question 1:

Examine whether providing targeted feedback during simulated driving impacts scanning behaviours at intersections. This was decomposed into two separate sub-questions:

Question 1.1. Examine the impacts of this training on simulated scanning behaviours.

Question 1.2. Examine the impacts of this training on on-road scanning behaviours.

Hypothesis: Based on the literature, feedback was proven to improve driving behaviours and we therefore expected an increase in scanning behaviours following training. Therefore, older adults receiving feedback during simulator training, either in the instructor feedback group or the computer feedback group, will show an increase in scanning behaviours between the pre and post training assessments compared to participants without feedback. We expected to see this change both during simulated driving and on on-road driving performance.

Question 2

Determine whether the feedback provided during simulator training can influence older adults' overall driving performance. This was decomposed into two separate sub-questions:

Question 2.1. Examine the impacts of this training on overall driving behaviours during simulated driving.

Question 2.2. Examine the impacts of this training on overall driving behaviours during on-road driving.

Hypothesis. Based on the literature, there is evidence to suggest that providing feedback contributes to increased self-awareness. Looking at the DEC model, self-awareness acts as a moderator which can impact driving performance. This specific relationship has never been studied and therefore this segment of the study was exploratory in nature. We hypothesized that the act of providing targeted feedback might translate into differences in self-awareness which could then influence global driving behaviour. In other words, older adults receiving the simulator training with feedback could show a change in overall driving errors on their simulated drive as well as on-road drive. On the other hand, the control group who does not receive any feedback during their training was expected to show no significant difference in their on-road or simulated driving performance following the completion of the simulator training.

Chapter 3: Methods

Research Design

This study followed a mixed design Randomized Control Trial (RCT) consisting of two intervention arms (SAT - automated simulator training and SIT - simulator instructor training group) and a control group using a pre-post on-road test. Older adult drivers over the age of 65 were recruited and randomly assigned to one of the three training conditions. The control group completed the pre-post on-road test along with four simulated training drives with no feedback. The two intervention groups also completed the pre-post on-road test but were either given computer generated feedback (SAT) or live instructor feedback (SIT) during the simulator sessions.

There were approximately 4-6 weeks between the pre and post training on-road assessment. Participants received free parking on campus and free driver training as compensation (SAT and SIT groups). Participants from the control group were also offered free driver training upon completion of the study. This study followed a single-blind design, therefore research personnel conducting the on-road assessments remained unaware of group allocation.

Participants

Participants were recruited as a convenience sample through local ads in the Ottawa Citizen newspaper and through posters in recreational facilities and community centres. These advertisements contained preliminary information about the study and had a contact section which participants could use to either call or email the research team. Participants who stated their interest were contacted by the research team to share additional information regarding the study (i.e., number of sessions, parking, etc.). This exchange was also used as an opportunity to answer any questions that the participants may have had.

Sample size estimation

Based on similar projects involving older adult drivers, the study aimed to recruit a total of 80 participants, consistent with sample sizes ranging from 21 to 75 in previous studies (Bédard et al., 2010; Horswill et al., 2013; Jones et al., 2011, 2012; Lavallière et al., 2012; Romoser et al., 2009, 2013; Sangrar et al., 2022; Yamani et al., 2016). Among these studies, only a select few examined the impact of feedback on observational errors and utilized rather small sample sizes between 20-54 participants (Lavallière et al., 2012; Romoser et al., 2009, 2013). Moreover, it is important to note that driving simulator studies typically account for an attrition rate of 25% due to simulator sickness (Brooks et al., 2010), which would bring the total number of participants to 60; n≈20 for each of the three conditions. Using GPower, a statistical software for power analysis, in order to achieve a power of 0.80 with an alpha of 0.05 and an estimated medium effect size of 0.25, a total sample size of 42 participants would be necessary (see appendix A for output of analysis). Many of the aforementioned studies did not report their effect size. That being noted, the estimated effect size used for this calculation is derived from a few comparable studies in the literature, which report effect sizes ranging from $\eta^2 = 0.20$ (Kosuge et al., 2021) to Cohen's d values of 0.74-0.77 (Cuenen et al., 2019; Pigeon et al., 2020), indicating medium to large effect sizes in all cases. In combination with guidelines from Cohen's statistical power analysis guidelines (1988), a medium effect size was thus selected.

A total of 78 healthy older adult drivers were recruited between 2018 and 2022. However, after initial screening, a total of 17 participants were excluded from the study either due to simulator sickness (*n*=11), low MoCA score (*n*=1) or resulting from personal circumstances (*n*=5). The final sample was comprised of 61 participants aged between 65-89 years with an average age of 72.4 (SD=4.48), including 37 men and 24 women.

Inclusion and Exclusion Criteria

The inclusion criteria for participants were as follows: aged 65 years or older, possessing a valid driver's license, proficient in English or French, and in good general cognitive and physical health. Additionally, participants were excluded if they did not meet the criteria on the following measures: 1) passing a range of neck motion test, and/or 2) showing insignificant symptoms of simulator sickness as assessed by a simulator sickness questionnaire (refer to the measures section below for details on exclusion criteria). These criteria were also contingent on the participant`s ability to travel to the University campus and complete the preliminary orientation route.

Outcomes

Primary outcomes

The primary outcomes in this study consisted of the number of scanning errors and global driving errors both on the simulator and on the road. See the section below on data preparation and coding for a detailed description of each outcome and type of error. These outcomes were used for the main analyses of the study.

Secondary outcomes

The following visual measures were administered, and their results were used to compute correlations with the main outcome measures of the study.

Pelli-Robson Contrast Sensitivity Test (Pelli, Robson, & Wilkins, 1988; see Appendix D). This test assesses a person's contrast sensitivity by determining the faintest contrast letters that are correctly read on the chart. It consists of 8 lines of letters which are organized into two groups of triplets per line which gradually become fainter. The Pelli-Robson test is to be mounted on a wall at eye level in a well-lit room (i.e., range of luminance is 60 to 120 cd/m^2)

and used at a recommended distance of 1 metre between the participant and the chart. Participants read the letters with each individual eye beginning at the top left of the chart. After reading with each eye separately, they were asked to read the chart with both eyes at once. Research has demonstrated that the Pelli-Robson test has good reliability (Elliott & Conkey, 1990; Mäntyjärvi & Laitinen, 2001), with an adequate coefficient of repeatability (Thakur et al., 2018; Thayaparan et al., 2007). Additional studies marked its test-retest value at 95% (Haymes et al., 2006) and confirmed its validity (Leat & Woo, 1997). A score of 2.0 on this measure indicates normal contrast sensitivity of 100 percent while a score below 1.5 is consistent with a form of visual impairment.

Peripheral Motion Contrast Threshold (PMCT; Henderson, Gagnon, Collin, Tabone, & Stinchcombe, 2013). This assessment has been developed to predict a driver's risks for collisions, near-collisions, and overall hazardous driving. It does so by assessing the magnocellular channel's sensitivity to objects in a driver's visual periphery. The PMCT is performed on a computer by presenting low spatial frequency and high temporal frequency sine waves within a driver's peripheral vision. The initial version of this test had an administration time of 10 minutes. However, researchers adapted the test to be administered in two minutes, demonstrating that the PMCT maintained reliability comparable to the 10-minute version (Henderson et al., 2015). Lower scores on this task indicate a better performance whereas higher scores indicate a lower performance. Elevated scores on this test are highly correlated with crashes in simulated driving (Henderson et al., 2015). No further information about psychometric properties is available.

Measures

Screening Measures

Montreal Cognitive Assessment (MoCA; Nasreddine, Phillips, Bedirian, Charbonneau, Whitehead, & Collin, 2005; see Appendix B). This questionnaire serves as a screening tool for the detection of cognitive disorders. Administration time is approximately 12 minutes and consists of a series of questions that assess short-term memory, visuospatial abilities, executive functions, attention/concentration/working memory, language and attention to time and place. The MoCA has been validated for persons between the ages of 55-85 years old. A cut-off score of 26 has a sensitivity of 80% and specificity of 91% when detecting various cognitive disabilities (Nasreddine et al., 2005). A more recent systematic review and metanalysis showed, however, that a cut-off score of 23 could achieve comparable sensitivity and specificity (Islam et al., 2023). It was demonstrated to have adequate convergent validity with the Mini Mental State Examination ($r = 0.66$, $p < .001$) as well as supported criterion validity (Lam et al., 2013) and construct validity (Vogel et al., 2015). While the psychometric properties of this tool are promising, it nonetheless remains a screening tool and should not be used exclusively to diagnose any form of cognitive impairment. For the purpose of our study, no hard cut-off score for the MoCA was used. However, MoCA scores, along with the participant's ability to travel to campus and complete the preliminary practice route, were used to assess eligibility for inclusion in the study. In other words, participants who obtained low or high MoCA scores but who could not complete the practice route were excluded from the study. Participants' scores were taken into consideration for analyses to determine if there is an association between their cognitive screening result to the primary outcomes of the study. Research assistants who administered the MoCA all underwent official certification.

Marottoli Method (Marottoli, Richardson, Stowe, Millet, Brass, Cooney & Tinetti, 1998). This method measures a person's range of neck motion and peripheral vision, similar to performing a shoulder check. Participants were asked to stand against a wall and were instructed to turn their head to read numbered cards that were placed over their shoulders by a research assistant. Participants were eligible for the study if they could successfully read the cards by only turning their necks. Conversely, they were excluded from the study if they could not correctly identify the numbers or if they had poor range of neck motion.

Simulator Sickness Questionnaire (SSQ; Kenndy, Lane, Berbaum & Lilienthal, 1993; see Appendix C). This questionnaire measures a person's level of sickness in virtual or simulated environments. It consists of a total of 16 questions using a 4-point Likert scale ranging from 0 (None) to 3 (Severe). The original version of this questionnaire yielded three factors: Nausea, Disorientation and Oculo-motor. However, a newer recent study revisited the factor structure with a more general population as their sample and yielded uniquely two factors: nausea and oculomotor (Bouchard, Robillard, & Renaud, 2007). A recent study examined the psychometric properties of the SSQ in comparison to other known measures of cyber or simulator sickness and concluded high correlations for discriminant validity (r = 0.92) and adequate internal consistency (Cronbach's α = > 0.70) but showed no evidence for construct validity or test-retest reliability (Sevinc & Ilket, 2020). Any participants who reported severe simulator sickness were excluded from the study. Clinical judgment was also used in the event where some participants underreported their symptoms but appeared visibly unwell. In these situations, extended breaks were taken and if participants continued to be visibly unwell, they were asked to withdraw from the study for their own health and safety.

Equipment and Route Descriptions

On-Road Driving Assessment

Participants were asked to use their own vehicles for the on-road assessments. Participant's vehicles were equipped with a Garmin Nuvi 249/LMT navigational system that was preprogrammed with the designated routes. Their vehicle was also set up with two cameras with dual rotating lenses (1080P Dual Dash Cam Front and Cabin Inside, Vantrue N2 Pro 2.5K 1440P Front and Rear Dash Camera) to record pre and post training driving behaviours and to capture drivers' scanning behaviours. These cameras were connected to an external battery bank while the GPS was connected directly to the vehicle's power outlet. Participants also had access to a Motorola MOTO E smartphone in case of emergency and to clarify directions at any given moment.

A total of four different routes were programmed into the GPS, including an orientation route and three test routes (see Appendix E for routes). The test route was developed in collaboration with a certified driving school in Ottawa and was intended to simulate a G2 test route. The orientation route took approximately 15 minutes to complete and was intended to be used to acclimate the participant to following GPS instructions. The acclimation route spanned approximately 2.4km and took place in majority in a University of Ottawa adjacent neighbourhoods. This also allowed for the opportunity to troubleshoot for any technological issues prior to the test drive.

As for the road test route, a total of three different routes were used to test participants. Since the study spanned over multiple years, construction in Ottawa resulted in many road closures on some sections of the test route. Therefore, two alternate routes with a detoured segment were planned and programmed in the GPS. When possible, a detour was made to closely resemble the changed segment of the drives. All routes began and ended at the designated parking spot at the University of Ottawa. Each route included a highway segment, a residential segment as well as driving in a densely populated area. The initial test route (Route 1) as well as the second test route (Route 2) were approximately 12.4km long while the last test route (Route 3) was 11km long. All routes were similar in structure; they each took approximately 25-35 minutes to complete. The speed limits across all routes ranged from 40km/h to 100km/h. In terms of intersections, Route 1 was comprised of a total of 78 intersections; 35 signalized, 13 stop-sign controlled and 30 non-signalized intersections. Route 2 was comprised of 86 intersections; 38 signalized, 13 stop-sign controlled and 35 non-signalized intersections. Route 3 was comprised of 74 intersections; 32 signalized, 21 stop-sign controlled and 21 non-signalized intersections.

Simulator Training

A Dell precision Tower (Intel Xeon CPU E5) equipped with an NVIDIA Quadro M2000 graphics card was used to run the simulator software from York Computer Technologies (version YDS06-0312-2018-U). The simulated road environment was displayed on three Samsung monitors (71 x 40 cm, model s32d850t) which were placed side-by-side with the left and right screens positioned at a 30° angle. A gaming steering wheel and pedals (Thrustmaster T300RD Racing Wheel, PS4, PC) were used to drive the simulator. A standard fixated office chair acted as the driver’s seat and was positioned approximately 81cm away from the three monitors. Three webcams (i.e., Microsoft Lifecam HD-3000) were set up around the participant (i.e., behind the participant on the wall or mounted on the frame of the left monitor and on the right monitor) to view and take note of the participant’s driving behaviour while the participants operated the simulator. Data collected from the webcams was used for coding driving errors but also acted as a means for the instructor to observe the participant and to communicate live constant feedback. See Appendix F for details.

Participants drove four simulated training courses that were 12 kms long with a duration of approximately 20 minutes each. Participants were instructed to drive as they would normally drive and to follow the rules of the road. Directions were pre-programmed into the simulator and given to the drivers at the beginning and throughout the course of their trip. In order to simulate city driving, some of the courses contained sections with one to three lanes as well as highway sections. Participants sometimes made left and right turns, used turn signals and made lane changes. A total of four drives were completed, two drives per session with a 5-10 minute break in between. It is important to note that some participants (n = 8) completed courses that were different from the collective sample. The routes for these participants contained several turns which consequently led to many participants experiencing simulator sickness. In order to control for simulator sickness, the routes were modified and the number of turns per route was reduced to a total of three. The number of visual stimuli in the simulated environment was also reduced. In terms of intersections, these routes contained one-, two-, three-, and four-lane stops, as well as intersections controlled by traffic signals (see Table 1 for the number and type of intersections per training course).

Table 1

Number and Type of Intersections by Training Session

Intersection Type	Session 2		Session 3	
	Training 1.1	Training 1.2	Training 2.1	Training 2.2
Stop-sign controlled	41	38	35	36
Signalized	3	11	3	12
Non-signalized	43	27	38	26
Total	87	76	76	74

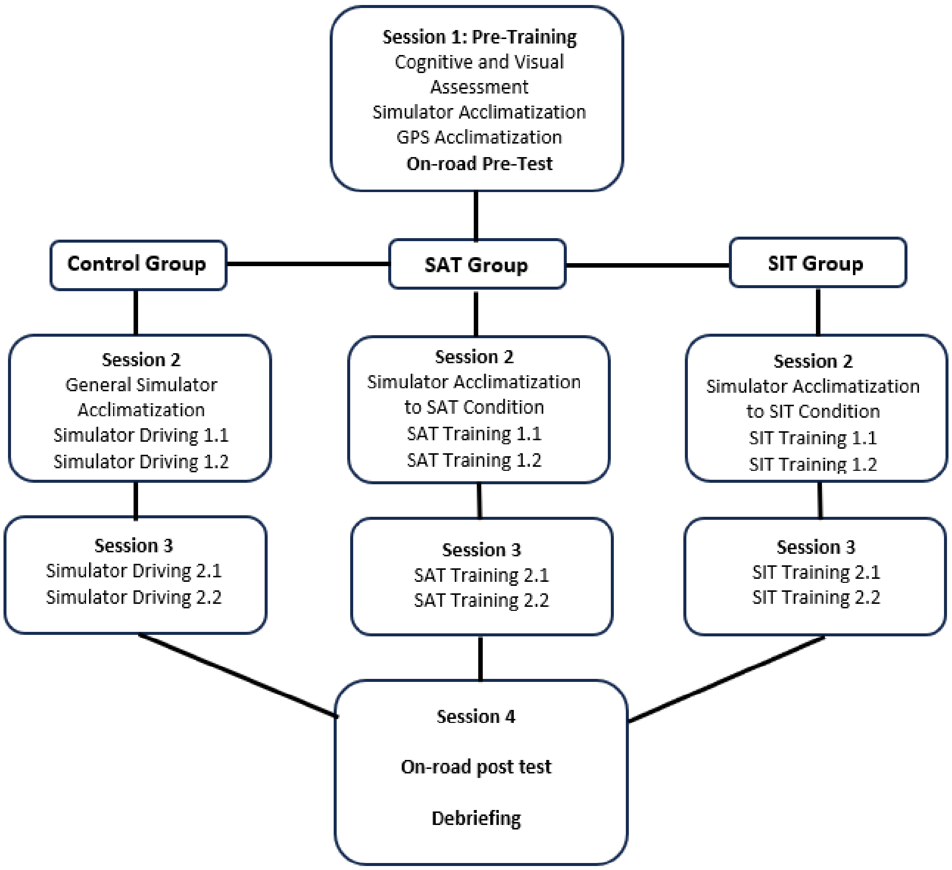
Procedure

Recruitment and Group Assignment

Participants were randomly assigned to one of the three training groups (i.e., control, automated feedback or instructor feedback) by using a randomization tool (**https://www.randomizer.org/)**. Participants then proceeded to booking their first assessment session with a member from the research team. Each session was completed within 2 hours or less. A total of four testing sessions were conducted, which is depicted and detailed in Figure 2 below.

Figure 2

Summary of Participant Group Allocation and Testing



Session 1 - Cognitive and Visual Assessments, Simulator Acclimation, and On-road Pre-Training Assessment.

Participants were greeted by a research assistant at the designated university parking lot. The research assistant then led them to the Cognitive Aging and Driving laboratory where the training portion of the study took place. Upon arrival, participants were requested to review key segments from the consent form (i.e., the study's requirements, risks and benefits, privacy and anonymity, and the participant's ability to withdraw from the study at any time without penalty) prior to obtaining their written informed consent (see Appendix G). Participants then underwent a first screening to determine eligibility by administering the cognitive assessment (i.e., MoCA) and the range of neck motion test (i.e., Marottoli method). Participants also had the opportunity to acclimate to the driving simulator through a 15-minute orientation scenario where they practised accelerating, decelerating, activating signals, turning and maintaining speed. Any participant who exhibited symptoms of simulator sickness at this point were excluded from the study.

Following the simulator acclimation, all participants underwent an on-road assessment on one of the routes described above to measure their baseline driving performance. A member from the research team installed the dual rotating cameras and navigation device in the participant's vehicle prior to the drive. One of the cameras was mounted and centred on the windshield to simultaneously capture the front field of view as well as a view of the driver. The second camera was centred along the passenger window to capture a sidelong view of the driver and to capture any oncoming cars to the right and left of the driver. None of the cameras obstructed the driver's view of the road and surrounding environment. All on-road assessments were conducted in daylight, during non-rush hour times and under adequate weather conditions. In the case of adverse weather conditions, the pre or post training on-road assessments were postponed until a later time.

A research assistant was not present in the vehicle for the on-road drives. Instead, participants were directed to follow instructions from the navigation device, which was pre-programmed with instructions according to the route that was designed. Participants underwent a 2.4 km practice drive to acclimate to the GPS instructions. After successfully completing the orientation route, participants were then instructed to complete the test route. The start and end points for the drives of all participants were at the Cognitive Aging and Driving designated participant parking spot at the University of Ottawa main campus, steps away from the laboratory. Each participant was provided with a hands-free speaker phone connection to the Cognitive Aging and Driving Lab's research assistant. This allowed them to receive additional assistance if they went off course or to withdraw from the study if they chose to discontinue the route. To aid in any navigation difficulties, the research assistant tracked the participant's location at all times using either a smartphone application (FollowMee GPS Tracker; https://www.followmee.com) or Google Map's location sharing feature. Participants were additionally asked not to wear sunglasses unless necessary for their safety and to turn off their radio to maximize the audio output from the GPS and the phone.

Sessions 2 and 3: Visual Assessments and Simulator Training.

