Cerebrovascular and cardiorespiratory responses in young, mid-aged, and older adults during simulated driving

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Abstract

Very little is known about the cerebrovascular and cardiorespiratory adjustments drivers make during typical driving task on highways and in urban areas. Near infrared spectroscopy (NIRS) can measure changes in oxygenated (HbO_2) and deoxygenated (HHb) haemoglobin concentration in the prefrontal cortex (PFC) during physical activities including driving. Heart rate responses can be measured through an electrocardiogram (ECG). This study recruited 29 participants to fulfill three age categories: young adults (18-25), mid-aged adults (26-64), and older adults (65+). Participants completed a Useful Field Of View (UFOV) test and four driving sessions using a driving simulator. Neuroimaging studies have suggested that the PFC plays a role in executive function while psychocognitive driving models have suggested that planning, judgement, and decision making are necessary cognitive skills for safe driving. This study investigated the cognitive and physiological stresses and demands of navigating urban areas and highways on a driving simulator and compared age groups. There were no statistically significant differences between age groups in UFOV scores of divided and selective attention or for heart rate variability (HRV) variables. Heart Rate (HR) increased by ~3 beats per minute (BPM) during city driving and HbO_2 increased slightly during driving tasks. Throughout most of the study, tissue oxygenation index (TOI) remained near resting baseline values. The general trend was slightly increased hemodynamic responses during driving with periods of decreased PFC activity.

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List of Abreviations

IADL...Instrumental activity of daily living

IIHS…Insurance Institute of Highway Safety

MET…Metabolic Equivalent

CBF…Cerebral Blood Flow

fMRI…Functional Magnetic Resonance Imaging

PET…Positron Emission Topography

IOR…Inhibition of Return

DEC…Driving as an Everday Competence Model

NIRS…Near-Infrared Spectroscopy

RT…Reaction Time

UFOV…Useful Field of View

cHB…Total cerebral hemoglobin

TOI…Tissue Oxygenation Index

ECG…Electrocardiogram

HR…Heart Rate

HRV…Heart Rate Variability

BPM…Beats per minute

IBI…Interbeat interval

SD…Standard Deviation

ANOVA…Analysis of Variance

BMI…Body Mass Index

1.0 Introduction

Driving is a nearly universal task for North Americans who are 16 years of age or older, and is considered an instrumental activity of daily living (IADL)(1). In 2015 there were 25 million licensed drivers in Canada and 218 million in the United States(2). There are some 40 million drivers over the age of 65 in the US alone. This number of senior drivers represents a 50% increase since 1999 (3). According to the Insurance Institute for Highway Safety (IIHS) (4) these older drivers rival younger drivers aged 16 to 25 in the statistics reporting fatal crashes per mile traveled with the numbers of fatalities beginning to increase at 70 years of age and reaching the peak for drivers over the age of 85. In Canada, senior citizens (age 65+) are the most susceptible age group to driver fatalities with 21.8% of all driver fatalities occurring in this age group (4). This age demographic of older drivers is significant because age-related psychophysiological decline, particularly in vision and cognitive function, occurs in seniors.

Driving is considered an instrumental activity of daily living as it provides mobility and autonomy. For older adults driving is important for maintaining independence especially for those who do not live in urban areas. It is also linked to activities of daily living (6;7;8;9;10) Determining whether a person has the physical stamina, visual competence, and cognitive capacity to drive safely is paramount to keeping the public safe. Currently, in most Canadian jurisdictions physicians report unfit drivers to the motor licensing authority due to impaired vision or medical conditions (11). While limiting driving due to some medical conditions is intuitive not

much has been done to determine levels of physiological and cognitive capacity necessary to safely operate a vehicle. Accuracy in measuring driving ability is crucial to ensuring that older adults are capable of driving safely are not stripped of their independent mode of transportation, while older adults who are incapable of driving safely are not permitted to pose a threat to themselves or others.

In terms of whole body energetics, driving is considered a sedentary physical activity with an estimated energy expenditure of double the resting metabolic rate (2.0 Metabolic Equivalents (METS)) (12). However, driving requires the utilization of diverse cognitive functions including perception, attention, working memory, decision making, and motor control (13) and thus has large cognitive demands. Drivers must be attentive to the environment around them and be able to generate appropriate motor responses. Nonetheless, it seems that the evaluation of neurophysiological variables that govern driving has been somewhat neglected.