Participants were administered additional screening measures at the beginning of session 2, notably the Peripheral Motion Contrast Threshold (PMCT) and Pelli-Robson Contrast sensitivity test. Participants completed two simulated driving scenarios in each session which lasted approximately 20 minutes each. Each simulated scenario resembled city driving conditions comprised of both signalized, non-signalized and stop-sign controlled intersections. Participants were asked to make lane changes and turns only on a few occasions to minimize chances of simulator sickness. Participants underwent the following simulator training based on their group allocation.

SIT Training Condition. Participants in this training group received live instructor feedback in relation to scanning behaviours at intersections. The SIT condition aimed to replicate a scenario similar to one with a driving instructor. Participants were required to independently scan intersections and received feedback—either positive ("Great/Perfect") or corrective ("Remember to look both ways at the intersection next time/Remember to look right next time/Remember to look left next time")—based on their performance. The instructor took note of the time points and frequency of feedback given at each driving scenario.

SAT Training Condition. Participants in this training group received automated computer feedback rather than instructor feedback. Contrary to the SIT condition, participants in the SAT condition had to complete a peripheral detection task at intersections. To do so, construction cones were placed on the roads at some intersections. Participants were required to scan, detect and then indicate the cones' presence by applying on the left or right button on the steering wheel. More specifically, participants were instructed to press the left button once if one cone was present, twice if two cones were present and to press the button on the right if no cone was present. They had to complete this maneuver at every single intersection. If participants correctly identified the presence or absence of a cone, they heard a cheerful sound (i.e., positive feedback) or heard a buzzer if they incorrectly identified the presence of a cone or left a cone undetected (i.e., negative feedback).

Simulator Control Condition. Participants in this condition completed the same simulated routes with the same parameters but were instructed to drive as they normally would and follow the road rules. They did not receive any type of feedback regarding their scanning behaviours.

Session 4: Post-Training On-Road Evaluation.

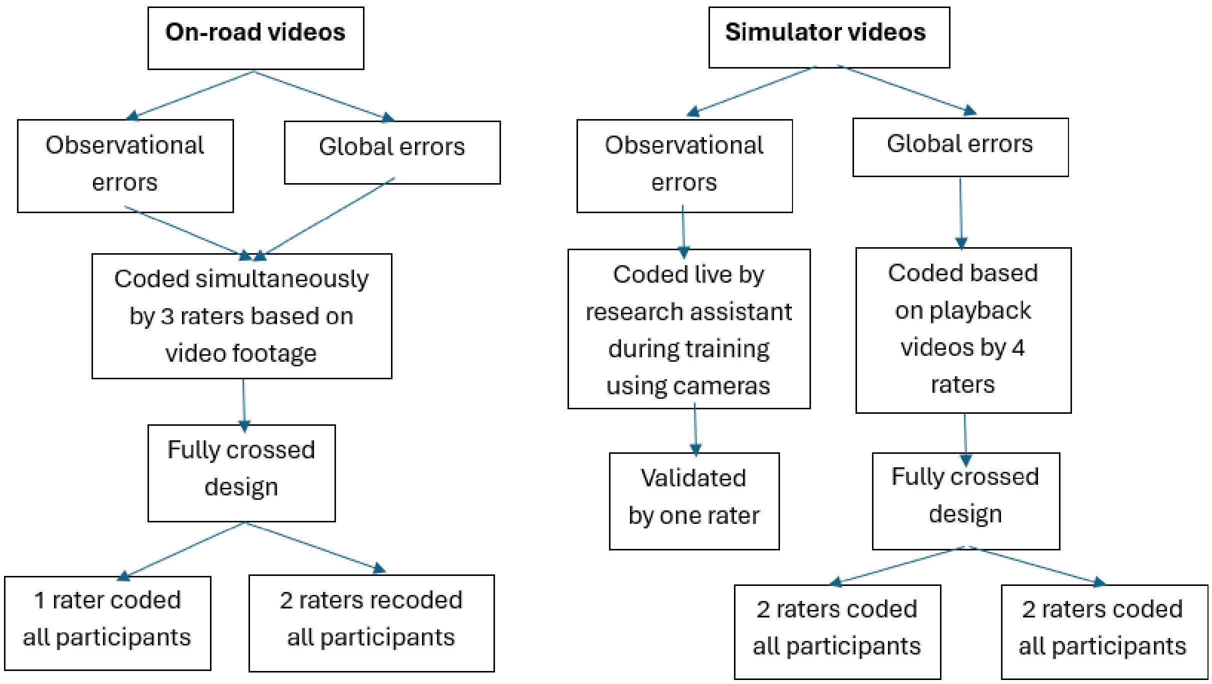
This was the final session of the study which participants underwent after having completed the simulator training. All participants completed an on-road post-training drive which was identical to their pre-training route. This allowed for accurate and detailed comparison of differences in overall driving performance between pre and post simulator training. Once completed, participants were thanked for their involvement in the study and were asked if they had any feedback (i.e., aspects to improve, aspects they enjoyed, etc.) about their experience with the study. Additionally, participants were given a debriefing letter which summarized the goals and objectives for this study (see Appendix H). Participants who were assigned to the control condition were offered to schedule an additional simulator training session if they desired to receive feedback on their scanning behaviours.

Data Preparation and Coding

In order to answer the aforementioned research questions, all the videos including pre- and post- training routes as well as simulator training routes were compiled, randomized and given a unique identification number to protect participant identity and ensure that the independent raters were blind to the condition of allocation. Videos were only accessible to coders once participants completed all drives to ensure blindness. The study followed a fully crossed design, whereby each video was coded by two independent raters. This allowed for any systematic bias between coders to be assessed and controlled for when calculating interrater reliability (IRR). Only one rater's coding was used for the final data analysis once sufficient reliability was obtained. Additionally, confirmatory analyses were conducted using the second rater`s coding. At the end of data preparation, all coders involved in reviewing either the on-road or simulated drives confirmed that they were unaware of the condition and the timing of videos (i.e., pre or post). Figure 3 summarizes the coding structure across raters for both simulated and on-road driving errors.

Figure 3

Data Coding Procedure for Simulated and On-Road Videos



On-road driving errors

Driving error types. Driver errors were coded based on a validated and preestablished coding scheme used in similar driving studies (Gagnon et al., 2019; Porter, 2013; Sawula et al., 2018). See Appendix I for summary table. This coding scheme targets unsafe driving actions (UDAs) which is composed of vehicle control, procedural, observations and compliance errors. Vehicle control errors were comprised of: a) signaling (e.g., too early, not given, not cancelled); b) hand position on wheel (e.g., too high, too low, hand-handed, no hands); or other (e.g., wipers, hazard lights, gears). Importantly, participants who drove standard vehicles were not penalized for driving one-handed. Procedural errors were comprised of: a) position in lane (e.g., left, right, waders, straddles line); b) stop position (e.g., over line, blocks crosswalk, too early); c) flow (impedes traffic, too fast, too slow); d) drives in wrong lane; e) position on approach (e.g., too far from curb/centre); f) response to traffic lights (e.g., amber); g) left at light (e.g., wait position, wheel position) and h) right on red light (e.g., complete stop). Observation errors were comprised of not completing scans in the following manners: a) mirror checks (e.g., while driving, while slowing, while stopped); b) blindspot checks for lane changes; c) blindspot checks for turning; d) intersection scans; and e) looking in direction of movement. Finally, compliance errors were comprised of: a) stops (e.g., incomplete); b) impedes traffic (e.g., lane changes, merges, too slow); c) fails to yield (e.g., pedestrians, bikes, ambulance, traffic); d) fails to clear the intersection; e) right of way (e.g., car, pedestrian, bike); f) follows too closely; g) turns (e.g., turns into wrong lane); h) stops without cause; i) drives on the wrong side of the road; j) passing too close; k) hits a curb/anything; and l) disobeying street signs (e.g., no turn on red light, one-way street, etc.). Each route was divided by intersection and each intersection was separated by a segment of straight drive. A coding scheme based on these segmentations and driving errors was built. Participants were given one point per UDA at each segment of the route when observed. This means that a higher overall score indicated that more UDAs were made. Despite following an orientation route to acclimate to the GPS, some participants nonetheless remained confused or missed some directions. Therefore, any errors made due to confusion regarding the GPS directions were not counted.

Editing of On-road video recordings. All on-road driving videos were copied over to the laboratory computer. Since two dual lens cameras were installed, a total of four possible views were produced: two front-facing (in front and behind the windshield) and two side-facing (in front and behind the passenger window). All four videos were compiled and edited into one single video (see Figure 4) to facilitate coding. Videos were deidentified and the nature of pre or post intervention drive as well as training condition were unknown to coders.

Figure 4

Camera View Used to Code On-Road Driving Errors

It is important to note that due to technological operational glitches, some of the cameras ceased recording during a participant's drive. However, in these situations one of the two cameras remained operational and was able to capture one view of the participants' drive. A total of 36 out of 122 videos had a camera view missing. These segments lasted from either a few minutes or spanned the majority of the participants' drive. In the instance where the missing view was from the front-facing camera, coding was done based on the side facing view, which required that scanning behaviours could only be captured with head movements instead of head or eye movements. This limitation will be addressed in the discussion.

Training. Three research assistants were trained on the coding of the on-road driving errors. They were each preliminary trained didactically and taught the required criteria for each driving error. Additionally, the main researcher conducted a practice drive to serve as a guide and demonstrate specific driving behaviours to aid with error coding. The main researcher established the coding scheme and coded a total of four participants' drives to use as training videos for the research assistants. The raters` coding for each training video was reviewed by the main researcher and detailed feedback on any inconsistencies or differences between the codings was provided. If an interrater reliability of 0.9 or less was achieved following the mandatory four training videos, additional training videos were assigned and detailed feedback was provided until they attained the designated inter-rater correlation. Each video lasted approximately 25-40 minutes and took approximately 1-1.5 hours to code.

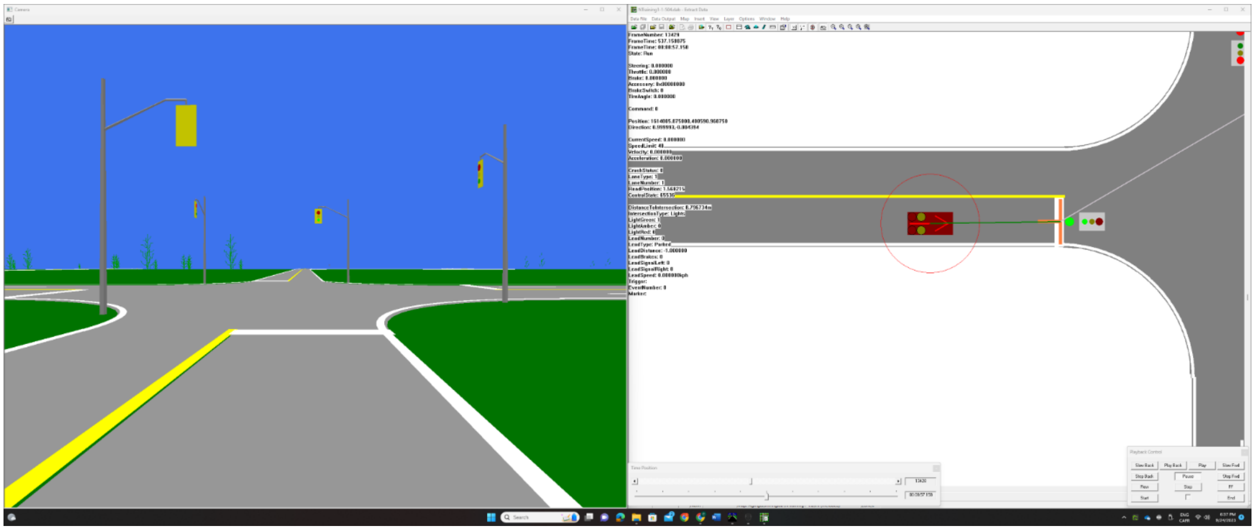
Simulated driving errors

Simulated driving error types. As previously stated, visual demands and stimuli were kept low to reduce the chances and rates of simulator sickness. To address differences between these routes and the on-road routes, a distinct yet comparable set of driving errors was evaluated. The coding scheme in this case was adapted from the Manitoba Road test, which is a common on-road evaluation rating scheme. Certain criteria within this assessment (e.g., fails to yield to an emergency vehicle; too close to pedestrians; passes when unsafe, shoulder checking, etc.) were eliminated due to the nature of a simulated driving environment which would not allow for these behaviours to be observed. The remaining criteria for each category thus included: 1) speeding, stopping, turning, signal violations, moving on roadway and observation errors. See Appendix I for summary table. The speeding category was comprised of: a) speeding; or b) hindering (i.e., going too slow). The stopping category was comprised of: a) stops for no reason; b) excessive preparation for a stop; c) not stopping at a safe place; d) distance to intersection (e.g., too far or over the line). The turning category was comprised of : a) improper signal (e.g., not given, wrong signal, not cancelled); b) improper approach or excessive anticipation; c) improper turn (e.g., turning when not advised to do so, turned the opposite way); d) improper speed on turn; e) strikes/over the curb; f) fails to yield; g) fails to clear the intersection; and h) crosses solid or dotted line. The signal violation category refers to: a) entering through on a red light; b) entering through on an amber light; c) entering trough on red at right turn (e.g., without a complete stop); and d) rolls through stop sign. The moving on roadway category refers to: a) fails to drive in proper lane; b) crosses solid or dotted line; c) wanders (e.g., drifts in lane); d) straddles traffic lane; e) drives on the wrong side of the street; f) drives on paved shoulder; g) drives off route; and h) improper lane change (e.g., mirror check, signal).

Video editing. Raters used the preprogrammed playback function of the York Driving Simulator software to code the simulated driving errors. The playback function allowed raters to obtain a bird's-eye view as well as a first-person view of the participants' drives (see Figure 5). Moreover, the playback function allowed for the automatic and objective tracking of certain data such as the participants' speed and distance to the intersection which were used to observe certain errors. The cameras which were installed on the computer monitors allowed for a direct view of participants eye gaze and head turns. This function was utilized to code intersection scanning errors in real-time or to replay the recordings for validating the initial live coding.

Figure 5

Camera View Used to Code Simulated Driving Errors



Training. Seven research assistants were recruited and trained on the coding of simulated driving errors. All research assistants underwent a training process comparable to the coding of the on-road videos. Two of these research assistants were trained exclusively to code scanning errors on the simulator since this necessitated the viewing of a different video than for the global errors. Specifically, these two raters used the recordings from the webcams which tracked participants eye and head movements during their simulated drive to score scanning errors. The first rating was obtained live during the training sessions where the research assistant would track the scanning errors during the participants' drive. This aided in the provision of feedback for the SIT condition but was tracked regardless for the other two conditions as well. Since the first rating was done live, a second rating was done based on the video recordings to ensure reliability and validate the initial coding. The remaining five research assistants were trained on the global driving errors previously described but did not include scanning errors in their coding.

Several explanatory and demonstration videos were provided to the raters to illustrate examples of the various types of codable errors.

Statistical Analysis

Demographics

All outcome measures being examined were initially screened for outliers, and assumptions of normality and variance were assessed for where appropriate. Preliminary descriptive analyses (i.e. mean, sample size, standard deviation, minimum and maximum) were conducted on all scaled variables. Additionally, counts and percentages were used to describe categorical data where applicable. Comparisons were also made between the baseline number of errors across all training conditions to examine whether they were both comparable before the intervention. Any differences between baseline assessment scores will be taken into consideration in the discussion section.

Primary analyses

Prior to conducting primary analyses on the data, inter rater reliability was calculated across all of the previously described categories of errors. This project aimed to compare pre-post differences in driving scores across scanning errors and global driving errors across all training conditions. In order to test these differences, an analysis of variance, more specifically a mixed factorial ANOVA was selected with time (i.e., pre and post or simulated training session) as the within-subjects factor and training condition as the between-subjects factor. Where any statistically significant differences were found, post-hoc analyses were conducted. To adjust for multiple comparisons and reduce chances of type 1 errors, either a Bonferroni correction or a Benjamin Hocklin method was used were appropriate.

Additional analyses

Additional analyses employing Pearson correlation coefficients were conducted to examine the associations between cognitive/visual measures (i.e., MoCA, Pelli-Robson Contrast Sensitivity, PMCT) and the changes in on-road scanning errors.

Chapter 4: Results

Participant characteristics

Sixty-one participants, evenly distributed among the SAT condition (*n* = 21), SIT condition (*n* = 20) and CG condition (*n* = 20) were included in the statistical analyses. Participant characteristics by training condition and for the overall sample are detailed in Table 2. Some of the demographic information presented below (i.e., age, PMCT) is based on a subset of the sample due to the unavailability of the information of some participants. This is specified when applicable. Participants were aged between 65-87 years with an average age of 72.4 (SD = 4.48). The mean of the participants' age is based on a sample of 54 participants rather than the full 61 due to the unavailability of the demographic information of 7 participants. There were a total of 37 men, and 24 women. The mean MoCA score was 26.2 (SD = 2.5), with a range from 19 to 30. A total of 19 participants scored in the Mild Cognitive Impairment (MCI) range on the MoCA. The majority of participants were English-speaking (91.8%), while only a few were French-speaking (8.2%). Scores on the Pelli Robson are divided into left, right and binocular scores. The left and right visual acuity both had means of 1.5 (SD = 0.19) with a range of 0.9 to 1.80. The binocular visual acuity had a mean of 1.64 (SD = 0.17) with a range of 1.05 to 1.95. PMCT scores are based on a sample of 50 participants instead of 61 due to missing data. The mean score for the average threshold was -36.8 (SD = 4.27) with a range of -45.53 to -18.97. The use of randomization ensured that the characteristics were similar across all three training conditions, and no significant differences were found between the training conditions in terms of age, sex, MoCA score, Pelli-Robson score, or PMCT scores ($p > 0.05$).

Table 2

Demographic Characteristics of Participants at Baseline

	Total (*N* = 61)	SIT (*n* = 20)	SAT (*n* = 21)	Control (*n* = 20)
Age (years) [mean (SD)]	72.4 (4.48)	72.37 (4.88)	72.53 (4.05)	72.3 (4.6)
Sex [*n* (%)]				
Men	37 (60.7)	14 (70)	12 (57)	11(55)
Women	24 (39.3)	6 (30)	9 (43)	9 (45)
Level of Education [*n* (%)]				
High School	24 (39.3)	7 (35)	7 (33.3)	10 (50)
Post-Secondary	29 (47.5)	11 (55)	10 (47.6)	8 (40)
Graduate Degree	8 (13.2)	2 (10)	4 (19.1)	2 (10)
Language [*n* (%)]				
English speaking	56 (91.8)	20 (100)	18 (85.7)	18 (90)
French speaking	5 (8.2)	0 (0)	3 (14.3)	2 (10)
MoCA [mean (SD)]	26.3 (2.5)	26.38 (2.85)	26.05 (2.51)	26.87 (2.03)
PMCT [mean (SD)]	-36.8 (4.27)	-35.31 (5.59)	-37.86 (3.26)	-37.05 (3.55)
Pelli-Robson [mean (SD)]				
Left	1.50 (0.19)	1.43 (0.23)	1.52 (0.19)	1.55 (0.18)
Right	1.50 (0.19)	1.44 (0.2)	1.48 (0.23)	1.54 (0.17)
Binocular	1.64 (0.17)	1.58 (0.22)	1.67 (0.12)	1.67 (0.15)

Note. The values presented for age and PMCT are based on a sample of 54 participants and 50 participants, respectively.

Route characteristics

Route characteristics including weather conditions, route selection and time between on-road assessments are summarized in Table 3 according to training condition and by total sample. The average interval between pre and post on-road assessments was approximately three weeks (SD = 1.47). Approximately equal numbers of road assessments were conducted under fall/winter conditions (44%) and spring/summer conditions (56%). Similarly, there was an even distribution of participants across Route 1 (33%), Route 2 (39%) and Route 3 (28%). There were no significant differences between route allocation and time between pre and post assessment across all training conditions ($p < 0.05$).

Table 3

Summary of Route Characteristics Across Training Conditions

	Total (*N* = 61)	SIT (*n* = 20)	SAT (*n* = 21)	Control (*n* = 20)
Weather condition [*n* (%)]				
Fall/Winter	27 (44.26)	11 (55)	5 (23.81)	11(55)
Spring/summer	34 (55.74)	9 (45)	16 (76.19)	9 (45)
Weeks between pre-post [mean (SD)]	3.05 (1.47)	3.2 (1.24)	2.81 (1.37)	3.15 (1.79)
Route [*n* (%)]				
Route 1	20 (32.79)	8 (40)	3 (14.29)	9 (45)
Route 2	24 (39.34)	2 (10)	15 (71.43)	7 (35)
Route 3	17 (27.87)	10 (50)	3 (14.29)	4 (20)

Interrater reliability

An interclass correlation coefficient was computed between the two set of raters' coding on each error category for both on-road and simulated driving behaviours. Inter rater reliability results for on-road errors are found in Table 4. Results showed very strong correlations ranging from 0.94 to 0.99 across the different on-road driving errors between coders.

Table 4

Interclass Correlations (ICC) Between Rater Coding for On Road Driving Errors Across Pre- and Post-Training Sessions

	Total	Vehicle control	Procedural	Intersections	Observations	Compliance
Pre	0.98	0.99	0.94	0.97	0.97	0.98
Post	0.98	0.99	0.95	0.96	0.97	0.98

Similarly, interclass correlations between coders for simulated driving errors are summarized in Table 5. Results once again showed very strong correlations ranging between 0.97 to 0.99 across the categories of simulated driving errors.

Table 5

Interclass Correlations (ICC) Between Rater Coding for Simulated Driving Errors Across Training Sessions

	Total	Speeding	Stopping	Turning	Signal Violation	Moving on roadway
Training 1.1	0.99	0.99	0.97	0.99	0.99	0.99
Training 1.2	0.99	0.99	0.98	0.99	0.99	0.91
Training 2.1	0.99	0.98	0.97	0.99	0.99	0.99
Training 2.2	0.99	0.99	0.98	0.99	0.99	0.99

Scanning behaviours at intersections

In this section we examined scanning errors at intersections committed both during simulator training and during on-road assessments. Since each route contained a different number of intersections, all scores presented in the following section were converted to percentages before conducting the analyses.

Simulated scanning behaviours

Percentage means of scanning errors across simulator training sessions are presented in Table 6. Baseline means at the initial training session for scanning errors were varied across all conditions, averaging 52.41% (SD = 23.36) for the CG, 6.65% (SD = 6.59) for the SIT and 5.69% (SD = 6.51) for the SAT conditions. These means suggest that the feedback provided an effect as soon as the first training session, a finding that is further supported with the analysis below.

Table 6

Means of Scanning Errors (%) Throughout Simulated Training Sessions

	Training 1.1 Mean (SD)	Training 1.2 Mean (SD)	Training 2.1 Mean (SD)	Training 2.2 Mean (SD)
Control	52.41 (23.36)	48.82 (26.50)	53.96 (26.03)	46.61 (25.34)
SAT	5.69 (6.51)	7.07 (5.83)	5.20 (5.27)	5.41 (3.76)
SIT	6.65 (6.59)	5.42 (4.04)	2.33 (3.79)	3.55 (3.76)
Total	21.32 (26.08)	20.21 (25.40)	20.24 (28.17)	18.31 (24.86)

When looking at the results, a difference between training 1.1 and training 1.2 revealed a reduction of 3.59% for the CG condition, 1.23% for the SIT condition and an increase of 1.38% for the SAT condition in scanning errors. Between trainings 1.2 and 2.1, participants saw an increase in scanning errors of 5.14% in the CG condition, but a reduction of 3.09% for the SIT condition and 1.87% for the SAT condition. Finally, between trainings 2.1 and 2.2, a decrease of 7.35% was observed for the CG condition while an increase of 0.21% for the SAT and 1.22% for the SIT conditions was observed for scanning errors.

A 3x4 mixed design factorial Analysis of Variance (ANOVA) was conducted to determine the main effects of training condition on older adults' scanning behaviours on the driving simulator over the course of the four training sessions. There was a significant main effect of training condition, $F(2, 58) = 73.03$, $p < 0.001$, with an effect size of $\eta^2 = 0.716$. No significant difference was found for the main effect of time, $F(3, 174) = 1.81$, $p = 0.148$, $\eta^2 = 0.03$ or for the time and training condition interaction, $F(6, 174) = 1.98$, $p = 0.07$, $\eta^2 = 0.06$.

Post-hoc analysis for the main effect of training condition using a Bonferroni correction showed a significant difference in scanning errors between the CG and SIT conditions ($p <$

0.001), as well as between the CG and SAT conditions (*p* < 0.001). No significant difference was found between the SAT and SIT conditions (*p* = 1.00). These results suggest that both the instructor-led training and the computer automated training performed better on scanning behaviours compared to the CG condition who did not during simulated driving.

On-road scanning behaviours at intersections

Baseline means for scanning errors on the road were similar across all training conditions averaging 62.9% for the CG condition, 63.5% for the SAT condition and 61.4% for the SIT condition. No significant differences were found between baseline means. A 3x2 mixed design factorial Analysis of Variance (ANOVA) was conducted to determine the main effects of training condition on older adults' scanning behaviours on the road before and after driving intervention. Table 7 summarizes scanning error means across all conditions based on the coding from both raters.

Table 7

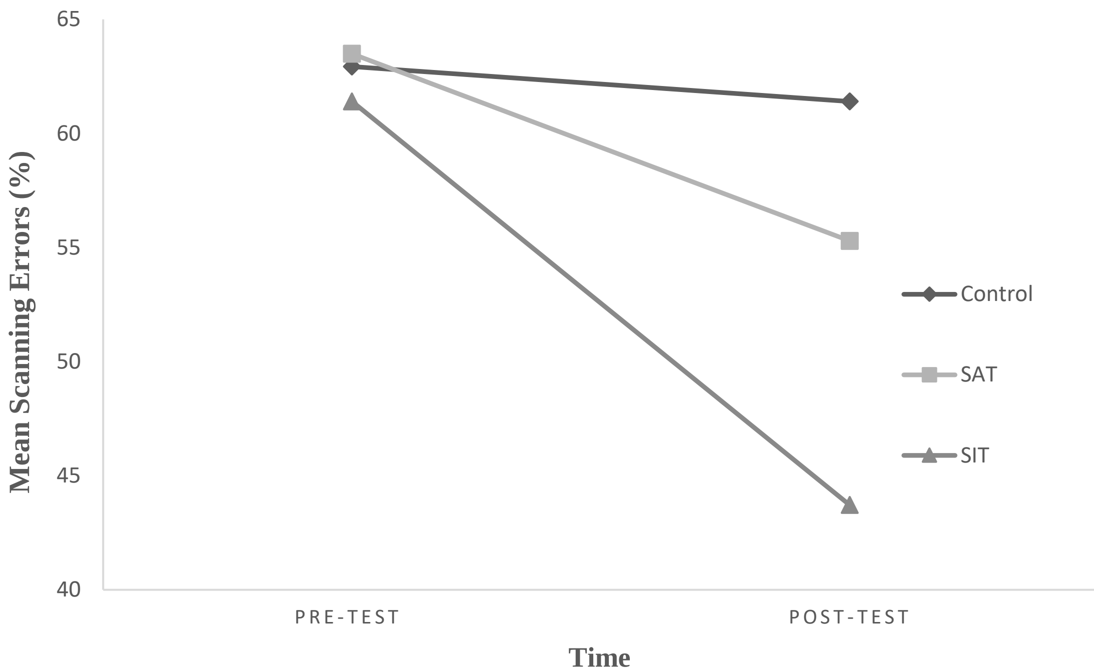
Rater Means (%) and Standard Deviations of Scanning Errors by Training Condition

	Rater 1			Rater 2		
	Pre-test Mean (SD)	Post-test Mean (SD)	Difference	Pre-test Mean (SD)	Post-test Mean (SD)	Difference
Control	62.93 (6.91)	61.40 (8.51)	1.53	62.30 (7.46)	60.94 (9.88)	1.36
SAT	63.49 (7.61)	55.29 (7.31)	8.19	64.11 (7.04)	56.17 (7.50)	7.94
SIT	61.40 (5.23)	43.71 (13.29)	17.69	59.72 (5.75)	41.37 (14.47)	18.35
Total	62.85 (6.62)	53.64 (12.37)	9.21	62.08 (6.92)	52.88 (13.62)	9.2

Driving errors from Rater 1 were used for all analyses given the high correlations between both raters codings and means are displayed in Figure 6.

Figure 6

Change in On-Road Scanning Errors by Training Condition Across Time



Since the within-subjects factor (i.e., time) only contained two levels, assumptions of sphericity are automatically assumed. The assumption of equality of covariance ($p = 0.08$) was met. Results indicated a significant main effect of time on scanning errors, $F(1,58) = 43.31$, $p < 0.001$ with an effect size of $\eta^2 = .43$. Given that this factor only consisted of two levels, the results indicate that there were fewer on-road scanning errors at post training compared to pre-training. There was a significant main effect of training condition on scanning errors, $F(1, 58) = 11.59$, $p < 0.001$ with an effect size $\eta^2 = 0.29$. A significant interaction effect between time and training condition was also found, $F(2, 58) = 12.23$, $p < 0.001$ with an effect size $\eta^2 = 0.30$. This effect indicates that the training condition had varying impacts on scanning errors before and after training.

Simple main effects were computed to explore the interaction effect by comparing training conditions at each time point (i.e., pre vs. post) and then comparing time points for each training condition (i.e., CG vs. SIT vs. SAT; see Table 8 for details). These multiple comparisons were adjusted using a Bonferroni correction. These analyses revealed significant differences between pre and post scanning scores for the SIT ($p < 0.001$), with a decrease of 17.69% and for the SAT ($p < 0.001$) condition, accounting for a difference of 8.2%. No significant difference between pre and post training assessment was found for the CG condition ($p = 0.65$), who only saw a change of 1.07%. When time was used as the grouping factor, results showed that all conditions performed a similar number of errors at pre-training assessment. However, at post-assessment, significant differences were found between the CG and SIT conditions (Mean difference = 18.14, $p < 0.001$) and between the SAT and SIT conditions (Mean difference = 11.58, $p = 0.001$). No significant differences at post assessment were found between the CG and SAT conditions (Mean difference = 6.56, $p = 0.120$). These results suggest that instructor led feedback had a significant impact at improving scanning errors compared to automated feedback or no feedback.

Table 8

Pairwise Comparisons Examining the Interaction Effect

Condition	Comparison condition	Difference in post score	*p*-value
CG Pre	CG Post	1.07	0.65
SIT Pre	SIT Post	17.69	0.000
SAT Pre	SAT Post	8.20	0.001
CG	SAT	6.56	0.120
CG	SIT	18.14	<0.001
SIT	SAT	11.58	0.001

While not a primary goal of the study, our data also allowed us to investigate the qualitative nature of scanning errors that were committed based on the type of intersection. More specifically, participants were faced with three different types of intersections; signalized, unsignalized and stop-sign controlled. It is important to note that since this section was not among our hypotheses or part of our methodology, the following statistics focus exclusively on a descriptive analysis. Descriptive results will be presented based on two different error totals. The first segment will present the total number of errors committed at each of the three types of intersections based on the total number of combined scanning errors. In other words, the total of each type of intersection error will be divided by the total number of scanning errors. The second segment presents the total number of errors committed per intersection type, but this time based on the total number of intersections available in each category. In other words, the total of each type of intersection error will be divided by the total number of their respective signalized, unsignalized and stop-sign controlled intersections available.

To start, the following descriptives are calculated based on the total number of scanning errors as outlined above and can be found in Table 9. During pre assessment, a total of 51.31% of committed errors occurred at signalized intersections, 0.69% at stop-sign controlled intersections and 48.38% at non-signalized intersections. Similar numbers were found at post assessment, with a total of 49.08% errors at signalized, 0.51% at stop-sign controlled intersections and 49.76% at non-signalized intersections. These results suggest that regardless of the training condition, older adult drivers made fewer scanning errors at stop-sign controlled intersections compared to signalized or unsignalized intersections. The CG saw very small increases in the proportion of errors committed between pre and post training assessments, with an increase of 0.8% in signalized errors and 0.22% in stop-sign controlled errors. Conversely, the proportion of errors committed at non-signalized intersections saw a reduction of 1.21%. The SIT condition saw slightly higher changes between pre and post training assessment, with a reduction of 4.24% in signalized errors and of 0.82% in stop-sign controlled errors. They however saw an increase of 5.13% in non-signalized errors. Finally, the SAT condition saw a decrease in signalized errors of 3.21%. However, the proportion of stop-sign controlled errors as well as non-signalized errors increased slightly by 0.05% and 0.28%, respectively.

Table 9

Mean Percentages and Standard Deviations of Scanning Errors by Intersection Type Based on Total Errors Committed

		Control Mean (SD)	SAT Mean (SD)	SIT Mean (SD)	Total Mean (SD)
Pre	Signalized	50.27 (3.46)	50.70 (4.24)	52.99 (3.86)	51.31 (3.99)
	Stop-sign controlled	0.77 (1.87)	0.15 (0.69)	1.18 (2.65)	0.69 (1.92)
	Non-signalized	48.98 (3.72)	50.23 (3.56)	45.82 (4.64)	48.38 (4.35)
Post	Signalized	51.08 (2.96)	47.49 (6.43)	48.75 (6.52)	49.08 (5.68)
	Stop-sign controlled	0.99 (2.12)	0.20 (0.65)	0.36 (0.89)	0.51(1.39)
	Non-signalized	47.77 (4.13)	50.51 (6.15)	50.95 (7.04)	49.76 (5.98)

The following descriptives are calculated based on the total number of each type of intersection and can be found in Table 10. Interestingly, when examining the proportion of errors based on the total number of each type of intersection rather than the total number of errors committed, a different pattern was observed when looking at the scanning errors committed. Specifically, participants did not perform appropriate stop-sign controlled intersections scans 2.12% of the time at baseline and 1.15% of the time at post assessment. However, they missed a significant number of scans at non-signalized intersections both at baseline (83.28%) and post-assessment (74.31%), the highest among all intersection types. This was followed by 74.34% and

61.21% of scans missed at signalized intersections during the pre- and post-assessments, respectively. When examining differences between conditions, participants in the CG condition showed minimal changes, improving their scanning at stop-sign controlled and unsignalized intersections by approximately 0.5-1% at post-assessment. Participants who were trained in the SAT condition were able to appropriately scan signalized intersections 12.03% more than at baseline. They saw minimal change within their stop-sign controlled scanning (0.30%) but saw a better ability to scan non-signalized intersections (10.22%). The SIT condition saw a similar trend to the SAT condition but with larger differences after training. They were able to scan 27.57% more at signalized intersections, 2.12% more at stop-sign controlled intersections and 15.31% more at non-signalized intersections.

Table 10

Mean Percentages and Standard Deviations of Scanning Errors by Intersection Type Based on Total Number of Each Intersection Category

		Control Mean (SD)	SAT Mean (SD)	SIT Mean (SD)	Total Mean (SD)
Pre	Signalized	74.47 (8.15)	73.89 (7.70)	74.78 (6.53)	74.37 (7.38)
	Stop-sign controlled	2.91 (8.00)	0.73 (3.36)	2.79 (6.26)	2.12 (6.12)
	Non-signalized	82.78 (5.17)	82.75 (5.80)	84.34 (5.17)	83.28 (5.18)
Post	Signalized	74.53 (10.38)	61.86 (11.88)	47.21 (17.29)	61.21 (17.33)
	Stop-sign controlled	2.40 (4.97)	0.43 (1.35)	0.67 (1.66)	1.15 (3.18)
	Non-signalized	81.45 (10.51)	72.53 (10.76)	69.03 (21.26)	74.31 (15.62)

Looking at Tables 9 and 10, these findings suggest that while the ratio of errors committed across the different types of intersection remained consistent, the total number of errors committed at each type of intersection diminished for the SAT and SIT conditions.

Global driving behaviours

This portion of the study acted as an exploratory analysis and therefore assumed a two-tailed hypothesis. Given the large number of driving error categories, many comparisons had to be made to investigate the significant main and interactions effects found, which consequently inflates the Type 1 error rate. Common methods for adjusting the Family Wise Error Rate (FWER), such as the Bonferroni method, which measure the proportion of false discoveries among all tests conducted, are often too conservative when multiple comparisons are made and typically result in a reduction of statistical power (Midway et al., 2020). A less conservative approach to controlling Type 1 error rates is to use the False Discovery Rate (FDR), which measures the proportion of false discoveries during multiple testing. One common adjustment within this category is the Benjamini-Hochberg (BH) adjustment, which is less stringent than FWER adjustments and results in increased statistical power (Benjamini & Yekutieli, 2001). This method ranks each obtained p-value and compares it to a critical value based on the rank, the number of tests, and the desired false discovery rate (e.g., 5%). Given the large number of comparisons made, the BH method was selected. Based on the total number of hypotheses and comparisons made in the sections below, a *p*-value of $p = 0.02$ or less was deemed to be significant.

Simulated global driving errors

The global simulated driving behaviours are divided into six categories of errors: speeding, stopping, turning, signal violations, moving on roadway and total errors. Scanning errors are not included in this section as they were previously reported. Due to technological failures, a total of 4 driving sessions (two from training 1.1, one from training 1.2 and one from training 2.1) were not recorded and were therefore not coded. Two out of these participants were from the SIT condition, while the other two were divided between the control and SAT condition. Based on these factors, the missing data can be classified as Missing Completely At Random (MCAR; Papageorgiou et al., 2018). A common method for managing MCAR is to exclude participants with missing data from the analysis, which would allow for unbiased results, but is known for affecting the power of a study (Kang, 2013). Given the evenly distributed nature of the missing data across conditions and the low number of missing counts, this method was selected to preserve the integrity of the original data. Power analysis following the removal of these 4 points continued to reveal a power over 0.9.

See table in Appendix J which summarizes mean scores across the different categories of simulated driving errors for each condition. In this section, means are presented as total number of errors, rather than percentages. These descriptives are also depicted in Figures 7 through 12 below. Speeding errors accounted for the highest number of errors in the total sample both at baseline (M=38.81) and throughout the training sessions. The signal violation category showed the least number of errors across all training sessions. At baseline, the SAT condition committed the greatest number of total errors (M = 75.50, SD = 33.75) as well as speeding (M = 49.95, SD = 23.79), stopping (M = 8.60, SD = 7.06), signal violation (M = 4.10, SD = 6.21) and moving on roadway errors (M = 9.40, SD = 12.52). Conversely, the CG condition performed the highest number of turning errors at baseline (M = 6.95, SD = 9.13). At the end of the four training sessions, the CG condition committed the greatest number of total errors (M = 44.32, SD = 22.27).