2.0 Literature Review

2.1 Motor Control

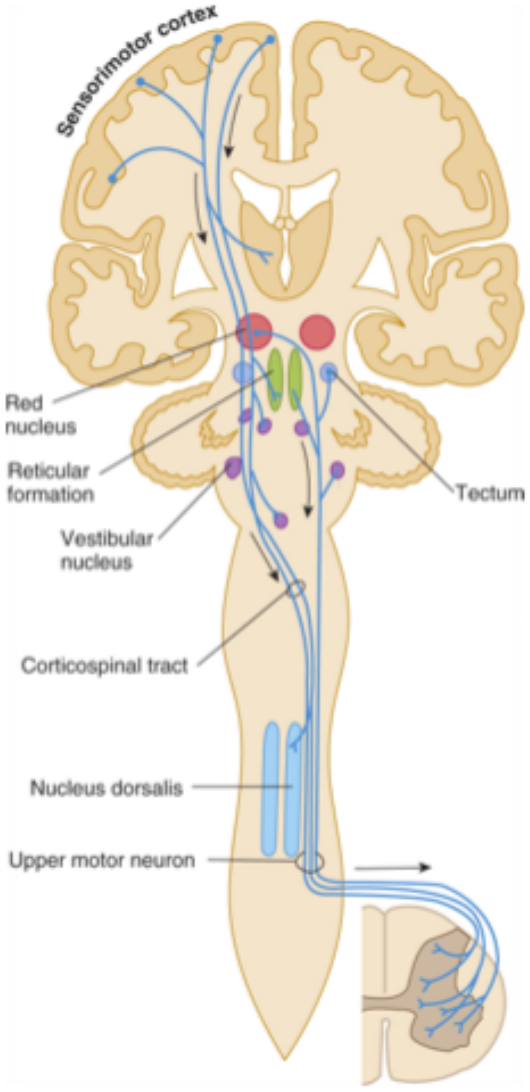
Driving a vehicle requires the driver to position themselves in a manner that they can view the road, reach the accelerator and brake, and hold the steering wheel all in a way that they are able to rapidly maneuver the vehicle in response to environmental stimuli. The motor control system is a very complex network of ascending and descending pathways in humans in which motor commands must be sent to numerous muscles and joints must be stabilized. Reflexes are controlled mainly at the spinal level. Repetitious movements involve mainly the spinal cord, brain stem, and cerebellum. Specific goal directed movements are initiated in the cerebrum. Included in the motor system are the cortical and sub-cortical gray areas, the corticobulbar, corticospinal, corticopontine, rubrospinal, reticulospinal, vestibulospinal, and tectospinal tracts, gray areas of the spinal cord, efferent nerves, cerebellum, and basal ganglia.

2.1.1 Corticospinal and corticobulbar tracts

The sensiormotor cortex is located in the frontal and parietal lobe around the central sulcus. The corticospinal and corticobulbar tracts orginate in the sensorimotor cortex and follow similar pathways. Approximately 55% of their fibers originate in area 4 and 6 (primary motor cortex and premotor cortex), 35 % of the fibers originate in area 3,1,2 (the postcentral principal sensory area) and 10% of the fibers originate from other frontal or parietal areas (14). Fibers originating from areas 4 and 6 are concerned with motor functions whereas the parietal lobe portion is concerned with modulation

of ascending tracts. The tracts synapse in the ventral nuclei of the thalamus, the brain stem, and the anterior horn motor neurons and interneurons in the spinal cord. However, the corticobulbar tract terminates in the brain stem. It is the upper motor neurons that provides efferent output for the cranial nerves. These nerves control the muscles of the face. The corticospinal follows a similar path as the corticobulbar tract going through the internal capsule, crus cerebri, and efferent nuclei of the brain stem however the corticospinal tract continues further. The corticospinal tract passes through the pyramids of the medulla, decussates and descends down the lateral column of the spinal cord. Approximately 90% of the fibers decussate in the medulla travel down the later column and terminate in the ventral gray horn. From there lower motor neurons deliver impulses to targets. This lateral corticospinal tract controls the distal musculature involved in fine motor skills and fractionated movement. Approximately 10% however do not decussate in the medulla and remain on the ipsilateral side and descend via the anterior white column. Many of these fibers then decussate via the anterior white commissure and cross over to the contralateral side; however, some do not decussate (about 3%) (14).The anterior corticospinal tract is responsible for gross and postural motor function and controls the trunk and proximal limbs. This allows the maintenance of an upright stance and the gross positioning of the limbs.

Figure 1 Corticospinal and motor efferents (Figure adopted from (14))



2.1.2 Rubrospinal, Reticulospinal, Vestibulospinal, and Tectospinal tracts

The rubrospinal tracts begins in the red nucleus. It receives input from the motor cortex and the cerebellar nuclei in bilateral fashion. Crossed fibers from the rubrospinal tract descend down the lateral column of the spinal cord and synapse with interneurons. The reticulospinal tract begins in the reticular formation of the brain stem. Input is received by the reticular formation from the sensorimotor cortex and then sent down the lateral column to interneurons. Vestibulospinal tract arises in the vestibular nuclei which is located just below the 4^{th} ventricle. Afferents are received from the vestibular nerve as well as the cerebellum. There are both crossed and uncrossed fibers. The reticulospinal tract plays a role in maintaining an erect posture. Tectospinal tract comes out the superior colliculus and crosses the mid-brain near the level of the red nucleus. Tectospinal tracts integrate into either the medial longitudinal fasciculus in the medulla or the anterior funiculus in the spinal cord. The tectospinal tract is responsible for reflex movements in the upper trunk, neck, and eyes in response to visual stimuli. Reflexive response to sudden visual stimuli is a necessary action required for safe driving and allows drivers to follow unanticipated visual cues.