Figure 7

Change in Simulated Speeding Errors by Training Condition Across Training Sessions

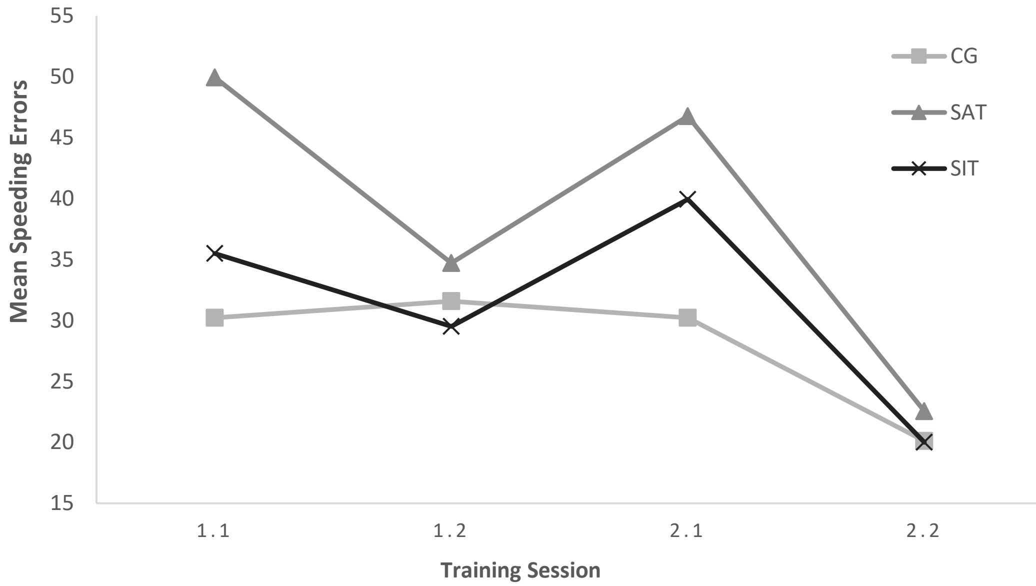


Figure 8

Change in Simulated Stopping Errors by Training Condition Across Training Sessions

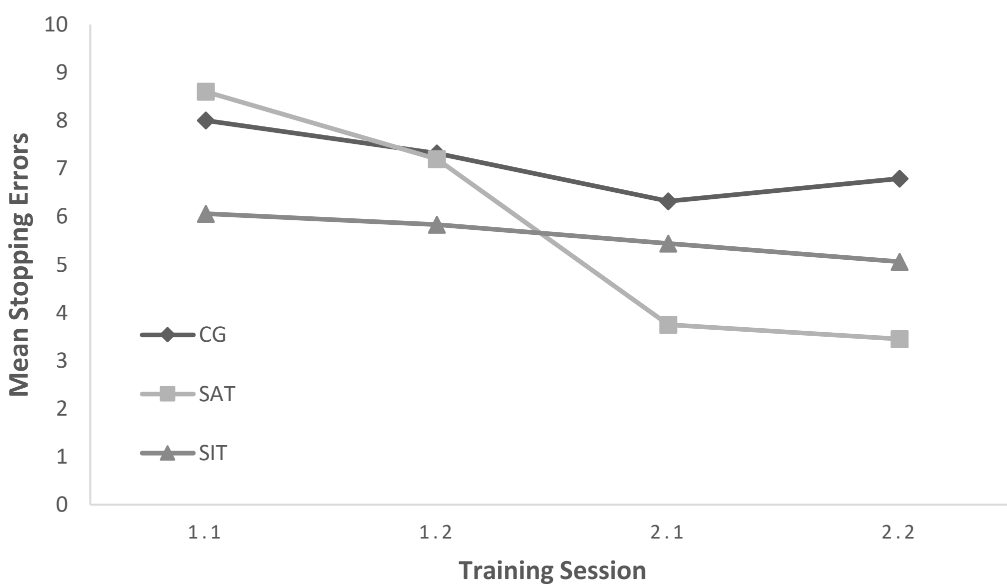


Figure 9

Change in Simulated Turning Errors by Training Condition Across Training Sessions

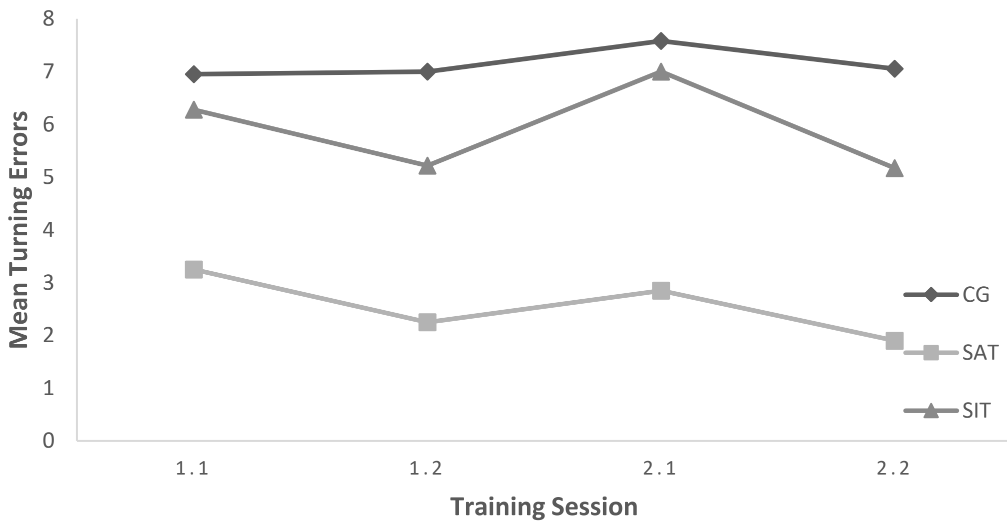


Figure 10

Change in Simulated Signal Violation Errors by Training Condition Across Training Sessions

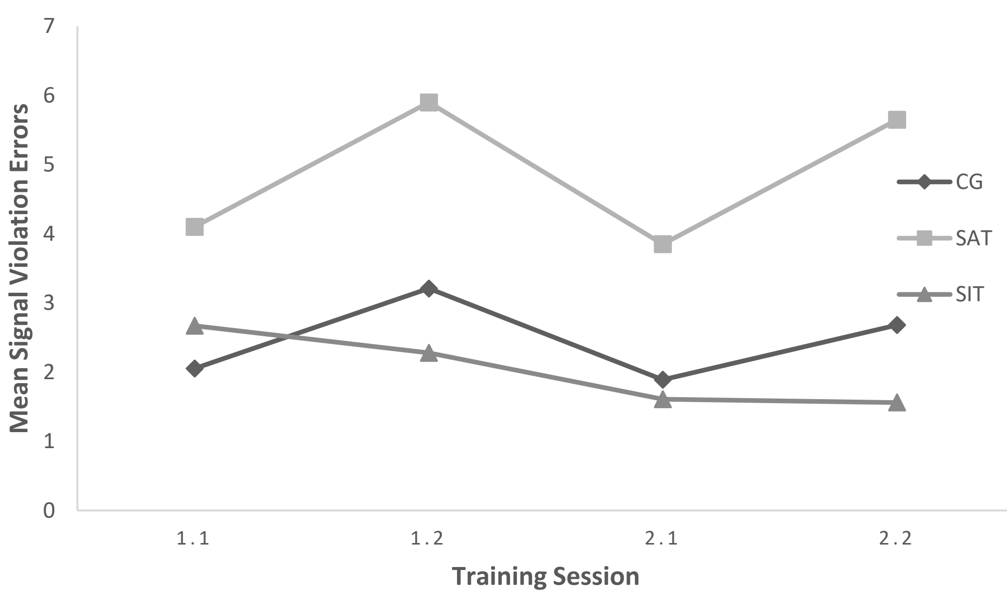


Figure 11

Change in Simulated Roadway Errors by Training Condition Across Training Sessions

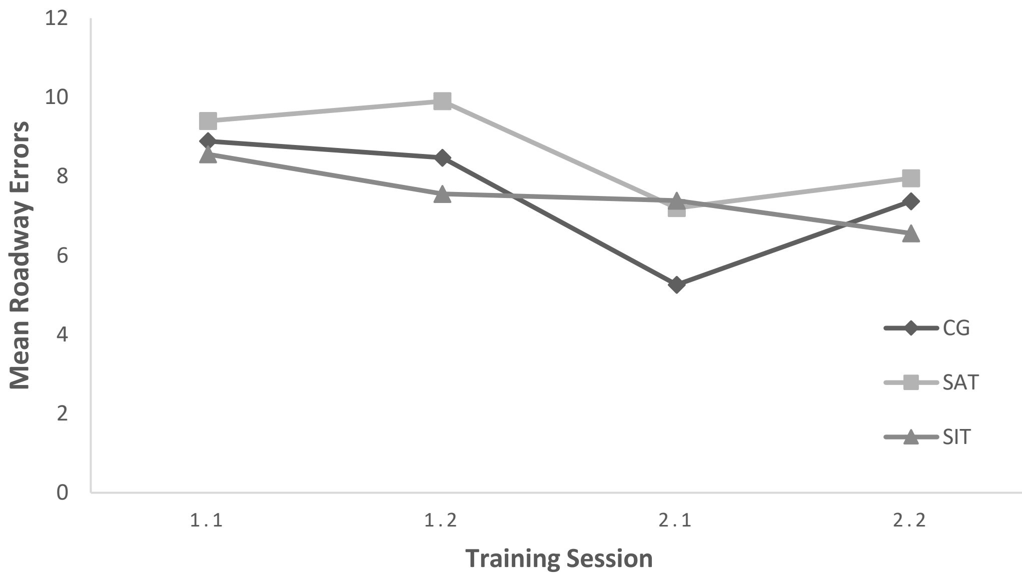
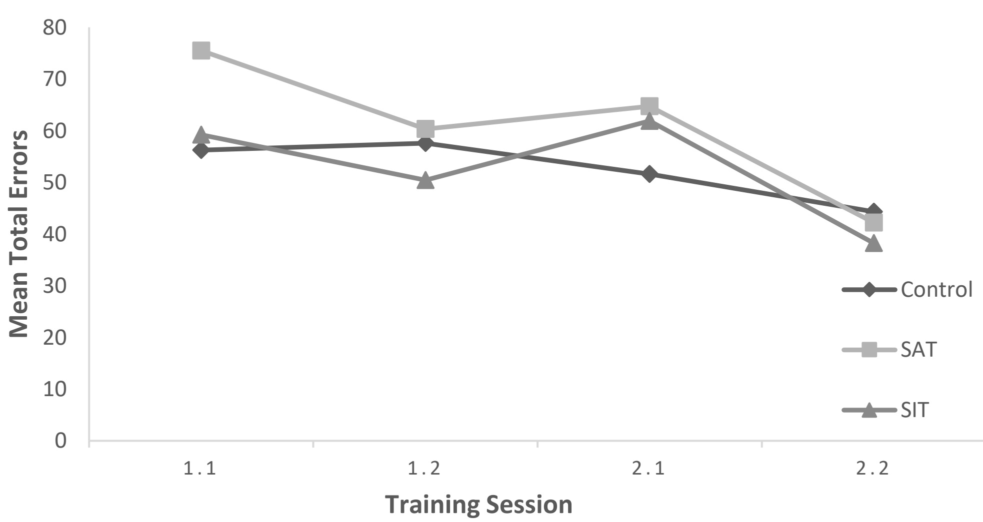


Figure 12

Change in Total Simulated Errors by Training Condition Across Training Sessions



A 3x4 mixed design factorial Analysis of Variance (ANOVA) was conducted to determine the effects of training condition on older adults' simulated driving behaviours over the course of the four training sessions. There was a significant main effect of training session across total driving errors $F(3, 162) = 45.06$, $p < 0.001$, $\eta^2 = 0.44$; speeding errors, $F(3, 162) = 46.73$, $p < 0.001$, $\eta^2 = 0.46$; stopping errors, $F(3, 162) = 9.49$, $p < 0.001$, $\eta^2 = 0.15$; turning errors, $F(3, 162) = 5.196$, $p = 0.002$, $\eta^2 = 0.09$; signal violation errors, $F(3, 162) = 5.86$, $p = 0.001$, $\eta^2 = 0.10$; and moving on roadway errors, $F(3, 162) = 4.68$, $p = 0.004$, $\eta^2 = 0.08$. There were no significant main effects of training condition across all categories of errors evaluated: total errors, $F(2, 54) = 0.59$, $p = 0.56$, $\eta^2 = 0.02$; speeding errors, $F(2, 54) = 1.81$, $p = 0.17$, $\eta^2 = 0.06$; stopping errors, $F(2, 54) = 0.48$, $p = 0.62$, $\eta^2 = 0.02$; turning errors, $F(2, 54) = 1.99$, $p = 0.15$, $\eta^2 = 0.07$; signal violation errors, $F(2, 54) = 2.76$, $p = 0.07$, $\eta^2 = 0.09$; and moving on roadway errors, $F(2, 54) = 0.121$, $p = 0.89$, $\eta^2 = 0.004$.

A significant interaction effect was found for the total number of errors committed $F(6, 162) = 5.25$, $p < 0.001$, $\eta^2 = 0.16$; speeding errors $F(6, 162) = 5.03$, $p < 0.001$, $\eta^2 = 0.16$; stopping errors, $F(6, 162) = 3.05$, $p = 0.007$, $\eta^2 = 0.10$; and signal violation errors, $F(6, 162) = 2.37$, $p = 0.032$, $\eta^2 = 0.08$. No significant interaction effect was found for turning errors, $F(6, 162) = 1.20$, $p = 0.307$, $\eta^2 = 0.04$ and for moving on roadway errors, $F(6, 162) = 0.76$, $p = 0.604$, $\eta^2 = 0.03$.

Post-hoc pairwise comparisons for the main effects of training session for turning and moving on roadway errors are presented in Table 11. Results show that when ignoring the effect of training condition, there was a significant difference in turning errors between the first and last training session ($p = 0.039$), between the second and third sessions ($p = 0.002$) and between the third and fourth sessions ($p < 0.001$). Similarly, when ignoring the effect of training condition, there is a significant difference in errors for moving on roadway between the first and third session (*p* = 0.008) and between the second and third session (*p* = 0.002).

Table 11

Post-hoc Analysis Examining the Main Effect of Time for Turning and Moving on Roadway Errors

Driving error category	Time	Comparison time	Difference in score	*p*-value
Turning	Training 1.1	Training 1.2	0.67	0.093
	Training 1.1	Training 2.1	-0.32	0.251
	Training 1.1	Training 2.2	0.785	0.039
	Training 1.2	Training 2.1	-0.99	0.002*
	Training 1.2	Training 2.2	0.12	0.725
	Training 2.1	Training 2.2	1.10	<0.001*
Moving on Roadway	Training 1.1	Training 1.2	0.31	0.696
	Training 1.1	Training 2.1	2.33	0.008*
	Training 1.1	Training 2.2	1.66	0.056
	Training 1.2	Training 2.1	2.03	0.002*
	Training 1.2	Training 2.2	1.35	0.045
	Training 2.1	Training 2.2	-0.67	0.209

*indicates significance after applying the BH adjustment

Table 12 presents the simple main effects that were conducted to examine the significant interaction between training session and training condition for the total number of simulated driving errors. Specifically, these tests revealed that the total number of errors on the simulator was significantly lower at training session 2.2 than at training sessions 1.1 ($p = 0.002$) and 1.2 ($p = 0.001$) for the CG condition. The SIT condition also saw significantly less total driving errors between sessions 1.1 and 1.2 ($p = 0.002$), between 1.1 and 2.2 ($p < 0.001$), between 1.2 and 2.2 ($p = 0.003$) and between 2.1 and 2.2 ($p < 0.001$). The participants from the SIT condition saw however a significant increase in total errors between sessions 1.2 and 2.1 ($p = 0.008$). The SAT condition saw significant decreases in the total number of errors between trainings 1.1 and 1.2 (*p*

< 0.001), between 1.1 and 2.1 ($p = 0.005$), between 1.1 and 2.2 ($p < 0.001$), between 1.2 and 2.2 ($p < 0.001$) and between 2.1 and 2.2 ($p < 0.001$). Conversely, the SAT condition did not see any significant improvement between trainings 1.2 and 2.1 ($p = 0.277$).

Table 12

Pairwise Comparisons Examining the Significant Interaction Effects for Total Errors

Comparison base	Training session	Comparison session	Difference in score	*p*-value
CG	Training 1.1	Training 1.2	-1.32	0.609
	Training 1.1	Training 2.1	4.68	0.216
	Training 1.1	Training 2.2	11.95	0.002*
	Training 1.2	Training 2.1	6.00	0.146
	Training 1.2	Training 2.2	13.263	0.001*
	Training 2.1	Training 2.2	7.26	0.042
SIT	Training 1.1	Training 1.2	8.78	0.002*
	Training 1.1	Training 2.1	-2.67	0.491
	Training 1.1	Training 2.2	21.00	<0.001*
	Training 1.2	Training 2.1	-11.44	0.008*
	Training 1.2	Training 2.2	12.22	0.003*
	Training 2.1	Training 2.2	23.68	<0.001*
SAT	Training 1.1	Training 1.2	15.15	<0.001*
	Training 1.1	Training 2.1	10.80	0.005*
	Training 1.1	Training 2.2	33.30	<0.001*
	Training 1.2	Training 2.1	-4.35	0.277
	Training 1.2	Training 2.2	18.15	<0.001*
	Training 2.1	Training 2.2	22.5	<0.001*

*indicates significance after applying the BH adjustment

Simple main effects for the number of speeding errors (Table 13) show a significant decrease between sessions 1.1 and 2.2 ($p = 0.004$), between 1.2 and 2.2 ($p < 0.001$) and between 2.1 and 2.2 ($p = 0.002$) for the CG group. Similarly, both the SIT and SAT conditions saw significant decreases in speeding errors between sessions 1.1 and 1.2 (SIT $p = 0.018$; SAT $p < 0.001$), between 1.1 and 2.2 (SIT $p < 0.001$; SAT $p < 0.001$), between 1.2 and 2.2 (SIT $p = 0.003$; SAT $p < 0.001$) and between 2.1 and 2.2 (SIT $p < 0.001$; SAT $p < 0.001$). Interestingly, both training conditions however saw an increase in speeding errors between sessions 1.2 and 2.1

(SIT p=0.002; SAT p<0.001). No differences between sessions 1.1 and 2.1 were found for either the SIT (*p* = 0.164) or SAT (*p* = 0.289) conditions.

Table 13

Pairwise Comparisons Examining the Significant Interaction Effects for Speeding Errors

Comparison base	Training session	Comparison session	Difference in score	*p*-value
CG	Training 1.1	Training 1.2	-1.37	0.569
	Training 1.1	Training 2.1	0.00	1.00
	Training 1.1	Training 2.2	10.11	0.004*
	Training 1.2	Training 2.1	1.37	0.669
	Training 1.2	Training 2.2	11.47	<0.001*
	Training 2.1	Training 2.2	10.11	0.002*
SIT	Training 1.1	Training 1.2	6.00	0.018*
	Training 1.1	Training 2.1	-4.44	0.164
	Training 1.1	Training 2.2	15.50	<0.001*
	Training 1.2	Training 2.1	-10.44	0.002*
	Training 1.2	Training 2.2	9.50	0.003*
	Training 2.1	Training 2.2	19.94	<0.001*
SAT	Training 1.1	Training 1.2	15.25	<0.001*
	Training 1.1	Training 2.1	3.20	0.289
	Training 1.1	Training 2.2	27.4	<0.001*
	Training 1.2	Training 2.1	-12.05	<0.001*
	Training 1.2	Training 2.2	12.15	<0.001*
	Training 2.1	Training 2.2	24.20	<0.001*

*indicates significance after applying the BH adjustment

Simple main effects for stopping errors (Table 14) did not reveal any significant differences between the pairs of any training sessions for the CG and SIT conditions ($p > 0.02$). They however showed a significant decrease in stopping errors between sessions 1.1 and 2.1 ($p < 0.001$), between 1.1 and 2.2 ($p < 0.001$), between 1.2 and 2.1 ($p = 0.001$) and between 1.2 and 2.2 ($p = 0.001$) for the SAT condition. No significant difference was found for the SAT condition between sessions 1.1 and 1.2 ($p = 0.110$) and between 2.1 and 2.2 ($p = 0.679$).

Table 14

Pairwise Comparisons Examining the Significant Interaction Effects for Stopping Errors

Comparison base	Training session	Comparison session	Difference in score	*p*-value
CG	Training 1.1	Training 1.2	0.684	0.442
	Training 1.1	Training 2.1	1.68	0.108
	Training 1.1	Training 2.2	1.21	0.238
	Training 1.2	Training 2.1	1.00	0.991
	Training 1.2	Training 2.2	0.53	0.632
	Training 2.1	Training 2.2	-0.47	0.525
SIT	Training 1.1	Training 1.2	0.22	0.807
	Training 1.1	Training 2.1	0.61	0.566
	Training 1.1	Training 2.2	1.00	0.342
	Training 1.2	Training 2.1	0.39	0.704
	Training 1.2	Training 2.2	0.78	0.491
	Training 2.1	Training 2.2	0.39	0.612
SAT	Training 1.1	Training 1.2	1.40	0.110
	Training 1.1	Training 2.1	4.85	<0.001*
	Training 1.1	Training 2.2	5.15	<0.001*
	Training 1.2	Training 2.1	3.45	0.001*
	Training 1.2	Training 2.2	3.75	0.001*
	Training 2.1	Training 2.2	0.30	0.679

*indicates significance after applying the BH adjustment

Finally, simple main effects for signalling errors (Table 15) showed a similar pattern to the stopping errors. Overall, the SIT and CG conditions once again did not show any significant differences in signalling violations across any pairs of sessions ($p > 0.02$). However, the SAT condition showed significant differences in signal violation errors between sessions 1.1 and 1.2 ($p = 0.007$), between 1.1 and 2.2 ($p = 0.007$), between 1.2 and 2.1 ($p = 0.001$) and between 2.1 and 2.2 ($p = 0.001$).

Table 15

Pairwise Comparisons Examining the Significant Interaction Effects for Signal Violation Errors

Comparison base	Training session	Comparison session	Difference in score	*p*-value
CG	Training 1.1	Training 1.2	-1.59	0.082
	Training 1.1	Training 2.1	0.16	0.758
	Training 1.1	Training 2.2	-0.63	0.267
	Training 1.2	Training 2.1	1.32	0.035
	Training 1.2	Training 2.2	0.53	0.372
	Training 2.1	Training 2.2	-0.79	0.512
SIT	Training 1.1	Training 1.2	0.39	0.671
	Training 1.1	Training 2.1	1.06	0.049
	Training 1.1	Training 2.2	1.11	0.060
	Training 1.2	Training 2.1	0.67	0.290
	Training 1.2	Training 2.2	0.72	0.234
	Training 2.1	Training 2.2	0.056	0.916
SAT	Training 1.1	Training 1.2	-1.80	0.007*
	Training 1.1	Training 2.1	0.25	0.617
	Training 1.1	Training 2.2	-1.55	0.007*
	Training 1.2	Training 2.1	2.05	0.001*
	Training 1.2	Training 2.2	0.25	0.662
	Training 2.1	Training 2.2	-1.80	0.001*

*indicates significance after applying the BH adjustment

On-road global driving errors

The global on-road driving behaviours are divided into four categories of errors: vehicle control, procedural, observation and compliance errors. The observation errors in this section include mirror checks and blindspot checking and do not include intersection scanning as those findings were previously reported above. Errors in this section are presented as a total number of errors committed. Due to the different routes used across the duration of the study, the number of errors committed was adjusted based on the number of intersections per route.

Refer to the table in Appendix K, which summarizes the mean scores for various categories of on-road driving errors for each training condition and the total sample. The descriptive data of each category of errors is also depicted visually in Figures 13 through 17 below. The greatest number of errors was recorded under observational errors with an average of 42.91 errors (SD = 8.91) committed during baseline assessment. The least number of errors committed was found in the procedural category with an average of 7.48 (SD = 3.79). At baseline, the SIT condition committed the greatest number of total (M = 77.75, SD = 11.86), vehicle control (M = 18.43, SD = 8.45) and compliance errors (M = 12.07, SD = 6.43). Conversely, the CG condition performed the greatest number of procedural errors (M = 8.31, SD = 3.22), while the SAT condition performed the greatest number of observation errors (M = 46.31, SD = 9.39). After post assessment, the CG condition committed the highest number of total errors (M = 77.97, SD = 12.65) among all the conditions.

Figure 13

Change in On-Road Vehicle Control Errors by Training Condition Across Time

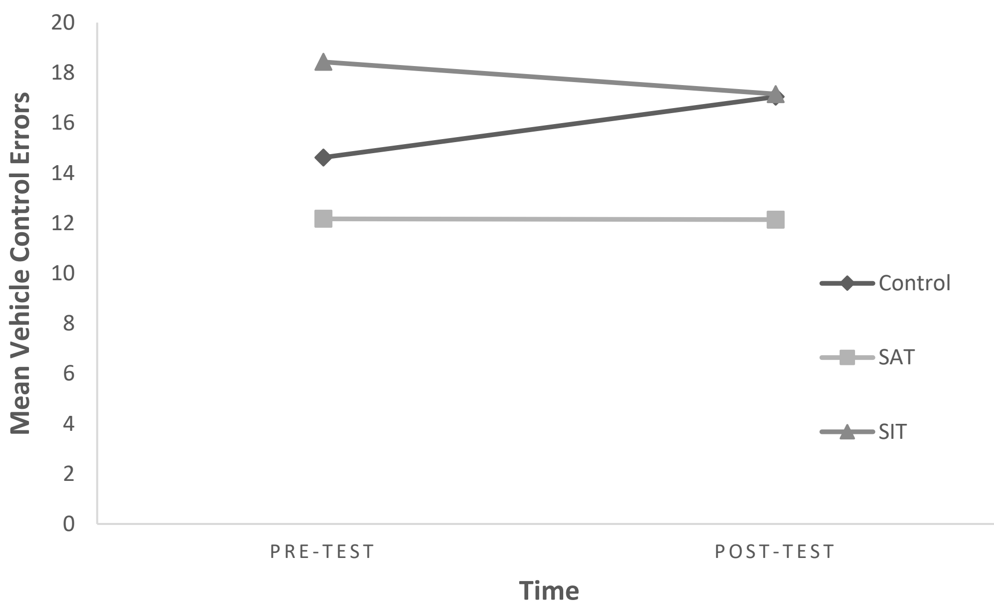


Figure 14

Change in On-Road Procedural Errors by Training Condition Across Time

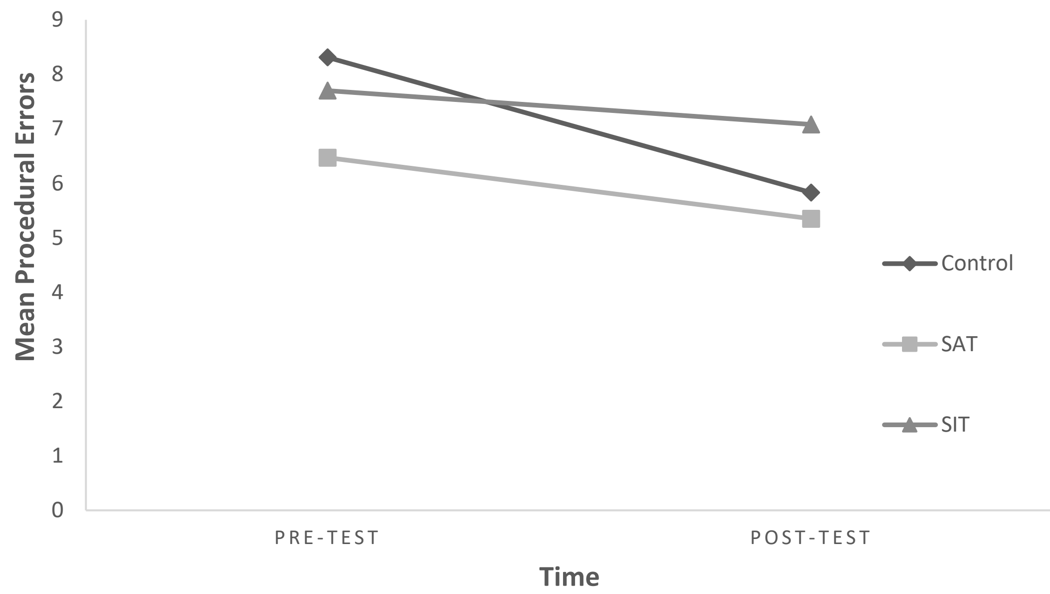


Figure 15

Change in On-Road Observational Errors by Training Condition Across Time

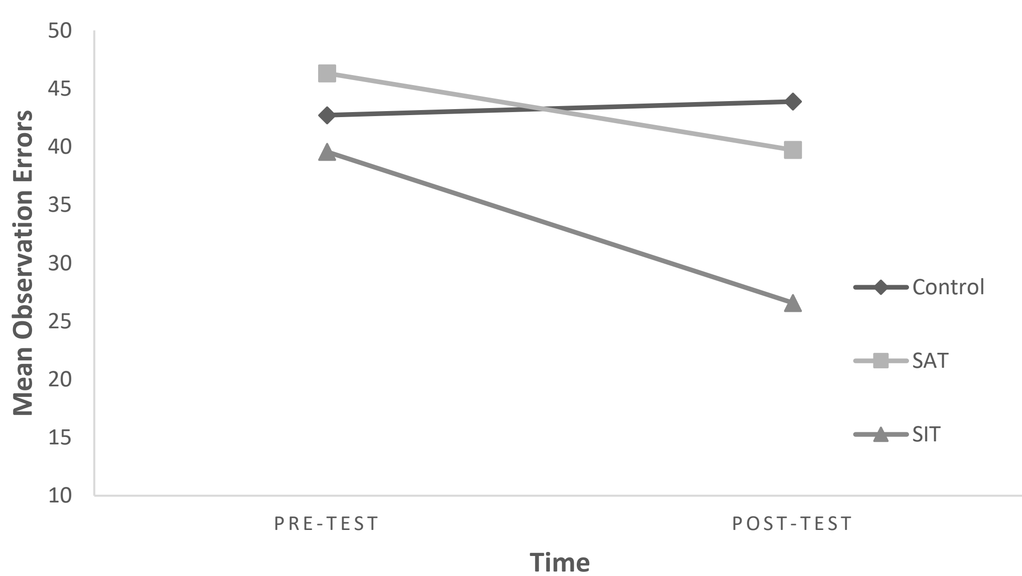


Figure 16

Change in On-Road Compliance Errors by Training Condition Across Time

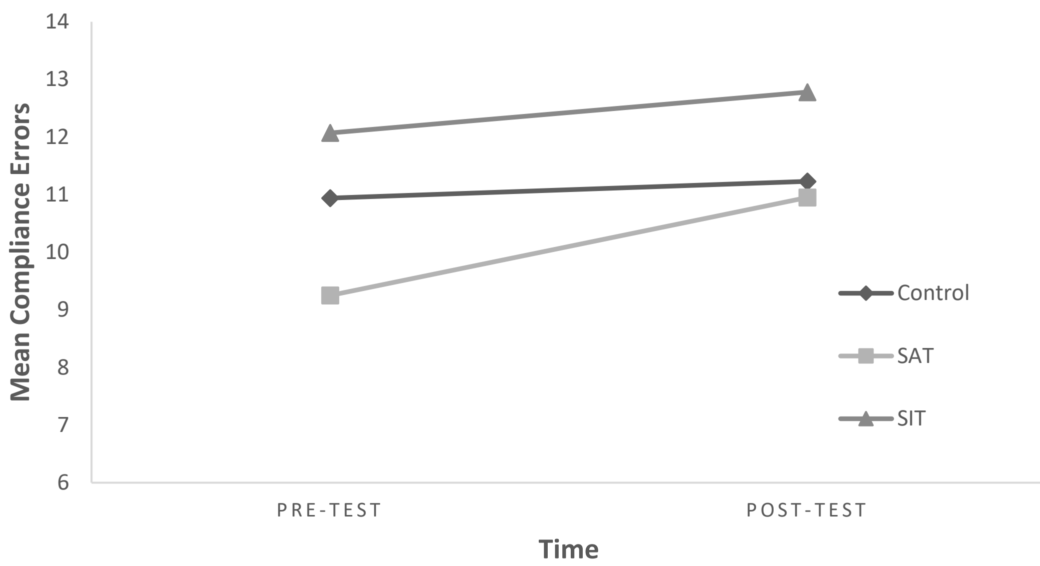
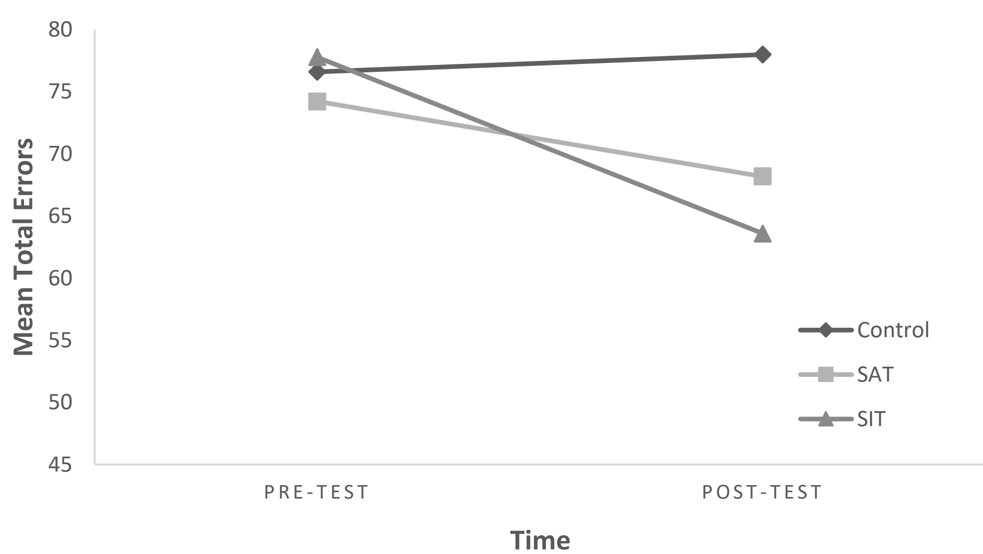


Figure 17

Change in On-Road Total Errors by Training Condition Across Time



A 3x2 mixed design factorial Analysis of Variance (ANOVA) was conducted to assess the main effect of training condition on older adults' on-road driving behaviours across the error categories evaluated. There was a significant main effect of time on the total number of errors committed, $F(1, 58) = 14.76$, $p < 0.001$, $\eta^2 = 0.20$; number of procedural errors, $F(1, 58) = 9.98$, $p = 0.003$, $\eta^2 = 0.15$; and on the number of observational errors, $F(1, 58)=21.34$, $p < 0.001$, $\eta^2 = 0.27$. There were no significant main effect of time on vehicle control errors, $F(1, 58) = 4.22$, $p = 0.71$, $\eta^2 = 0.002$ or on compliance errors, $F(1, 58) = 2.31$, $p = 0.134$, $\eta^2 = 0.04$. Examining the mean differences between the pre and post-training assessments for each category indicates that there were significantly fewer errors committed in the post-assessment for total, observational, and procedural errors. Conversely, participants saw a slight increase at post assessment, although not significant, for vehicle control and compliance errors.

A significant main effect of training condition was found for observational errors only, $F(2, 58) = 10.80$, $p < 0.001$, $\eta^2 = 0.27$. Training condition did not have any significant impact across the number of total errors, $F(2, 58) = 2.31$, $p = 0.108$, $\eta^2 = 0.07$; vehicle control errors, $F(2, 58) = 2.97$, $p = 0.059$, $\eta^2 = 0.09$; procedural errors, $F(2, 58) = 1.12$, $p = 0.334$, $\eta^2 = 0.04$; and compliance errors $F(2, 58) = 0.91$, $p = 0.406$, $\eta^2 = 0.03$.

A significant interaction effect between time and training condition was found for total errors, $F(2, 58) = 7.47$, $p = 0.001$, $\eta^2 = 0.21$, and for observational errors $F(2, 58) = 9.34$, $p < 0.001$, $\eta^2 = 0.24$. However, no significant interaction effect was found for vehicle control errors, $F(2, 58) = 1.17$, $p = 0.317$, $\eta^2 = 0.04$; procedural errors, $F(2, 58) = 1.53$, $p = 0.225$, $\eta^2 = 0.05$; and compliance errors, $F(2, 58) = 5.42$, $p = 0.604$, $\eta^2 = 0.02$.

Simple main effects were computed to examine the significant interaction effect between time and training condition for total and observational errors (Table 16). This analysis showed a significant decrease between pre and post-training assessment scores for the total errors category in the SIT condition ($p < 0.001$). No significant difference was found between pre and post on-road total scores for the SAT ($p = 0.034$) and CG conditions ($p = 0.626$). For observational errors, simple main effects analysis revealed a significant decrease between pre and post-training assessment scores within the SIT ($p < 0.001$) and SAT ($p = 0.005$) conditions. The CG condition did not show any significant difference between pre and post assessment ($p = 0.617$) for observational errors.

Table 16

Pairwise Comparisons for the Interaction Effects with Observation and Total Errors

Error category	Training Condition	Comparison condition	Mean difference	*p*-value
Observational	CGpre	CGpost	-1.18	0.617
	SITpre	SITpost	12.98	<0.001*
	SATpre	SATpost	6.59	0.005*
Total errors	CGpre	CGpost	-1.40	0.626
	SITpre	SITpost	14.17	<0.001*
	SATpre	SATpost	6.04	0.034

*indicates significance after applying the BH adjustment

Additional Analyses

Correlational analyses were performed to examine the relationship between baseline cognitive and visual measures (e.g., MoCA, PMCT and Pelli-Robson Contrast Sensitivity) with the change between pre and post scanning behaviours on the road. Results are presented in the table below.

Table 17

Correlations Between Baseline Measures and On-Road Observation Error Difference Scores

Outcome Measure	Training Condition	Pearson Correlation (*r*)	*p*-value
MoCA	CG	-0.161	0.497
	SIT	0.135	0.571
	SAT	0.165	0.476
	Overall	0.060	0.648
PMCT	CG	-0.250	0.369
	SIT	-0.358	0.173
	SAT	-0.131	0.593
	Overall	-0.130	0.367
Pelli-Robson Contrast Sensitivity (bilateral)	CG	-0.253	0.283
	SIT	0.025	0.916
	SAT	0.212	0.357
	Overall	-0.067	0.606
Pelli-Robson Contrast Sensitivity (right)	CG	0.074	0.755
	SIT	-0.101	0.672
	SAT	0.034	0.884
	Overall	-0.059	0.652
Pelli-Robson Contrast Sensitivity (left)	CG	-0.072	0.763
	SIT	-0.108	0.651
	SAT	-0.203	0.378
	Overall	-0.182	0.161

Overall, analyses revealed that there was no significant correlation between MoCA scores and the change in on-road scanning errors ($r = 0.060$, $p = 0.648$) as well as between PMCT scores and the change in scanning errors ($r = -0.130$, $p = 0.367$). Similar conclusions were found for correlations between a participant's contrast sensitivity score and their on-road scanning error change across bilateral ($r = -0.067$, $p = 0.606$), left ($r = -0.182$, $p = 0.161$) and right contrast scores ($r = -0.059$, $p = 0.652$). Additionally, no correlations were found between any of these measures and the change in scanning errors when controlling for group allocation.

Chapter 5: Discussion

Summary of findings

The number of older adult drivers has been steadily increasing, becoming a topic of interest in research in particular due to the questions it raises about the competence and safety of older adults and other road users. Past research has shown that navigating intersections is a particularly challenging segment for older adults, due to the increased complexity and cognitive load that drivers are faced with in these road segments (Romoser et al., 2013). Many interventions such as refresher courses, education courses, cognitive/physical interventions and simulated or on-road training programs have been tested as a means to address some of these concerns (Ball et al., 2010; Castelluci, 2020; Casutt et al., 2014; Cuenen et al., 2016; Marottoli et al., 2007; Roenker et al., 2003; Romoser & Fisher, 2009; Ross et al., 2016; Staplin et al., 2021). However, many of these methods are costly and risky, underscoring the appeal and necessity of driving simulators as a low-cost, low-risk alternative. Research has long demonstrated the relevance of driving simulators compared to real life road environments (Bédard et al., 2010; Desmond & Matthews, 1997; Kaptein, Theeuwes & Van Der Horst, 1996; Lemieux et al., 2014; Meuleners & Fraser, 2015). Prior evidence also suggests that one of the most effective ways in improving driving behaviour in older adults is by utilizing individualized driver training (Fausto et al., 2021; Romoser & Fisher, 2009; Gagnon et al., 2019; Sangrar et al., 2022). We also know that active learning methods such as training and feedback are more effective than passive learning methods such as educational courses (Akbari et al., 2021; Bédard et al., 2008; Gagnon et al., 2019; Fausto et al., 2021; Marottoli et al., 2007; Sawula et al., 2018). These findings align well with the conceptual model on which this work is partly based, which suggests that individualized training for older adults can influence driving performance.

The aim of this study was to assess the effectiveness of a driving simulator intervention involving targeted feedback and to evaluate its influence on the driving behaviours of older adults on the road. It also sought to compare the efficacy of two different feedback modalities: instructor-based feedback (SIT) versus automated feedback (SAT). To do so, the following research questions were emitted. Firstly, the principal aim of the study was to explore the influence of delivering targeted feedback during simulated driving sessions on scanning behaviours at intersections. This was examined on two fronts: effects on scanning behaviours during actual road driving and effects on scanning behaviours during simulated driving. This study sought to further explore the potential impacts of feedback as a driving intervention and determine if the training outcomes could be extrapolated towards generalized driving behaviours. As such, the second component of the study was exploratory in nature and sought to determine whether the feedback provided during simulator training can influence older adults' overall driving performance via an assumed increase of their self-awareness. This was once again examined at two levels: global on-road driving behaviours and global simulated driving behaviours.

Scanning behaviours

The primary outcome of interest in this study was to examine the impact of individualized feedback on scanning behaviours at intersections. While the on-road scanning behaviours were of particular importance, we also sought to examine the pattern of these behaviours during simulated driving. We therefore hypothesized that older adult drivers would commit fewer scanning errors in the instructor or automated feedback conditions compared to the CG condition, both in the simulator and on the road.

The findings from the scanning errors throughout the course of simulated training sessions are in line with our hypothesis. Firstly, the results shed light on the immediate impact of training interventions on older adults' scanning behaviours. Notably, means of scanning errors differed across training conditions at the first training session, with the CG condition exhibiting significantly higher error rates than either the SAT or SIT conditions. This suggests that both instructor and automated feedback had an immediate impact in reducing scanning errors right from the initial training session. This impact is further highlighted when examining the CG condition`s lack of significant progress over the course of the four training sessions. Interestingly, the participants trained in the CG condition made some improvements between trainings 1.1 and 1.2 on the first day, and between trainings 2.1 and 2.2 on the second day. These variations suggest the presence of a short-term learning or practice effect, but this learning does not persist over time, which is in clear contrast with the findings from the SAT and SIT conditions, who both showed more consistent and significant improvements over time. Indeed, participants in the CG condition made errors at 47% and 49% of intersections in the best-performing sessions in comparison to the SAT and SIT conditions who made 7% and 6%, respectively, on their worst performing sessions. These results lead us to conclude that no significant improvement in visual scanning behaviours can be observed in the absence of feedback, regardless of its nature.