2.1.3 Basal Ganglia

The basal ganglia involve complex loops of neurons that provide feedback loops important for motor control. The main job of the basal ganglia is inhibition. The striatum, which is made up of the caudate and putamen, is the major site of input within the basal ganglia. Afferents are directed there from the sensorimotor cortex, premotor cortex, and frontal eye fields to the striatum via corticostriate projections. The striatum then sends inhibitory axons to the globus pallidus, which is one of the two

major output sites of the basal ganglia. The globus pallidus then sends inhibitory axons in small bundles (ansa lenticularis and lenticular fasciculus) to the thalamus (either ventral anterior or ventral lateral) which pass through the internal capsule on the way there. Lastly, the thalamus sends the inhibitory response back to the cerebral cortex which completes the feedback circuit. This allows the brain to stop any unwanted movements. The other major output site of the basal ganglia is the substantia nigra. The feedback loop of the substantia nigra involves a reciprocal connection to the striatum. In the striatum, there are excitatory dopamine receptors and inhibitory dopamine receptors. However, that is not the only feedback loop the substantia nigra is involved in. It also sends projections to the thalamus and limbic system.

Of particular importance for driving, the substantia nigra sends axons outside of the basal ganglia to modulate head and eye movements. There are also loops involving the cerebellum. These loops do not involve the thalamus as the relay station; instead, the prerubral field and red nucleus act as the relay and modification station. The motor cortex and deep cerebellar nuclei send input to the red nucleus while the globus pallidus sends projections to the red nucleus as well. The red nucleus sends motor output via the rubrospinal tract. The rubrospinal tract descends via the lateral column and synapses with interneurons.

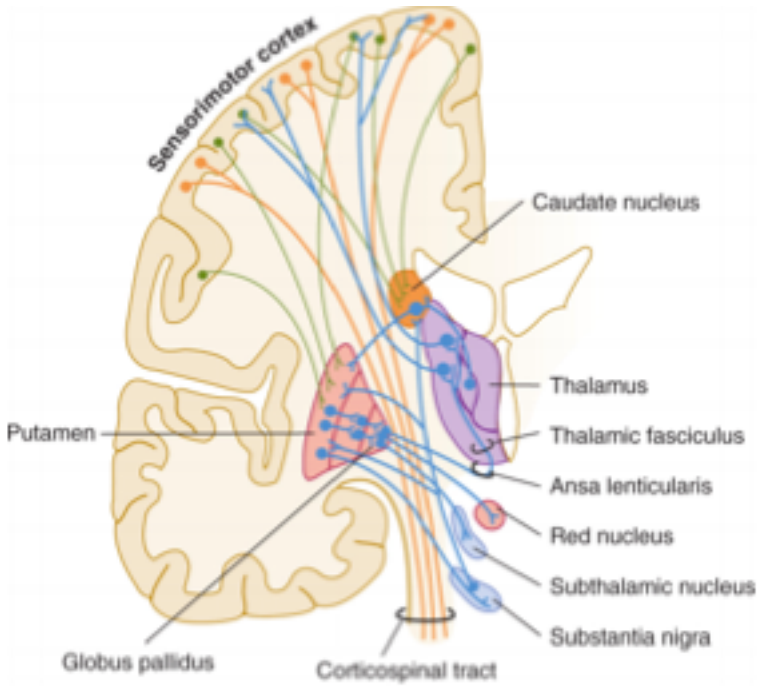


Figure 2 Basal ganglia and efferents (Figure adopted from (14))

2.1.4 Cerebellum

There are three peduncles that connect the brain stem to cerebellum. The superior cerebellar peduncles connects the midbrain to the cerebellum. Neurons from the motor cortex go through thalamic relay centers and connect to the midbrain and then superior cerebellar peduncles. The middle cerebellar peduncles receives communication about voluntary motor responses initiated by the motor cortex. These signals arrive via the pons. The inferior cerebellar peduncles connect the medulla with the cerebellar and is involved in muscle proprioception, equilibrium, and balance. The cerebellum functions by receiving simultaneous bilateral input from proprioceptors in the body and the motor cortex of the cerebrum. The cerebellum then calculates the best response by analyzing variables such as force, direction, muscles contraction,

postures, and smooth motion. Once analyzed the cerebellum sends a “blueprint” for coordinated motion to the motor cortex.

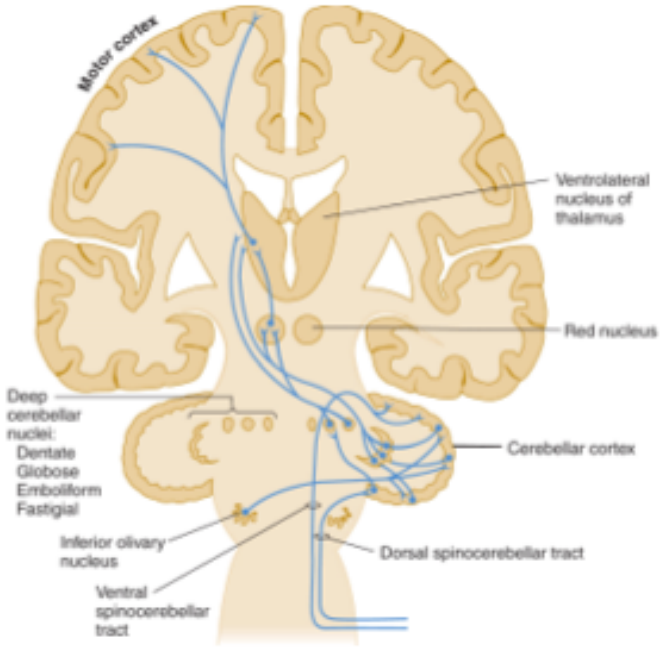


Figure 3 Cerebellar Outflows (Figure adopted from (14))