Regarding on-road scanning behaviours, findings once again show support in favour of our hypothesis which indicated that the SIT and SAT conditions showed substantial decreases in scanning errors, with the SIT condition demonstrating the most change. Specifically, results from the SIT condition revealed a statistically significant difference between them and the CG condition, which demonstrates the transferability of the simulated training towards on-road driving. Interestingly, although the SAT condition saw a significant reduction in errors, there was no significant difference between them and the CG condition, which highlights the effectiveness of instructor-led feedback over automated feedback or no feedback. This specific finding contrasts the earlier outcomes observed during training in the simulator, where a notable difference was observed between the CG condition and both the SIT and SAT conditions. One plausible explanation for these variations could be rooted in the mechanism and intent behind the scanning behaviours within the SAT condition. In the simulator training sessions, participants assigned to this condition were tasked to scan intersections and to identify construction cones. Feedback was given based on their accuracy in cone identification. Therefore, the feedback provided based on this behaviour may have encouraged participants to focus primarily on this specific task rather than scanning the actual intersection itself. As a result, the artificial nature of the task of scanning for cones may be less transmittable to natural scanning at intersections while on the road, in comparison to the instructor feedback group. Likewise, the degree of realism in a simulated environment may also have an influence. For instance, Van Paridon and colleagues (2021) investigated the perception of cyclists in a simulated driving environment. Participants in their study noted an enhanced ability to detect road objects in the simulator compared to real-world conditions. This was attributed to the simplified nature of the simulated environment, which minimized distractions and allowed participants to focus more intently on the targeted objects. Expanding this concept to the SAT condition, one might infer that scanning intersections with cones in the simulator was marginally simpler due to the reduced number of stimuli in the simulated driving environment. Conversely, scanning intersections on the road presents a slightly greater challenge due to the amalgamation of stimuli in a real environment which warrant a driver`s attention.

Overall, the findings from the analysis of scanning behaviours align with the DEC model presented earlier, indicating that targeted intervention within the personal factors (e.g., a driver`s training and experience) at the level of specific contextual factors can indeed influence driving performance. These findings are also consistent with the literature, as numerous studies have underlined the efficacy of training interventions to support driving behaviour. That said, it is somewhat challenging to directly compare the simulated driving outcomes with previous literature since many studies employing simulated training interventions failed to incorporate simulated driving performance as a key outcome measure. However, a similar study conducted by Romoser and colleagues (2009) observed enhancements in secondary scanning behaviours among older adults subsequent to receiving delayed feedback, both on the road and in the simulator. Similar to our study, they also saw improvements in scanning behaviour for the active training condition both on the simulator and on the road. However, it is difficult to determine whether improvements in this case resulted from a combination of feedback in both driving environments, or exclusively from on-road feedback or simulated feedback. Our study suggests that simulator-based feedback is sufficient to improve scanning behaviours. This highlights the potential of simulator-based training as a cost-effective and safer alternative for driver training. Our results are also consistent with recent studies suggesting that simply engaging in active practice alongside educational interventions is insufficient for effectively transferring training outcomes to on-road driving. Instead, our findings align with previous research emphasizing that driving-specific feedback, combined with these interventions, is essential for achieving positive outcomes (Lavallière et al., 2012). While Lavallière`s study specifically did not target intersection scanning, feedback was provided through video playback on other observational behaviours such as blind spot and mirror checking. Nonetheless, the mechanism of providing specific feedback within our study continues to be consistent with previous evidence in the literature. More recently, Sangrar et al. (2022) utilized video feedback mechanisms, such as voice-over commentary based on pretest drives, to target various driving behaviors. Among the categories of driving behaviours that were examined, they noticed a significant reduction in observational behaviours. Interestingly, their observational errors also included mirror and blind spot checks, whereas our observational error category included intersection scanning exclusively. In contrast to our study, the feedback provided by these studies was given retroactively. Currently, asides from the immediate impact on simulated observational behaviours, it is difficult to discern whether live/immediate feedback during training or delayed feedback would translate into better outcomes on the road. When examining the percentage of change in scanning errors, there seems to be some evidence in favour of immediate feedback, as evidenced by our 17% reduction for the SIT and 8% for SAT conditions, in comparison to the reductions of 4.4% in previous research (Sangrar et al., 2022). However, making this comparison is challenging due to the differences in methodologies and outcome measures used across studies. Future research could investigate the efficacy of this by comparing the two feedback mechanisms within the same study.

Our results also shed light on the efficacy of instructor led feedback over automated feedback, as the former showed a larger impact than its automated counterpart. These findings are interesting given the known benefits of instructor-led feedback in improving driving performance among older adults. Our results specifically support the findings of Sawula et al. (2018) and Gagnon et al. (2019), suggesting that while they did not establish the effectiveness of simulator usage, they demonstrated that feedback from a trainer enhances driving performance and safety among older drivers. Our conclusions allow us to make a statement about the relevance and benefits of automated feedback. Indeed, while not as impactful as the instructor condition, the analyses clearly reveal a significant reduction in scanning errors for the SAT condition. This result, although anticipated, might be unexpected in light of the mixed conclusions among older drivers regarding automated feedback systems integrated into newer vehicles, as found by Shichrur and colleagues (2021). The effects they observed were inconsistent, and therefore the contribution of this system towards driving safety was inconclusive. In comparison to their study, our project reinforces drivers' appropriate reactions and informs them of inappropriate reactions. In contrast, alert systems only provide feedback under specific conditions, and it is possible that they may elicit a surprise reaction from the participant, diverting their attention from the problematic situation (Shichrur et al., 2021). Additionally, the focus of providing targeted feedback on a single safe driving reaction in our study likely facilitated the incorporation of the feedback received, as opposed to intelligent systems that focus on a variety of warnings and driving controls. In fact, these systems rely on the driver`s ability to make inferences about the error that was committed which could have led to the alert and therefore does not inform them about specific measures to change their behaviour. Overall, the current study confirms the beneficial effect that training with continuous and live feedback in a simulated context can have on older drivers' scanning behaviours at intersections.

Moreover, our data coding also allowed us to better quantify the nature of the errors performed based on the type of intersection. The results showed that regardless of training condition, participants showed fewer errors at stop-sign controlled intersections compared to non-signalized or signalized intersections. Previous research showed that older drivers exhibit different patterns of errors based on intersection type and that drivers were more likely to make more errors at complex intersections containing signals and or multiple lanes (Anstey et al., 2013; Min, Min & Kim, 2013; Romoser et al., 2013; Yamani et al., 2015). Most of these investigations focused on intersections categorized by the type of maneuver to be executed (e.g., right/left turns at T/4-way intersections), with little or no attention given to the specific signalization status of each. More pertinent to our study, Li and colleagues (2019) identified differences favoring increased observation time of specific segments (e.g., forward, right) at signalized intersections compared to non-signalized intersections. Their overall findings showed that more scanning behaviours, on average, were made at signalized intersections, although some differences are noted depending on the specific driving context and the maneuver to be executed (e.g., driving forward, turning right/left). The influence of the maneuver was also highlighted in another study that showed that the difficulty at signalized intersections is especially present when left turns are required, which can be related to a driver`s failure to yield the right of way (Braitman et al., 2007). Our results align with most previous findings, showing that participants across all training conditions made more errors at non-signalized intersections compared to signalized intersections. Part of the explanation for our results lies in the complexity of the non-signalized intersections participants encountered in the study, such as T-intersections situated on the opposite side of the road which could have potentially been obscured by other vehicles. Needless to say, these findings are interesting given the higher prevalence of crashes at signalized versus unsignalized intersections (Braitman, 2007; Yamani et al., 2016).

When examining differences in each training condition based on intersection type, we notice that all training conditions saw slight decreases in scanning errors at stop-sign controlled intersections, once again reaffirming the notion that these intersections are generally well navigated by drivers. However, the SAT and SIT conditions both saw notable decreases in scanning errors for signalized and unsignalized intersections, which the CG condition did not demonstrate. In fact, the SAT condition saw a 12% decrease in errors at signalized intersections and a 10% decrease at non-signalized intersections, while the SIT condition saw a 27% and a 15% decrease, respectively. This is unsurprising given the impacts of the training intervention as previously discussed as well as based on past research which delineates that drivers exhibit different patterns of errors based on intersection type (Li et al., 2019). Although these patterns were not the primary focus of the current study, they still provide insights into specific challenges older adults face in navigating intersections. These findings can guide future interventions by identifying potential areas for targeted improvement.

Overall, these results add to the growing body of evidence on the effectiveness of training interventions for older adult drivers, specifically regarding scanning behaviours (Lavallière et al., 2012; Sangrar et al., 2022; Sawula et al., 2018). While automated feedback led to some improvements in observational skills, the significant reduction in observational errors in the instructor feedback condition suggests that human interaction and personalized guidance may be more effective in facilitating learning and changes in driving behaviour in older adults on the road.

Global driving behaviours

The second primary objective of this study was to investigate whether feedback targeting a specific driving behaviour could lead to enhancements in overall driving performance. The underlying theory supporting this notion aligns with the DEC model, which suggests that driving training affects an individual's self-awareness, leading to modifications in their driving performance (Lindstrom-Forneri et al., 2010). As such, we hypothesized that drivers who underwent training, specifically receiving feedback on their scanning behaviours, would result in an increased self-awareness and therefore see changes in their global driving performance. In contrast, drivers in the CG condition, who did not receive feedback were expected to show no change.

The results obtained offer partial support of our hypothesis. Firstly, global driving errors over the course of the four simulated training sessions were examined. These errors were divided into six categories of behaviours: speeding, stopping, turning, signal violations, moving on the roadway, and total errors. The findings revealed that the SAT condition performed the highest number of total errors at baseline. This difference compared to the other two conditions could be attributed to the learning curve that participants from the SAT condition would have had to overcome. In particular, these participants did not only have to drive the simulator to scan intersections, but also had to select the appropriate response (button press) to indicate whether none, one or two cones were detected. Further, our results indicated that changes in all categories of errors over the course of the training sessions, independent of the training condition were noticed. This means that the training intervention on its own did not have an impact on improving participant's global driving performance on the simulator. Rather, participants seemed to naturally improve their driving performance over time regardless of the provision of feedback or lack thereof. However, our results also demonstrated significant interaction effects for speeding, stopping, signal violation and total errors. This suggests that the effectiveness of the training intervention varied based on the training condition and session of the training. In fact, all conditions saw a significant improvement in speeding errors committed between the first and last training sessions. Additionally, the SAT and SIT conditions saw more variability in their speeding errors between training sessions, especially between trainings 1.1 and 1.2 and between trainings 2.1 and 2.2. These variations suggest a short-term learning effect which is not sustained throughout the entirety of the training sessions. This is unsurprising given the structure of the simulated driving sessions. In fact, participants were exposed to two different trainings within the same day and this temporary improvement in errors could be attributed in part to a practice effect. This is further validated when seeing a significant increase in errors between trainings 1.2 and 2.1 which took place on two different days. Another factor supporting the idea of a practice effect lies in the sensitivity of the pedals used. In fact, these pedals lacked any gradual resistance to engage the speeding or stopping mechanism, which likely caused all participants to have difficulty managing their speeds. Thus, the SIT and SAT conditions would have had more difficulty regulating their speeds, as evidenced by their error scores, due to the additional task requiring them to scan their intersections in contrast with participants in the CG condition who did not have to do so.

Our results show more stable performance among most conditions for stopping errors. The SIT and CG conditions did not see any significant fluctuations in errors throughout the training sessions. However, the SAT condition saw the biggest change; they initially committed the most stopping errors at the first training session but committed the least by the last training session. They also saw significant decreases in stopping errors, session by session. Previous studies investigating the stopping behaviours of older drivers have identified inconsistent patterns, such as approaching intersections too rapidly and coming to abrupt halts, incomplete stops, and stopping either too far from or too close to the stop line (Hong et al., 2016). These findings are highly related to the type of stopping errors that were observed in our sample both during simulated drives and on-road drives. The SAT condition might have seen the most change in these types of errors as a result of the type of feedback provided to them. As participants were tasked with both scanning intersections and inputting their observations into the controls simultaneously, this process likely encouraged them to adopt a more deliberate approach to intersections, particularly those necessitating a stop. For example, participants would have required extra few seconds to process the presence of a cone and then input the response, which would have given them time to do a complete stop and therefore reduced their errors. Moreover, they would have been slower and more gradual in their approach to a stop to not miss a construction cone, which was sometimes obstructed and not visible until a certain point. Signal violations was the last category of errors that saw change dependent on training condition and training session. Our analysis once again revealed significant differences exclusively to the SAT condition between the first and last training sessions as well as from one session to the next, indicating a gradual improvement in performance over the course of the training sessions. Alike stopping errors, this difference in comparison to the other training conditions can be attributed once again to the multitasking that participants from the SAT condition faced. Hence, their progress would likely stem from becoming accustomed to concurrently managing intersection scanning, pressing buttons to signify cone presence, and staying aware of their surroundings to avoid signal violations.

However, as mentioned, our results also revealed significant effects of training session on turning and moving on roadway behaviours across all conditions. This means that all participants saw a change in these behaviours throughout simulated training sessions. In fact, the analysis revealed a significant increase between the second and third training sessions as well as a significant decrease between the third and last training sessions for turning errors. Similarly, participants also saw significant decreases between the second and third training sessions and between the first and third sessions for moving on roadway errors. These findings are not surprising given the sensitivity of the simulator equipment which could have contributed to participants having difficulty executing their turns and staying in their lanes at the onset of training. Throughout the course of the four training sessions, they would have naturally had the capacity to learn and adjust to the sensitivity which could explain their improvement.

The number of total errors committed throughout the four training sessions fluctuated according to training session and training condition, but all conditions saw a significant decrease in the total number of errors committed between the first and last training session. This finding is indicative of a practice effect rather than a specific training effect since all conditions saw changes in their performance. Prior research has demonstrated the potential for older adults to show an improvement in driving performance over time following driving training programs (Ball et al., 2010). In this regard, the pattern of a consistent improvement over the course of the sessions could be due to the effectiveness of repeated training sessions in increasing skill acquisition and retention in older adults. Even though the participants in the CG condition did not receive any feedback, they were unaware of this fact and could have perceived the simulated driving sessions as training, which could also explain their improvements on some of these measures. In other words, some improvement among all conditions is not unexpected since they all actively trained in the simulator, as is stipulated by learning theories in regard to a person`s ability to improve performance with practice (Boot et al., 2011, Collie et al., 2003; Cuenen et al., 2019). This conclusion is further supported in a study by Teasdale and colleagues (2016) where they determined that older adults who participated in multiple simulator training sessions showed improvements in driving performance over time.

The second sub question within our second research question postulated that there would be a difference in the participant`s global on-road driving behaviour following targeted training. Our results show only partial support of this hypothesis. On the road, participants were evaluated across five categories of errors: vehicle control, procedural, observation (excluding scanning behaviours), compliance errors and total errors. Among all the categories assessed, observational errors, such as checking mirrors and blindspots were the most common type of error committed by participants at baseline. This corresponds with prior research that underscores the difficulties older drivers encounter in upholding appropriate observation behaviours when navigating complex traffic environments (Gagnon et al., 2019; Lavallière et al., 2019; Owsley et al., 1991). The high prevalence of observational errors stresses the importance of interventions targeting visual scanning strategies and situational awareness among older drivers. Interestingly, this category of errors is also one that saw a significant change based on training condition. More specifically, both the SAT and SIT conditions saw a significant reduction in general observation errors, with the SIT condition demonstrating significantly less errors than any other condition. This suggests that the provision of feedback pertaining to intersection scanning was effective in also increasing general observation behaviours on the road. As seen previously, this finding was not replicated in simulated driving results as global observation errors were not studied due to the nature of a simulator which does not allow for blindspot checks and does not contain enough stimuli to warrant mirror checks. These findings are in line with the findings of Lavallière and colleagues (2012) who also saw significant changes in mirror and blind spot checks following simulator training.

In contrast to observation errors, procedural errors were less common overall, which coincides with previous research by Gagnon and colleagues (2019). Interestingly, results show that this type of error saw a significant decrease at post assessment, irrespective of condition allocation which is also comparable to previous findings by Gagnon and colleagues (2019) but contrasts with those of Sawula and colleagues (2018). Since this category of errors is largely influenced by the driving environment itself, this change can potentially be attributed to an increased familiarization with the route and GPS instructions for all participants. Differences in the presenting stimuli during the post-training assessment could also have been reduced which would have naturally decreased the number of reactions or behaviours that the participants would have had to respond with. For example, a participant may have been faced with more traffic or less red lights which would have decreased the possibility of errors related to stop line positioning. Finally, no significant changes were found for compliance and vehicle control errors across training conditions. This can potentially be attributed to the relatively stable nature of these driving behaviours, which are influenced by factors such as physical abilities and adherence to traffic laws.

Overall, the results of the second component of this study suggest that the provision of targeted feedback regarding scanning behaviours on the simulator could be generalized to similar behaviours, but not towards unrelated global driving behaviours on the road. These findings align somewhat with previous research which also examined UDAs as the main outcome measure. Firstly, Gagnon and colleagues (2019) trained a sample of older adults through a driving simulator using retroactive video feedback from their simulated drives. They found no training condition differences for vehicle control errors but saw significant change in favour of the training intervention for procedural, observational and compliance errors. More recently, Sangrar and colleagues (2022) trained a sample of older adult drivers using video feedback mechanisms based on both simulated and on-road driving videos. In line with the findings of Gagnon and colleagues, their results revealed that video feedback was successful in improving participants' observations of the roadway and their compliance with traffic and safety rules. There were also successful in improving older adults` vehicle control performance, which was not observed in both Gagnon et al. (2019) and in the current study. Interestingly, they did not find any changes in procedural errors, most likely due to the difficulty of scoring vehicle positioning through video. These findings contrast with some of the results in our study. However, a poignant point of differentiation lies in the fact that feedback in these studies was provided based on all types of errors committed, and not restricted exclusively to scanning errors, such as we did in this study, which could explain some of the differences.

Based on these comparisons, we can presume that a unique feedback based on a singular and specific driving behaviour does not necessarily extrapolate towards global driving behaviours. This suggests that a more detailed and directed feedback during training would be needed to induce changes in global areas of driving performance, such as those seen in the studies by Sawula et al., (2018), Gagnon et al., (2019) and Sangrar et al. (2022). In fact, this corresponds with the notion that training tends to yield better results when there is a closer alignment between the content of the training and the anticipated outcomes (Dahlin et al., 2008). Additionally, it is difficult to make any conclusions surrounding feedback and self-awareness. Even though many participants qualitatively reported an increased self-awareness as a result of their participation in this study, their self-perception was not quantified or examined formally as an outcome measure. Hence, there remains a possibility for the self-awareness aspect of the DEC model to hold validity, but subsequent research could replicate this methodology and incorporate self-perception assessment as a metric before drawing any additional conclusions in this regard.

Additional findings

Finally, this study also sought to examine the relationship between baseline cognitive and visual measures and changes in on-road scanning errors. Our findings revealed no significant correlations between any cognitive or visual measure administered and scanning errors on the road. The results remained insignificant both across the total sample and based on training condition. We know from previous comprehensive studies that visual function is important for driving safety, but that its relationship with specific driving performance outcomes may be complex and multifaceted. Specifically, low performance on visual measures such as visual acuity and contrast sensitivity were associated with poorer driving performance (Nguyen et al., 2022) but this performance was not specific or unique to scanning behaviours. Participants in our study averaged scores within the 1.5 to 1.7 ranges on a measure of bilateral contrast sensitivity which is above the cutoff for visual impairment, which could explain why no associations whether positive or negative could be observed with changes in scanning behaviours. This also suggests that the mechanism of scanning an intersection is not necessarily related to one`s contrast sensitivity. Vision, such as visual processing, might play a more important role in the actual detection and perception of hazards (McGwin & Owsley, 2022). This was in fact assessed in this study using a peripheral motion contrast threshold task, which interestingly also was not associated with a difference in scanning behaviours. We know from previous research that low sensitivity to visual motion is associated with higher crash rates at intersections due to a driver`s inability to perceive and then give right of way to other vehicles or hazards (Braitman et al., 2007; Henderson et al., 2015; Swain, McGwin & Owsley, 2022). However, we observed even lower average threshold levels in our sample compared to those in previous research, further highlighting the decline in visual abilities among older adults (Henderson et al., 2013; Henderson et al., 2015). Finally, as far as cognitive abilities are concerned, the MoCA, which is a general measure of cognitive function, was not associated with changes in scanning behaviours. This is not surprising as previous research had indicated mixed findings regarding the relationship between general cognitive abilities and driving performance outcomes (Anstey et al., 2005;

Classen et al., 2013). However, the sensitivity of this measure may also be limited in a sample of older adults who were mostly found to be cognitively healthy. Overall, these findings suggest that baseline cognitive or visual function as assessed may not be a strong predictor of improvements in scanning behaviours following intervention, notwithstanding their predictive value for broader indicators of driving safety (Anstey et al., 2005).