2.1.5 Perfusion

The brain is a complex organ that needs perpetual delivery of oxygen and nutrients to be sustained. Since, the brain does not store glucose without cerebral blood flow (CBF), it cannot maintain function without it. CBF is best described by Hagen-Poiseuille’s equation for laminar flow. Since there is a direct relationship between flow, cerebral perfusion pressure (CPP), and caliber of blood vessels as long as the vessels are not compromised and CPP is within normal ranges, CBF will remain relatively constant. CBF is variable across the brain and is dependent on neuronal activity.

$$\Delta P = -\frac{8\mu L}{R^2}U \text{or} \Delta P = -\frac{8\mu L}{\pi R^4}Q$$

Increases in activity cause an increase in the cerebral metabolic rate which results in a proportional increase in blood flow. This is termed flow-metabolic coupling (16). The delivery of oxygen and metabolic substrate to the areas of the brain that are more active is accomplished by vasoactive control mechanisms that re-distribute from areas of low activity to areas of high activity (17;18;19). Functioning vasoactive control mechanisms are an essential physiological function for competent driving.

2.1.6 Imaging and brain regions

Using various neuroimaging techniques, researchers have attempted to determine which regions of the brain are active during driving tasks. Using driving simulators, researchers have investigated which brain regions are more active during driving in comparison to resting (20;21;22;23). These studies used functional magnetic resonance imaging (fMRI) or positron emission tomography (PET) to map the brain. They revealed that the areas of the brain that are most active during driving are the parieto-occipital cortices, cerebellum, and cortical regions associated with perception and motor control. The activity in these areas was attributed to their impact in vision, motor skills, and visuomotor integration.

The pre-frontal cortex has been suggested to perform several functions. These include working memory for spatial and object-recall tasks, task management, and solving complex multitask problems. Psychological driving models suggest that it may

be necessary for safe driving however, neuroimaging studies have shown conflicting reports when it comes to activation in this brain region during driving and driving simulation. This is discussed in further detail in section 2.3. In addition to the prefrontal cortex the frontal lobe houses area 4, area 6, and area 8 which are the primary motor area, premotor cortex, and frontal eye field respectively. Area 4 gives rise to numerous axons that descend down the corticospinal tract. It is organized somatotopically and has a map-like homunculus for the various body parts and is located directly anteriorly to the central sulcus on the precentral gyrus. Area 6 is the premotor cortex holds a second motor map and supplements the primary motor area. Area 8 is provides eye movements.

The parietal lobe is involved is sensory integration. The primary sensory areas are areas 3,1,2 and are somatotopically respresented in a homunculus in a similar manner to the primary motor cortex. The primary somatosensory cortex is in the post-central gyrus directly posterior to the central sulcus. Posterior to the primary sensory cortex is the sensory association area which is areas 5 and 7.

The occipital lobe is most posterior lobe of the cerebrum and it is primarily concerned with vision. The geniculocalcarine radiation relays visual input from the lateral geniculate nucleus of the thalamus to the striate cortex. Upper parts of the retina/lower parts of the visual field are represented in the upper parts of area 17 while lower parts of the retina/upper parts of the visual field are represented in the lower parts of area 17. Areas 18 and 19 which are visual association areas are also housed in the occipital lobe.

The temporal lobe is primarily concerned with the sense of hearing. Area 41 is the primary auditory cortex and area 42 is the associative auditory cortex. The temporal lobe also plays a role in language comprehension and houses wernicke's area and also holds some visual maps.

The cerebellum functions in the coordination of both gross and fine movement and controls equilibrium and muscle tone. There is a memory mechanism that the cerebellum performs to help retain learned movements. This is important for driving because it allows tasks like steering and changing gears to become automatic allowing drivers to allocate their attentional resources elsewhere. Lesions in the cerebellum from stroke may cause difficulty with memory of learned motions making driving more challenging after brain injuries such as a stroke.

Walter and colleagues (18) compared the brain activity between passive driving and simulated driving and found that activity specific to driving was only found in the sensorimotor cortex and cerebellum. The passive condition involved a person steering the car from the outside. The sensorimotor cortex and cerebellum work together to produce motor output. The motor areas in the cerebral cortex signal the cerebellum of the intent to produce voluntary muscle contractions. Simultaneously the cerebellum receives input from proprioceptors and visual pathways to evaluate body position and momentum. Then the cerebellum sends the cerebral motor cortex a blueprint for coordinated movement. The basal ganglia have been suggested as playing a role in inhibition of unwanted movement patterns. Uchiyama and colleagues (21) reported co-

activation in the basal ganglia, thalamus, and premotor cortices. This suggests a basal ganglia loop is involved in optimizing motor control during simulated driving.

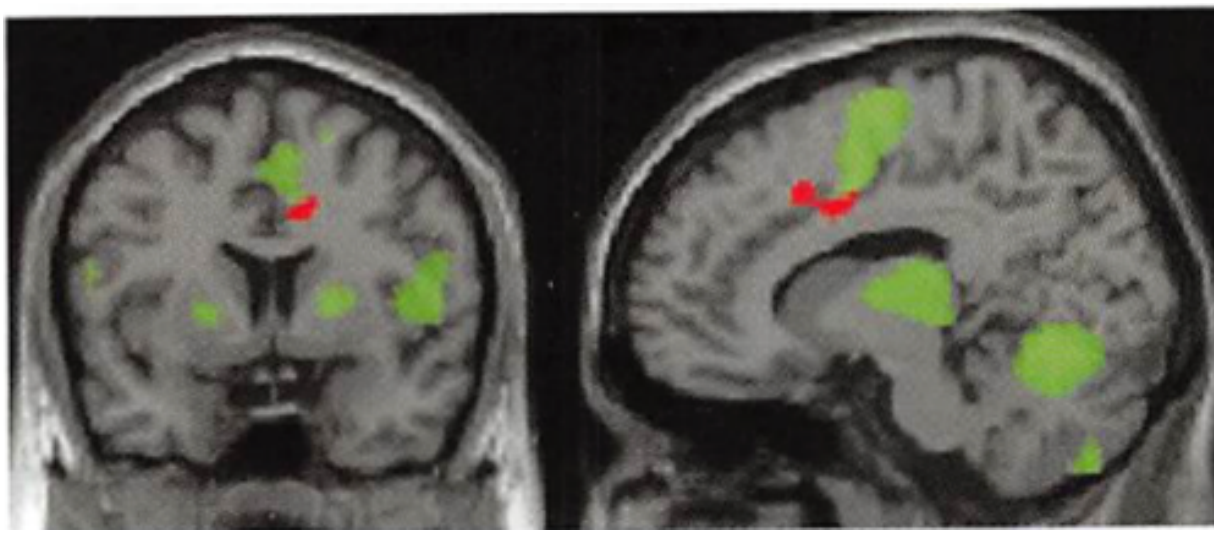


Figure 4 Brain Activity during driving (Figure adopted from *(21)*)

2.1.7 Vision

The retina is the part of the eye responsible for translating light into electrical impulses that can be interpreted by the brain. The fovea is a part of the retina that has the highest visual acuity due to closely packed cones. These cones synapse with bipolar cells which synapse with ganglion cells. Ganglion cells axons exit to the brain via the optic nerve. Approximately half the nerve fibers exiting via the optic nerve are carrying information from the fovea. The fovea normally lines up with the object or point a person fixates on. After impulses leave the eye they go to the lateral geniculate nucleus of the thalamus where they synapse to be relayed to the occipital-parietal areas of the cerebrum. Optic radiations deliver impulses to the primary visual cortex (V1) and other neurons in the occipital, parietal, and temporal regions where retinotropic maps of the visual world are present. Good vision is, of course, essential to safe driving. In New

Brunswick, holders of class 5 licenses must have a visual acuity of 20/40 in the best eye or better.

2.2 Attention

Humans have a limited capacity to process information and thus have to use their attention effectively especially during driving tasks. Numerous stimuli from the environment are available to drivers at any given time. Once the driver has received the input stimuli they must interpret the stimuli, select an appropriate corresponding response, and program that motor response. Lastly, the motor response is executed. Since drivers have limited resources they must filter out unimportant stimuli and focus their attention only on input stimuli that will lead to the programming of desired motor responses.

There are at least three types of cognitive attention relevant to driving: divided, selective, and sustained. Divided attention is a cognitive skill that allows individuals to process information from different sources and successfully carry out multiple tasks simultaneously. The ability to process and respond to multiple stimuli is a requirement for driving (23;24). Driving requires individuals to perform multiple tasks at the same time. For example, a driver must monitor environmental cues such as traffic lights, pedestrians, road signs, and other motorists all while maintaining control of the vehicle. Some studies that involve divided attention during driving often have the driver complete a secondary task that is irrelevant to driving in order to investigate if and why the secondary tasks affect driving performance. The first study done by Brown and colleagues (25) found that a reasoning task over the phone reduces driving

performance in tasks that involved decision making but did not affect “automatic tasks” such as changing gears. Future research in the area concurred with Brown and colleagues’ (25) findings (26;27;28) Operational control of a vehicle becomes an automatic task with experience (29). The physical demands of driving should not stress attentional resources. A study by Strayer & Johnston (30) investigated the difference between hands-free cell phone use and handheld cell phone use during simulated driving. They found that the deficits in driving performance were equivalent for both hands-free and handheld. Deficits in performance in the study included missing traffic signals and increased time to respond to stimuli. This is consistent with attention based issues and demands. It is also consistent with Strayer and colleagues’ (31) study which found eye-tracking impairments while using hands-free cell phones. In addition to eye-tracking impairments, Strayer (32) found that participants tended to “look at” but not “see” (process) the pertinent driving information. During dual-tasks, attention is diverted away from main tasks. Similarly, if there are many stimuli involved, for example, a busy multi-lane road with numerous traffics lights and signs, the driving process will require more attentional resources than a wide country road.