Limitations

Although the results of this study are promising, there are still some limitations worth discussing. Firstly, the analysis of participants' video sequences was conducted by judges who were blind to the participants' conditions. This represents a strength as it limited the presence of bias from the judges. However, there could nonetheless be some subjectivity in the scoring of behaviours. Even with collaboration among raters and the lead research assistant for uncertain scenarios, certain recordings did not consistently offer the best viewing angles to ascertain the presence of a visual scanning behaviour. To overcome this limitation, it would be beneficial to use a more sophisticated technological apparatus that could track eye movement in real time more accurately. This software would allow for a more objective confirmation of the observed differences. However, given the magnitude of the observed differences as well as the very high correlation coefficients obtained, this limitation does not seem sufficient to question the conclusions that were drawn.

Additionally, many environmental and technological factors could have affected the coding of scanning errors. Firstly, during on-road assessments, participants were advised against wearing sunglasses to ensure visibility of their eye movements. However, in the event that the sun would obstruct a driver`s vision, they were encouraged to wear glasses for their safety. This practice influenced the coding of their scanning behaviours, as coders had to rely solely on head movements to determine scanning activity, rather than a combination of eye glances and head turning. Similarly, due to technological failures, some of the on-road assessments were not properly captured by both front facing and side-facing camera views. When only a side-facing camera view was available, coders once again had to rely uniquely on head movements to determine if a scan was done. These two factors likely resulted in an underestimation of the number of glances made, as participants' eye movements were not observable, and they could have performed a scan solely using their eyes.

As previously outlined throughout this study, aging is not uniform across the population. While some older adults can be cognitively and physically healthy in older adulthood, it is unfortunately not the reality for many. This study examined the effects on a sample of older adults who were cognitively healthy, as evidenced by their MoCA score or by their ability to complete the orientation drive. However, given the prevalence of many forms of cognitive and physical ailments in older adulthood, this sample is likely not representative of the general population. Nevertheless, it shows promise in improving certain driving behaviours for older adults who are cognitively and generally physically healthy. Interestingly, while most of the participants were physically healthy with adequate mobility, a small number of participants self-identified with a form of physical disability or reduced mobility and were still able to participate and complete the study. We are also aware that various age groups within the older adult population, such as individuals aged over 80 years, may exhibit markedly different characteristics compared to those aged between 65 and 79 years old (Ayuso, Sanchez & Santolino, 2020; Noh & Yoon, 2017; Regev et al., 2018). Given the lack of representation of these presenting problems in this study, it is difficult to make any strong conclusions about the efficacy of our intervention on these groups. Nevertheless, the inclusion of older adults across diverse age ranges within the spectrum of older adulthood, including those grappling with mobility or other physical and functional limitations, appears as a promising endeavour for future research prospects. In fact, previous research has underscored that even older adults with mild cognitive impairments have the potential to enhance specific driving behaviours through simulator training using feedback (Teasdale et al., 2016).

A final important limitation arises from the use of a driving simulator, which has been discussed throughout most of the results. This study employed a lower-fidelity simulator, utilizing a personal computer with additional steering wheel and pedal components initially intended for video game purposes. The simulator lacked kinaesthetic feedback to the driver because of its fixed base and had restricted visual graphic capabilities. The sensitivity of the controls in comparison to real driving controllers used in a vehicle was also reported to be challenging for participants to navigate. These differences did not pose an issue for the main objective of this study, as scanning behaviours were not dependent on the sensitivity of the controls and particularities of the feedback. However, this may have played a larger influence on the second goal of the study, which was the global driving behaviours, and may explain in part, the lack of progress seen in this setting. Attempts of mitigating these factors could be made by providing several orientation sessions prior to simulated training.

Implications and future directions

The findings of the current study reflect the significant impact that feedback mechanisms can have on improving on-road observational behaviours in older adults. Older adults represent a group who are particularly vulnerable due to normative age-related declines. As the aging population continues to drive longer than ever before, the importance of maintaining functional and safe driving behaviours is of paramount importance. The feedback mechanism, regardless of its form (e.g., live, retroactive, in person, video playback, etc.), has been demonstrated to play a pivotal role towards enhancing drivers` performance on the road, both in our study and in numerous studies in the literature, as previously discussed. In other words, the results of this study demonstrate that providing timely and constructive feedback can lead to tangible enhancements in older adults' scanning skills, both in a driving simulator but more importantly on the road. Moreover, the inclusion of automated feedback, while less efficient than instructor feedback, holds promise for improving not only the efficacy but also the accessibility of trainings for older adult drivers. Given the complicated task of simultaneously scanning intersections and pressing buttons, future studies could look to simplify this task for participants to ensure that the confounding effects of potential information overload do not overshadow the impact of the intervention itself. Perhaps future studies could explore the use of eye-tracking software and link it to the same automated cues and look towards using a more sophisticated driving simulator to overcome some of its limitations that were previously discussed. However, an additional strength in this study is linked to the use of the driving simulator. By imbedding the training in a simulated environment, it allowed not only to control for potential safety risks, but also allowed for accurate replicability, which is difficult to guarantee in a real-world environment, given its multifaceted and constantly changing nature. Moreover, with the continuous advancement of technology, including virtual reality and artificial intelligence technologies, there is potential for more comprehensive, realistic and transmissible driver intervention and training opportunities, should simulator sickness be controlled for. It would also be interesting to determine if there are any long-term effects of this intervention on scanning behaviour. The likelihood of this prospect is promising, as some studies have shown long-term retention ranging from 3 months up to 2 years for active training groups (Anstey et al., 2018; Romoser et al., 2013).

However, it is essential to recognize that while the effectiveness of feedback interventions is promising, a causal link towards improving driving safety cannot be established. Certainly, an inference for an association between an increased ability to observe one`s environment and an increased safety or safe behaviours can be made, as has been previously suggested in the literature (Gagnon et al., 2019; Romoser et al., 2009; Romoser et al., 2013; Savage et al., 2018). Furthermore, while feedback interventions hold promise for enhancing on-road scanning behaviours among cognitively and generally physically healthy older adults, future studies could examine its efficacy among subgroups of the aging population by controlling for age (e.g., 65+ vs 80+), physical/functional limitations or disabilities (e.g., disabilities, mobility limitations, chronic diseases, etc.) and cognitive abilities (e.g., cognitively healthy vs mild cognitive impairment, etc.). It is also imperative to recognize that driving safety is not the sole responsibility of a single individual or group of individuals. Individualized training should be complemented by broader efforts aimed at promoting safe driving practices and fostering a culture of road safety. Consistent with theories from Lawton`s Person Environment fit framework, this would include policy interventions to improve road infrastructure and design, and community-based programs offering alternative transportation options for individuals who are no longer fit to drive, especially in rural areas where public transportation is not as accessible. This could also include making efforts to make our training and similar trainings (Romoser et al., 2009; Sangrar et al, 2022) accessible to the general older adult population through social and policy changes. This could potentially include changes in legislation and policy surrounding license renewal for older adult drivers to include mandatory retraining should their road test be unsuccessful. Additionally, some broader efforts in making structural changes to intersections are starting to emerge in research and show promising findings which highlight the importance of modifying the complexity of the road environment as to reduce cognitive overload (Zhang et al., 2022).

In conclusion, the findings of this study contribute and build upon the existing literature by providing empirical evidence on the effectiveness of feedback driven interventions to improve on-road observational behaviours among older adults. This study holds promise towards using safe and cost-efficient intervention programs towards addressing specific challenges faced by older adult drivers and consequently improving driving safety for all road users and promoting older adults’ independence and well-being.

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Appendix A

Power Analysis

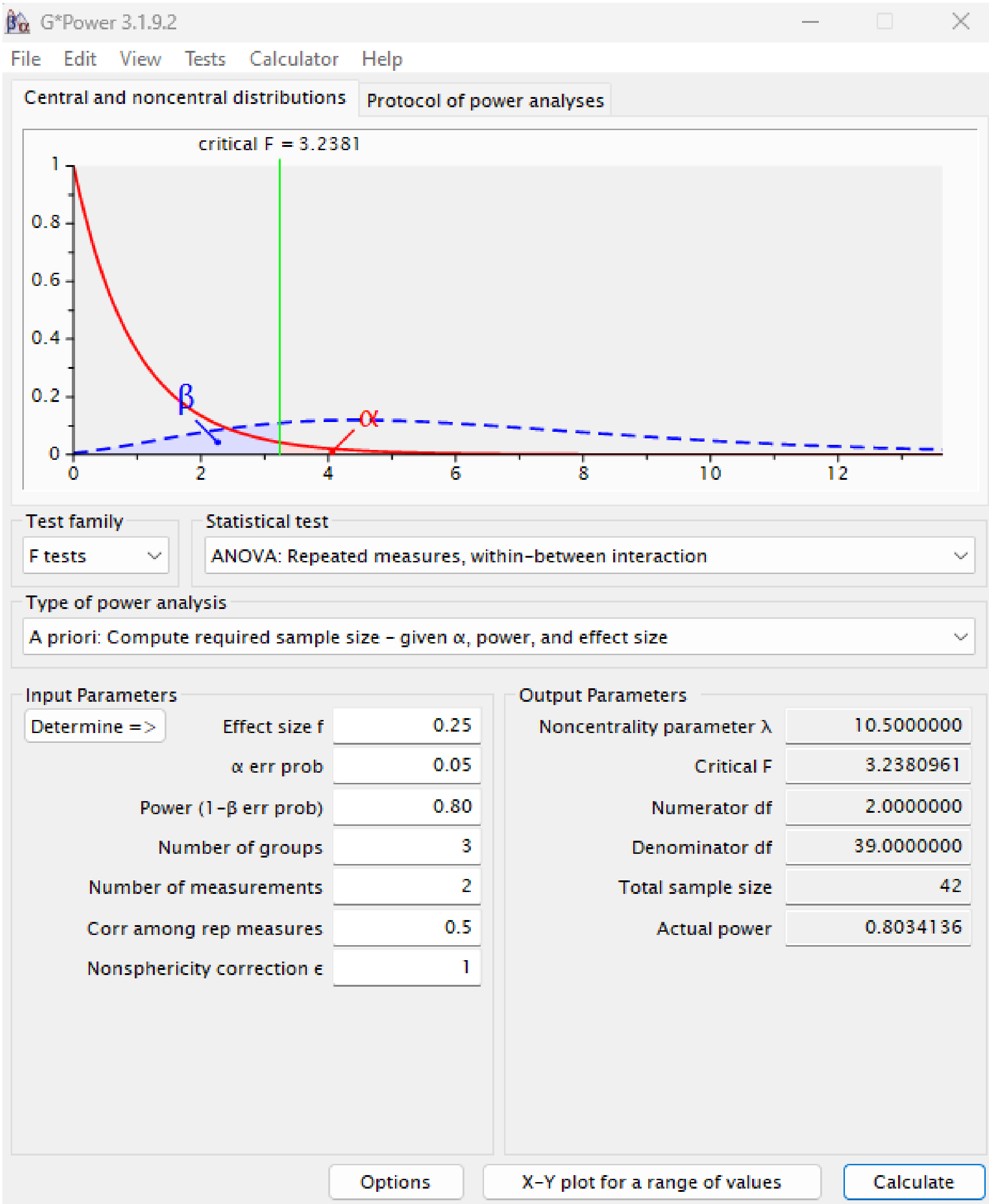


Figure A1. GPower output for power analysis

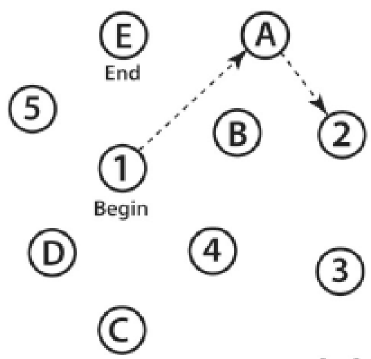
Appendix B

Montreal Cognitive Assessment

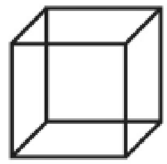
MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.1 Original Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE



[ ]



Copy cube

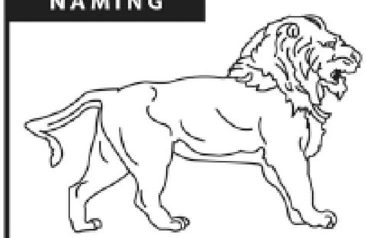
[ ]

Draw CLOCK (Ten past eleven)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

POINTS: ___/5

NAMING



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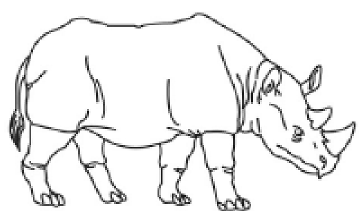
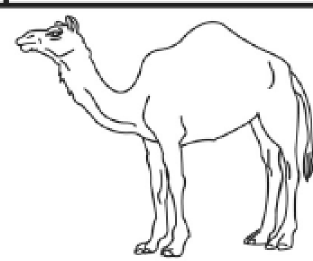


[ ]



[ ]

___/3

MEMORY		FACE	VELVET	CHURCH	DAISY	RED	
Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.	1st trial						No points
	2nd trial						

ATTENTION Read list of digits (1 digit/ sec.). Subject has to repeat them in the forward order [ ] 2 1 8 5 4
Subject has to repeat them in the backward order [ ] 7 4 2 ___/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B ___/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt** ___/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]
The cat always hid under the couch when dogs were in the room. [ ] ___/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] _____ (N ≥ 11 words) ___/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler ___/2

DELAYED RECALL	Has to recall words **WITH NO CUE**	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only	___/5
Optional	Category cue							
	Multiple choice cue							

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City ___/6

 www.mocatest.org Normal ≥26 / 30 TOTAL ___/30
Add 1 point if ≤ 12 yr edu

Administered by: ______________________

Appendix C

Simulator Sickness Questionnaire

No_______________ Date_____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology*, *3*(3), 203-220.

Simulator Sickness Questionnaire***

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

<u>Validation of the French-Canadian version of the SSQ developed by the UQO Cyberpsychology Lab :</u>

- Total : items 1 to 16 (scale of 0 to 3).
  - « *Nausea* » : items 1 + 6 + 7 + 8 + 12 + 13 + 14 + 15 + 16.
  - « *Oculo-motor* »: items 2 + 3 + 4 + 5 + 9 + 10 + 11.

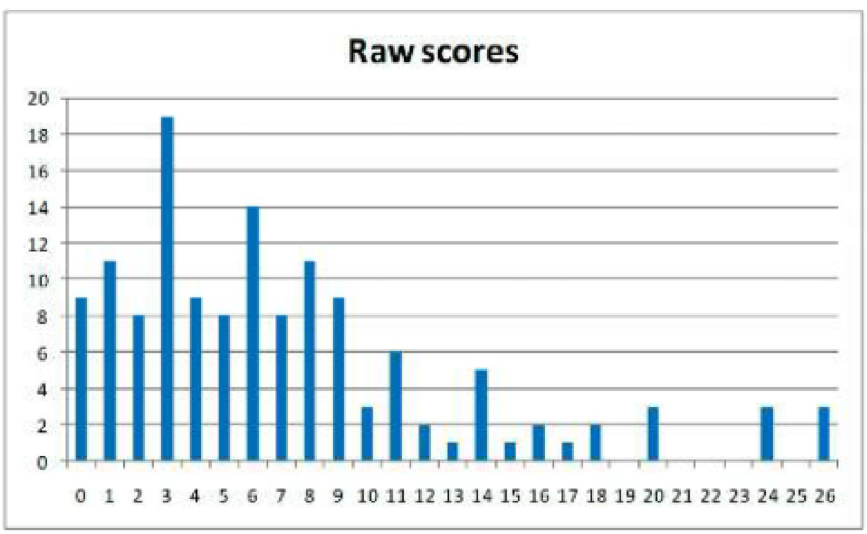
Please refer to the following articles for more information about the French-Canadian validated version :

BOUCHARD, S., Robillard, & Renaud, P. (2007). Revising the factor structure of the Simulator Sickness Questionnaire. Acte de colloque du *Annual Review of CyberTherapy and Telemedicine*, *5*, 117-122.

BOUCHARD, S., St-Jacques, J., Renaud, P., & Wiederhold, B.K. (2009). Side effects of immersions in virtual reality for people suffering from anxiety disorders. *Journal of Cybertherapy and Rehabilitation*, 2(2), 127-137.

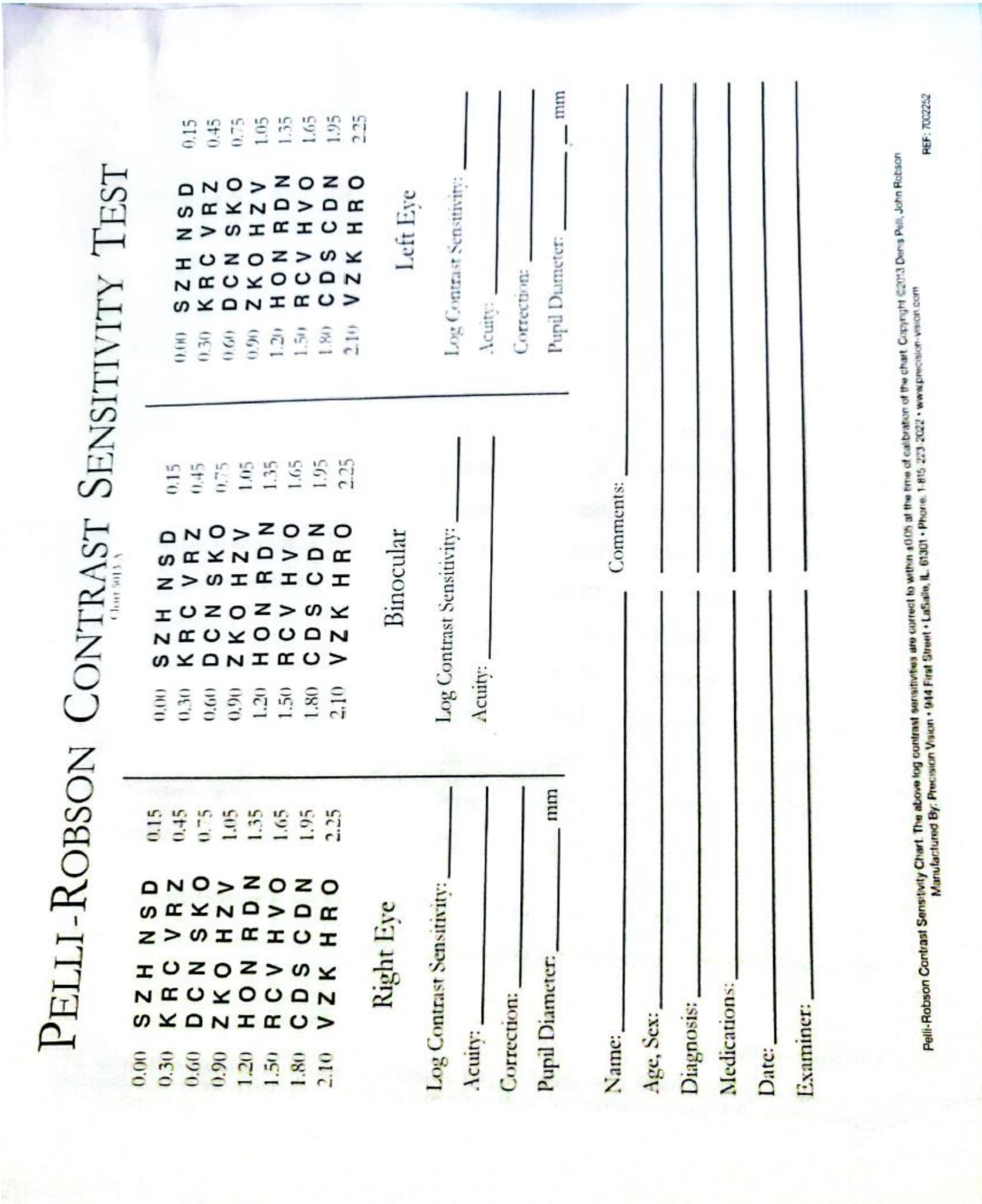
BOUCHARD, S. Robillard, G., Renaud, P., & Bernier, F. (2011). Exploring new dimensions in the assessment of virtual reality induced side-effects. *Journal of Computer and Information Technology*, *1*(3), 20-32.