Cognitive decline, which further taxes attentional resources, is a symptom of aging. Studies have shown that older adults have more difficulty dividing attention than younger adults (33; 34). It is possible that divided attention may be predictive of driving performance in older adults. As older adults may have difficulty with more complex driving tasks such as making left turns into oncoming traffic, merging, exiting, and lane changing (35). Most collisions during driving occur due to not recognizing and

yielding to oncoming traffic, failure to successfully search and scan environment, failing to abide by traffic signs and signals, failing to maintain position in lanes, poor positioning for turning, and poor judgement of distances of other cars for passing or stopping (36).

Selective attention is the process of focusing on a particular object in an environment for a period of time. Attention is a limited resource so selective attention allows an individual to focus on the important environmental cues and tune out all the other cues that are unimportant.

Visual attention is also limited because there is only a small amount of information available on the retina that can be used to control behavior. A person is only consciously aware of stimuli that they attend to and largely unaware of unattended stimuli. This is because unimportant visual stimuli are filtered out. The general model then is that at some point in time between visual input and behavioral response there is a competition between stimuli for representation and cognitive analysis. This competition is biased towards the information that is relevant to the task at hand or behavior. Research done by Duncan (REF) shows that when two visual stimuli are presented together competition between stimuli can create divided attention. When asked to identify properties of the objects they looked at, participants almost always had poorer performances when there were two objects in the visual field as opposed to one. This is also true when objects were placed in the periphery of the visual field. Objects in the visual field appear to compete throughout many regions of the brain. There are two major pathways a ventral and dorsal stream and they both

begin in the primary visual cortex (V1) (37). The ventral stream runs through the inferior temporal cortex and is thought to be important for object recognition while the dorsal stream runs through the posterior parietal cortex and is key for spatial and visuomotor performance (38,39). Objects can be processed in the ventral in parallel; however, information about those objects will decline as more objects are added to the field due to competition in the stream. In the dorsal stream when competition exceeds a certain limit, the parietal cortex will lack the ability to discern the locations of all the objects in the field. Moreover, with increased competition not all of the distractors will be filtered out and since the visuomotor neural systems are only able to focus on one object at a time this creates an issue relevant to driving performance. Also ensuring that all systems are in sync is another problem as the perception, spatial analysis, and motor control must work together. Impairment in attention switching skills has been linked to the likelihood of having driving problems (40). In a pioneering study by Kahneman and Colleagues (41) they found errors in shifting attention during dichotic listening tasks to be a predictor of accidents in a group of commercial bus drivers.

It has been suggested that older adults may attend to stimuli for longer than younger adults. A visual attention mechanism relating to this is called the “inhibition of return” (IOR). Inhibition of return refers to an individual’s ability to suppress previously attended to stimuli. If an individual is presented with stimuli which could be an object or event, they will not detect, orient, or respond to that stimuli. By inhibiting that stimuli, the individual is allowed to focus their attention on novel stimuli.

Consequently, this leads to the facilitation of visual search. IOR was first reported by Posner & Cohen (42) from doing tests which involved a brief cue in a box in the periphery of vision intended to grab the subject's attention. Then their attention was redirected to the central location. After a brief, random time interval, a target would appear in one of the boxes located in one the peripheral squares. The participants were asked to respond to that stimulus as quickly as possible. Results showed that responses were quicker for the cued targets than for the non-cued targets when time intervals were shorter; however, responses to the cued targets were slower when time intervals were longer. Posner & Cohen (42) suggested that this was because in the longer time intervals attention had been successfully disengaged from the target so IOR would prevent the return those cues so as to prevent attention from continually returning to previously attended to stimuli. Tipper and colleagues (43;44) added to this work when they found that IOR could relate to either an object or a location-based frame of reference. Tipper and colleagues (43;44) moved the squares around after cueing. They found that there were longer reaction times to both previously cued objects and to targets that were presented at cued locations. This was named object and environmental base IOR, respectively.

The parietal lobe has been linked to both environmental and object based IOR. IOR has been shown to be generated through the retinotectal pathways to the superior colliculus (45;46;47). The superior colliculus is in the midbrain and retinal ganglion cell axons terminate there, forming retinotropic maps as well as axons from the visual cortex. The superior colliculus sends impulses through the tectospinal tracts to co-

ordinate reflex movements in the head, neck, and eyes. The tectospinal tract provides synaptic input to ventral grey interneurons via the contralateral ventral white column and it is responsible for reflexive head turning from visual and auditory stimuli (14). Sapir and colleague (48) found that lesions of oculomotor parietal cortex in the intraparietal sulcus lacked environmental based inhibition location tagging and suggested it was because parietal oculomotor structures place inhibitory tags in those location co-ordinates which is generated through retinotectal pathways. IOR may be very relevant to driving because it allows for an effective time efficient visual scan of the surrounding area. Identifying the existence of brain lesions in the parietal cortex might be particularly relevant information for driver rehabilitation post-stroke and according to Kelly-Hayes (49) 70% of all clinical strokes occur in people 65 and older.

Safe driving requires time efficient visual scanning. A driver must be able to monitor the outside environment. Sustained attention is the ability to detect important cues over a prolonged period of time (50) It is usually measured by vigilance. A driver must be able to detect infrequent stimuli during this prolonged period. Vigilance has a lot to do with the level of alertness present in an individual. Alertness is a spectrum between deep sleep to high activity. Fluctuations in level of vigilance is a naturally occurring physiological phenomenon. There are several factors that affect vigilance. Time of day is a factor that depends on both the internal clock as well as outside environment particularly daylight/darkness. Circadian rhythms cause different hormones (such as cortisol and melatonin) to be released throughout the day which impact our level of vigilance or alertness at different time periods in the day.

In their analysis of meta-analyses Verhaeghen & Cerella (51) concluded that there was no age-related deficit specific to selective attention. It seems the attentional tasks that older adults may struggle with have more to do with divided attention.

2.3 Driving Models

While these older neuroimaging studies (18;19;20;21) describe the importance of motor control and perception during driving, they do not examine the importance of executive functioning. Executive functioning is a higher order cognitive process that involves mental functions which include decision-making, planning and carrying out plans, organization of ideas, insight and judgement, and concept formation. Executive functioning also includes complex goal-directed behaviors and deciding which behaviors are appropriate under certain circumstances (52). The prefrontal cortex is believed to play a role in executive functioning however, imaging during the previously mentioned studies showed little activity in the prefrontal cortex during simulated driving. Once the participants began simulated driving the prefrontal cortex "turned off" as activity levels decreased. These brain imaging studies did not translate from what was portrayed in psychological models of driving.

Michon's (28) paper proposed a change from motivational models of driving to a psychological model. This paper noted the change at the time in psychology to a cognitive perspective. He suggested that driving behavior could be modeled using this approach and proposed a hierarchy for driving behaviour with strategic planning at the top followed by tactical maneuvering, and lastly operational control at the bottom. The strategic level involved trip planning, choice of route, and an evaluation of the cost and

risk associated with the trip. Underneath the strategic planning is tactical maneuvering which involves tasks such as speed management, gap control, obstacle avoidances, sudden changes in direction, turning, and passing. Lastly, operational control of the vehicle which involves steering and changing gears. The operational control component is usually automatic (assuming that one is not a new driver) and does not require conscious control or substantial use of attention resources.

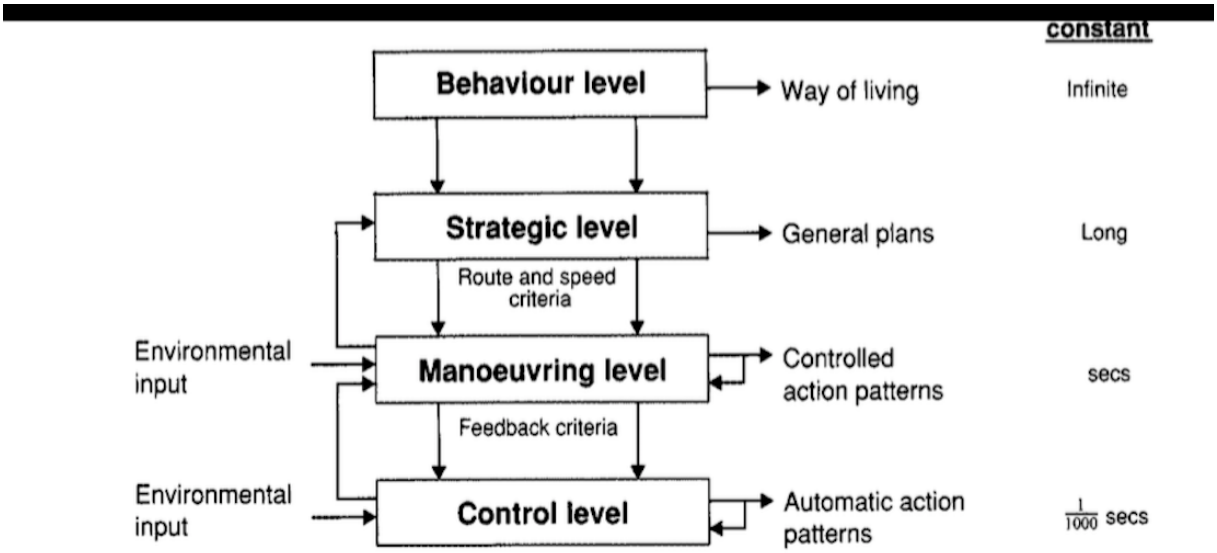


Figure 5 Hierarchical structure of a driving task (Adapted by Cocciabue 2010 from Michon (28))

Similar to Michon's Model (28), Rasmussen developed a driving performance model which divided driving into three categories: knowledge-based, rule-based, and skill-based behavior. Similar to operational control skill-based behavior requires very little conscious control and use of attentional resources. Rule-based behavior requires conscious control and uses attentional resources. Finally, knowledge-based behavior determines actions in specific situations. It used reasoning and problem solving.