Based on results from Bouchard, St-Jacques, Renaud, & Wiederhold (2009), below are the mean scores reported:



Appendix D

Pelli-Robson Contrast Sensitivity Test



Appendix E

On-road Routes for Orientation and Assessment Drives

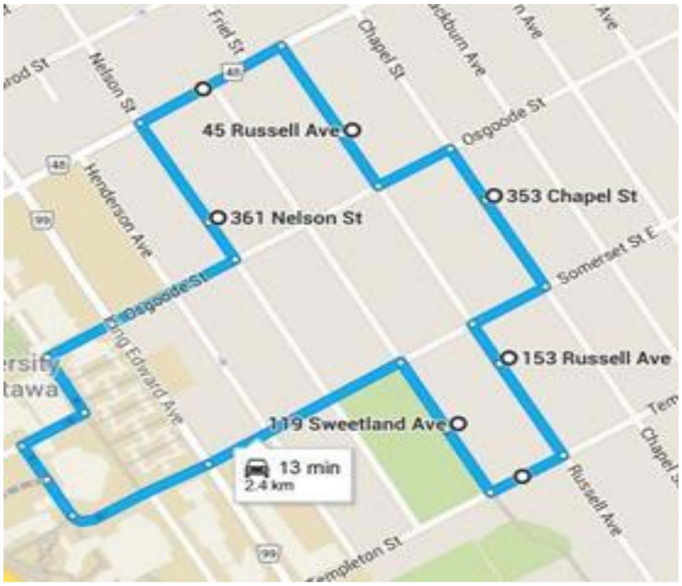


Figure E1. Map of GPS Directional Instructions for the Orientation Route.

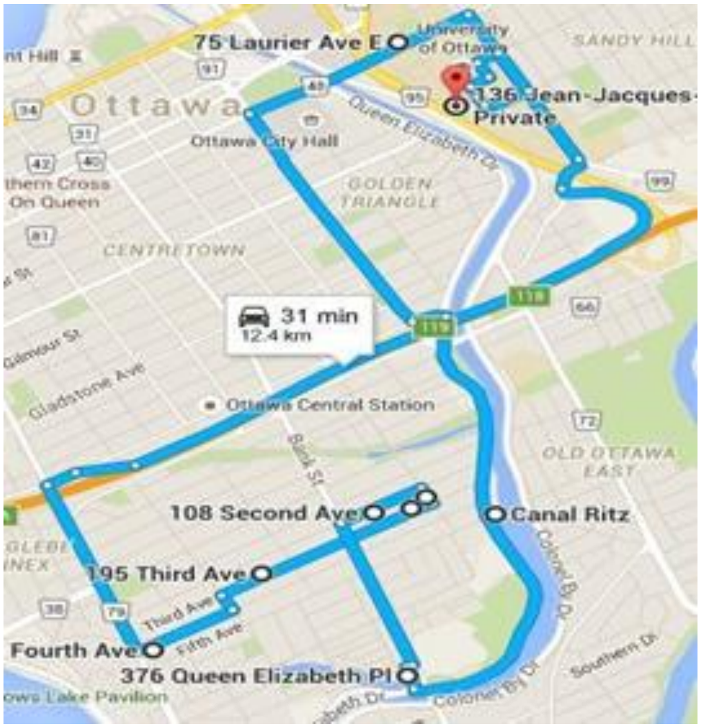


Figure E2. Map of GPS Directional Instructions for Route 1 for Pre and Post Assessment

Figure E3. Map of GPS Directional Instructions for Route 2 for Pre and Post Assessment

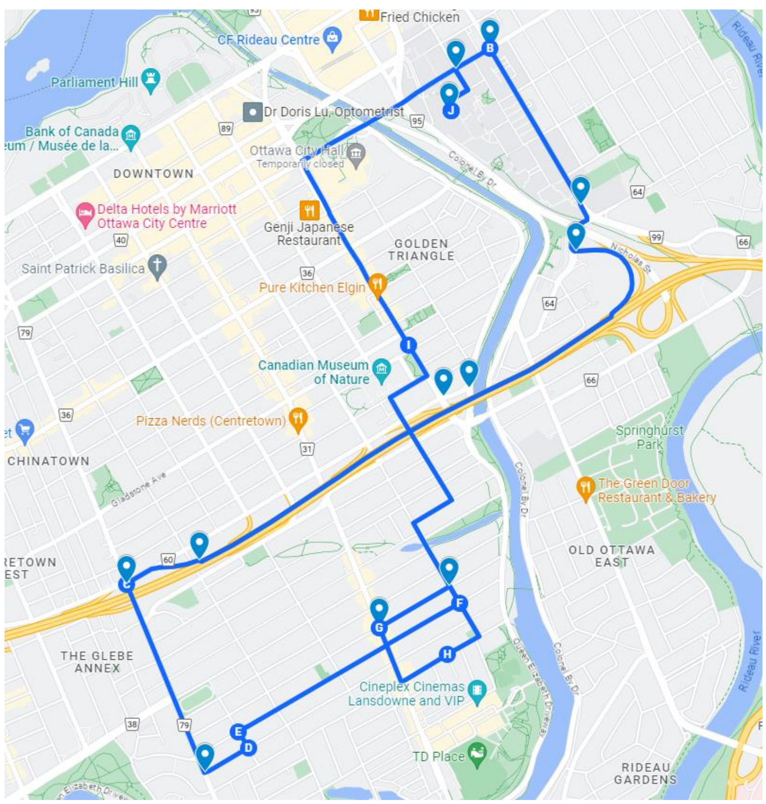


Figure E4. Map of GPS Directional Instructions for Route 3 for Pre and Post Assessment

Appendix F
Simulator Apparatus

Figure F1. Steering wheel and pedals used to operate the driving simulator

Figure F2. Monitor and webcam set up used to view the simulated drive

Appendix G

Consent Form

uOttawa

Université d'Ottawa | University of Ottawa
École de psychologie | School of Psychology
136 Jean-Jacques Lussier, room 3042 Ottawa, ON K1N 6N5
Phone: 613-562-5800 ext. 2515 Fax: 613-562-5147

Title of Project: Evaluation Of A Simulator Training Program With Automated Driving-Specific Feedback For Older Drivers

Primary Investigator: Sylvain Gagnon, PhD
University of Ottawa, Cognition Laboratory
(613) 562-5800 Ext. 2271,
E-mail: sgagnon@uottawa.ca

Co-Investigators: Amy Forster, Charles Collin, Michel Bédard, Arne Stinchombe, Stephanie Yamin

Funding Received from: Ministry of Transportation Ontario

I, ____, am invited to participate in the study conducted by Dr. Sylvain Gagnon and his research team of the Laboratory of Cognitive Aging at the University of Ottawa.

Purpose of Research Project

Older drivers are the fastest-growing segment of the driving population. They are also at increased risk of collision, as well as injury and mortality, as a result of those collisions. It is well established that older drivers commit errors related to observing the roadway environment (henceforth referred to as observational errors) that lead to crashes. Older drivers desire training opportunities to enhance their safety on the road, including simulator-based training. Yet, there is a shortage of research evidence regarding training efficacy for older drivers, particularly simulator-based training. In the absence of evidence, governments and decision makers are unable to recommend the use of simulator training to increase the safety of older drivers.

The objectives of this study are to: (1) to determine whether a simulator-training program targeting observational errors and providing automated feedback can improve on-road driving performance among older drivers; and (2) to compare the efficiency of simulator-based automated feedback with simulator-based instructor feedback.

Participant Involvement

The research study will require participants to commit to four sessions. All sessions will last approximately two hours.

Session 1

During the first session all participants will complete a cognitive assessment. Once complete they will familiarize themselves with the GPS that will be used to guide them on their pre-programmed route for the on-road driving evaluation. Participants will be asked to complete the on-road driving evaluation. Two cameras, each equipped with dual rotating lenses, will be placed inside the vehicle. Lastly, participants will acclimate themselves with the driving simulator.

Sessions 2 & 3

All participants will complete a visual assessment and will then acclimate themselves with the driving simulator. Participants will be assigned to a simulator training condition and will continue training throughout the third session.

Session 4

Participants are required to complete a post on-road evaluation with the same parameters as session 1.

Risks Involved

Some people experience motion sickness when using the driving simulator; we call this "Simulator Sickness". Some people also may have difficulties adjusting to simulator driving because their visual environment is moving and they are not. We will take all precautions to avoid this happening, but if it does occur, you can take a break or stop the simulated drive at any time. The research assistant will be trained in evaluating simulator sickness. We will also be using a tool called the Simulator Sickness Questionnaire to monitor you closely before, during, and after every simulation. If you do experience simulator sickness symptoms dissipate quickly and are not long lasting.

There is always a risk of physical injury in a non-simulated driving environment. We have taken proactive measure to try and mitigate the risk of physical injury by: scheduling participants at non-peak hour traffic times; by providing a GPS with specific, predetermined directions; by being monitored, and freely able to communicate with the research assistant in real time. If you are ever feeling uncomfortable while driving you may stop at any time.

Participation in this research is completely voluntary. The decision to participate or not is entirely mine. Even if I decide to participate, I may still withdraw at any time during the study without any penalty. I can request a break whenever needed. My state will be continuously monitored to ensure my well-being. I can also ask for more information at any time in order to gain a better understanding of the research. Dr. Gagnon and his team have assured me that the answers I provide will remain completely confidential and anonymous. All the data will be kept safely in the research laboratory for a minimum of 5 years to a maximum of 10 years, and only the researchers involved in this study will have access to it. Results will be reported in pooled format, seeking group differences, not individual differences, in order to protect my identity. Since there are no existing norms that would permit us to judge the quality of an individual performance, I understand that I will not have access to my individual results. Finally, I have been assured that my data will only be used for research purposes, such as scientific articles and/or presentations.

I understand that my participation in this study is conditional on the following:

1. I fully understand what I will be required to do as a participant in this study.
2. Participation in this research study is completely voluntary and I may: decline to answer any question; choose not to participate in any part of this study; or withdraw at any time without reprisal.
3. There are no anticipated major, long-standing physical or psychological risks associated with participation in this study. I understand that the physical risks of participating in this study will be the same as: experiencing motion sickness in a moving vehicle; and driving under normal on-road conditions for one hour.
4. My data will be confidentially stored in the Cognitive Aging Laboratory for a period of at least five years.
5. Should the researchers publish or make public presentations based on this research, my identity will remain anonymous.
6. Upon request, I will receive a summary of the project following the completion of the project.

This study has received ethics approval from the University of Ottawa's Social Sciences and Humanities ethics board. The appropriate research ethics board must approve all research projects involving humans or animals in order to ensure that ethical guidelines (including your rights as a research participant) are followed. Should you have any questions or comments regarding the ethics of this study, please do not hesitate to contact the Protocol Officer for Ethics in Research, Tabaret Hall, 550 Cumberland Street, Room 159, University of Ottawa, Ottawa, ON K1N 6N5, Tel.: (613) 562-5841, E-mail: ethics@uottawa.ca.

There are two copies of the consent form, one of which I may keep. If I wish to receive a copy of the final report of this study or have any questions about the conduct of the research project, I may contact Dr. Gagnon by mail, telephone, or e-mail at the addresses listed above.

Thank you in advance for your assistance in this study.

<u>Section to be completed by the participant:</u>

By signing the consent section of the document you are agreeing to the following:

- **I understand what I have read;**
- **I consent to take part in the research study;**
- **I consent to take part in the research processes that are described;**
- **I consent to the use of personal information as described.**

Signature: ________________________________

Date: __________________

<u>Section to be completed by the researcher:</u>

Signature: ________________________________

Date: __________________

Appendix H

Debrief Form

Title of Project: Evaluation Of A Simulator Training Program With Automated Driving-Specific Feedback For Older Drivers

Primary Investigator: Sylvain Gagnon, PhD
University of Ottawa, Cognition Laboratory
(613) 562-5800 Ext. 2271,
E-mail: sgagnon@uottawa.ca

Co-Investigators: Amy Forster, Charles Collin, Michel Bédard, Arne Stinchombe, Stephanie Yamin

Funding Received from: Ministry of Transportation of Ontario

Thank you for participating in this study. You may recall that the objectives of this study are to: (1) to determine whether a simulator-training program targeting observational errors and providing automated feedback can improve on-road driving performance among older drivers; and (2) to compare the efficiency of simulator-based automated feedback with simulator-based instructor feedback.

In order to reach this objective, we assigned our participants to three conditions: 1) training on the simulator without feed-back (our control group); 2) training in the simulator with feed-back from the research assistant; or 3) training in the simulator with feed-back from the simulator. The efficacy of the training will be determined after we compare the driving reactions before and after training. At this stage, we do not know if the two training groups had better driving reactions than did the control group. This will be achieved through an analysis of group data only. Nevertheless, if you were assigned to the control group and would like to receive an additional session of training with feed-back on your driving reactions, our research assistant will schedule an appointment with you.

We are convinced that the results from this study will help determining the best approach to the retraining of older drivers and whether simulation can help or not in that regard.

If you have any comments or reactions regarding your participation to this study, you may share them with the research assistant. You may also email me at the email address appearing above.

Regards,

Sylvain Gagnon, PhD
Professor
School of Psychology
University of Ottawa

Appendix I

Summary of On-Road and Simulated Driving Errors

	Error category	Description of errors
On road	Vehicle control	• Signaling (e.g., too early, not given, not cancelled) • Hand position on wheel (e.g., too high, too low, hand-handed, no hands) • Other (e.g., wipers, hazard lights, gears)
	Procedural	• Position in lane (e.g., left, right, waders, straddles line) • Stop position (e.g., over line, blocks crosswalk, too early) • Flow (impedes traffic, too fast, too slow) • Drives in wrong lane • Position on approach (e.g., too far from curb/centre) • Response to traffic lights (e.g., amber) • Left at light (e.g., wait position, wheel position) • Right on red light (e.g., complete stop).
	Observation	• Mirror checks (e.g., while driving, while slowing, while stopped) • Blindspot checks for lane changes • Blindspot checks for turning • Intersection scans • Looking in direction of movement
	Compliance	• Stops (e.g., incomplete) • Impedes traffic (e.g., lane changes, merges, too slow) • Fails to yield (e.g., pedestrians, bikes, ambulance, traffic) • Fails to clear the intersection • Right of way (e.g., car, pedestrian, bike) • Follows too closely • Turns (e.g., turns into wrong lane) • Stops without cause • Drives on the wrong side of the road • Passing too close • Hits a curb/anything • Disobeying street signs (e.g., no turn on red light, one-way street, etc.).

Simulated	Speeding	• Speeding • Hindering (i.e., going too slow)
	Stopping	• Stops for no reason • Excessive preparation for a stop • Not stopping at a safe place • Distance to intersection (e.g., too far or over the line)
	Turning	• Improper signal (e.g., not given, wrong signal, not cancelled) • Improper approach or excessive anticipation • Improper turn (e.g., turning when not advised to do so, turned the opposite way) • Improper speed on turn • Strikes/over the curb • Fails to yield • Fails to clear the intersection • Crosses solid or dotted line
	Signal violations	• Entering through on a red light • Entering through on an amber light • Entering trough on red at right turn (e.g., without a complete stop) • Rolls through stop sign
	Moving on roadway	• Fails to drive in proper lane • Crosses solid or dotted line • Wanders (e.g., drifts in lane) • Straddles traffic lane • Drives on the wrong side of the street • Drives on paved shoulder • Drives off route • Improper lane change (e.g., mirror check, signal)
	Observation	• Intersection scanning

Appendix J

Means of Simulated Driving Errors Based on Category Across Training Sessions

Error Category	Condition	Training 1.1 Mean (SD)	Training 1.2 Mean (SD)	Training 2.1 Mean (SD)	Training 2.2 Mean (SD)	Mean difference (from 1.1 to 2.2)
Speeding	CG	30.21 (19.23)	31.58 (19.93)	30.21 (14.97)	20.11 (14.29)	10.10
	SAT	49.95 (23.79)	34.70 (17.58)	46.75 (20.92)	22.55 (21.71)	27.40
	SIT	35.50 (21.55)	29.50 (18.09)	39.94 (23.52)	20.00 (13.87)	15.50
	Total	38.81 (22.91)	32.02 (18.35)	39.09 (20.89)	20.93 (16.70)	17.88
Stopping	CG	8.00 (6.90)	7.32 (6.42)	6.32 (4.68)	6.79 (5.91)	1.21
	SAT	8.60 (7.06)	7.20 (6.00)	3.75 (2.97)	3.45 (3.35)	5.15
	SIT	6.06 (5.96)	5.83 (5.76)	5.44 (6.33)	5.06 (7.19)	1.00
	Total	7.60 (6.61)	6.81 (6.00)	5.14 (4.84)	5.07 (5.72)	2.53
Turning	CG	6.95 (9.13)	7.00 (9.53)	7.58 (10.10)	7.05 (10.80)	-0.10
	SAT	3.25 (1.02)	2.25 (1.16)	2.85 (1.14)	1.90 (1.21)	1.35
	SIT	6.28 (9.85)	5.22 (8.3)	7.00 (9.07)	5.17 (7.90)	1.11
	Total	5.44 (7.70)	4.77(7.39)	5.74 (7.93)	4.65 (7.86)	0.79
Signal violation	CG	2.05 (2.95)	3.21 (2.96)	1.89 (2.33)	2.68 (2.06)	-0.63
	SAT	4.10 (6.21)	5.90 (7.59)	3.85 (5.63)	5.65 (6.75)	-1.55
	SIT	2.67 (2.28)	2.28 (2.30)	1.61 (2.15)	1.56 (1.50)	1.11
	Total	2.96 (4.27)	3.86 (5.14)	2.49 (3.86)	3.37 (4.54)	-0.41
Moving on roadway	CG	8.89 (9.01)	8.47 (7.98)	5.26 (4.41)	7.37 (5.52)	1.52
	SAT	9.40 (12.52)	9.90 (10.17)	7.20 (11.44)	7.95 (11.25)	1.45
	SIT	8.56 (8.15)	7.56 (7.52)	7.39 (6.54)	6.56 (4.72)	2.00
	Total	8.96 (9.98)	8.68 (8.58)	6.61(8.03)	7.32 (7.74)	1.64
Total	CG	56.26 (29.66)	57.58 (31.27)	51.58 (22.14)	44.32 (22.27)	11.94
	SAT	75.50 (33.75)	60.35 (28.61)	64.70 (32.68)	42.20 (30.37)	33.30
	SIT	59.22 (28.81)	50.44 (28.30)	61.89 (32.32)	38.22 (22.31)	21.00
	Total	63.95 (31.56)	56.30 (29.20)	59.44 (29.49)	41.65 (26.10)	22.3

Appendix K

Means of On-Road Driving Errors Based on Category

Error Category	condition	Pre intervention Mean (SD)	Post intervention Mean (SD)	Difference
Vehicle control	Control	14.62 (9.67)	17.04 (10.45)	-2.42
	SAT	12.17 (8.14)	12.14 (6.23)	0.03
	SIT	18.43 (8.45)	17.15 (7.29)	1.28
	Total	15.02 (9.00)	15.39 (8.37)	-0.37
Procedural	Control	8.31 (3.22)	5.83 (3.81)	2.48
	SAT	6.47 (3.65)	5.35 (2.80)	0.64
	SIT	7.70 (4.37)	7.08 (4.55)	0.65
	Total	7.48 (3.79)	6.07 (3.78)	1.41
Observations	Control	42.71 (8.80)	43.88 (9.56)	-1.17
	SAT	46.31 (9.39)	39.72 (9.59)	6.59
	SIT	39.56 (7.47)	26.58 (11.67)	12.98
	Total	42.91 (8.91)	36.78 (12.54)	6.13
Compliance	Control	10.94 (5.75)	11.23 (6.51)	-0.29
	SAT	9.25 (5.39)	10.95 (5.21)	-1.7
	SIT	12.07 (6.43)	12.78 (6.52)	-0.71
	Total	10.73 (5.89)	11.64 (6.05)	-0.91
Total	Control	76.58 (11.43)	77.97 (12.65)	-1.39
	SAT	74.20 (12.20)	68.16 (10.71)	6.04
	SIT	77.75 (11.86)	63.58 (16.05)	14.17
	Total	76.14 (11.73)	69.88 (14.37)	6.26