Michon (28) reviews older driving models and suggests the issues with them were generally that they were oversimplified, not capable of being learned, and that they are bottom up. Bottom-up refers to a strategy of processing information as it becomes available using perception and sensation first before the brain analyzes it. Top down processing, on the other hand, involves perception that is controlled by cognition. The brain applies what it already knows and what it anticipates it will perceive and then uses perception to fill in any missing blanks. Michon suggests that top-down models are oversimplified and are not verifiable or specific enough. Similarly, he explains the flaws in Wilde's risk homeostasis theory (52) as being merely descriptive as he does not describe the internal processes that are in theory involved. Thus, the model is only at an aggregate level. Wilde's risk homeostasis model explains how improvements in the driving environment, such as the road, vehicle, and even the driver's capability and skill are irrelevant because drivers attempt to balance their behavior to reach a stable level of subjective risk. In other words, they compensate in order to reach a fixed subjective level of risk. This theory is built on Taylor's (53) model of risk-speed compensation. In this model, a driver chooses their speed based on

perceived risk. Another proposed model is Naatanen and Summala's (54) whose hypothesis was based around zero-risk. The idea was the driver's avoidance behavior would be elicited when subjective risk passes a threshold. Normal everyday driving would be perceived as no risk. There is a slight improvement in Naatanen and Summala's model in the fact that it considers individual factors whereas Wilde's does not. In contrast to Wilde's theory, Naatanen and Summala's model suggests that only improvements in the environment will yield better results and thus it is too unidimensional. Fuller's model (55) combines some aspects of the previous two models and highlights the role of learned behavior. This model comes much closer to a cognitive model of driving. The model is based on threat avoidance where a discriminative stimulus for a potential adverse stimulus is used. Factors such as the drivers' perception of speed and environment combine to create an expectation of threat. When a discriminative stimulus is detected, a reward/punishment is calculated for different response alternatives.

The previously mentioned driving models focus on driving performance and lack the construct of driving competency which encompasses the ability of the individual to perform certain tasks beyond the actual driving behaviours observed (56). The motivational models (52;54;55) focus on the products of cognitive functions and can be classified on risk-compensation behaviours. Michon's model views the driver as a problem solver whose motivations and compensations occur at different levels. However, driving encompasses many more factors. Antsey (56) proposed a multi-factorial model for older adults that involves cognition, sensory, and physical

functioning. Fuller's (55) task-capability interface model focuses on the interaction between driver capability and task demand. Seeing the need for a model that encompasses both competency and performance, the Driving as an Everyday Competence (DEC) model was developed by Lindstrom-Forneri and colleagues (58). The DEC defines competency as the driver's capability during the circumstances of dynamic interactions between environment and individual factors. As a result, a driver's capabilities, including awareness and effective decision making on the road, fluctuate constantly due to the changing environment and changes within the driver. The DEC model combines Michon's model (28) with Willis' model of everyday competency (56), and the self-monitoring aspect of Antsey (57). The DEC includes global factors, specific contextual factors, moderators, and outcomes. Under the umbrella of global factors, the DEC includes individual factors and environmental factors. These factors have to do with the impact of the individual's life and are not specific to the driving task. Individual factors include health and cognition. Medical conditions including stroke have been shown to increase crash risk (59). Environmental factors at the global level are societal factors, which include social policies, health care services, and many others pertinent to older drivers.

Specific contextual factors refer to personal and environmental factors that specifically refer to driving competency and performance. Personal factors include physical, cognitive, emotional, sensory abilities, and driving experience and training. Physical factors include decreased psychomotor skills, reduced joint flexibility, and strength as a result of age-related changes that may lead to reduced driving

performance. Cognition involves attention, perception, visuo-spatial abilities, reaction time, memory, and planning which is described in Antsey et al. (59). It is likely that declines or injuries impacting these abilities will decrease driving performance because it could impact the driver's ability to make quick decisions and actions based on the perpetually changing environment. Emotional factors affect driving ability. The major example here being anxiety or older adults lacking confidence in their driving ability. Sensory abilities include vision and field of view which is discussed in other sections. Driving experience and training impact a driver's competence by giving them the skills and knowledge to perform safe driving actions.

Environmental factors include physical and social factors. Physical factors such as slippery roads and darkness play an important role in older drivers' restrictive behavior (60). Equipment such as mirrors, safety technology, and structures of the vehicles are factors. Financial factors influence the upkeep of the vehicle. The traffic designs of the roads can impact the difficulty of maneuvering through traffic. Dynamic aspects of the road such as unexpected changes involving other vehicles or conditions. Social factors include the behaviors of other drivers and passengers can either increase or decrease the competency of the driver. Passengers my help with navigation or on the other hand distract the driver.

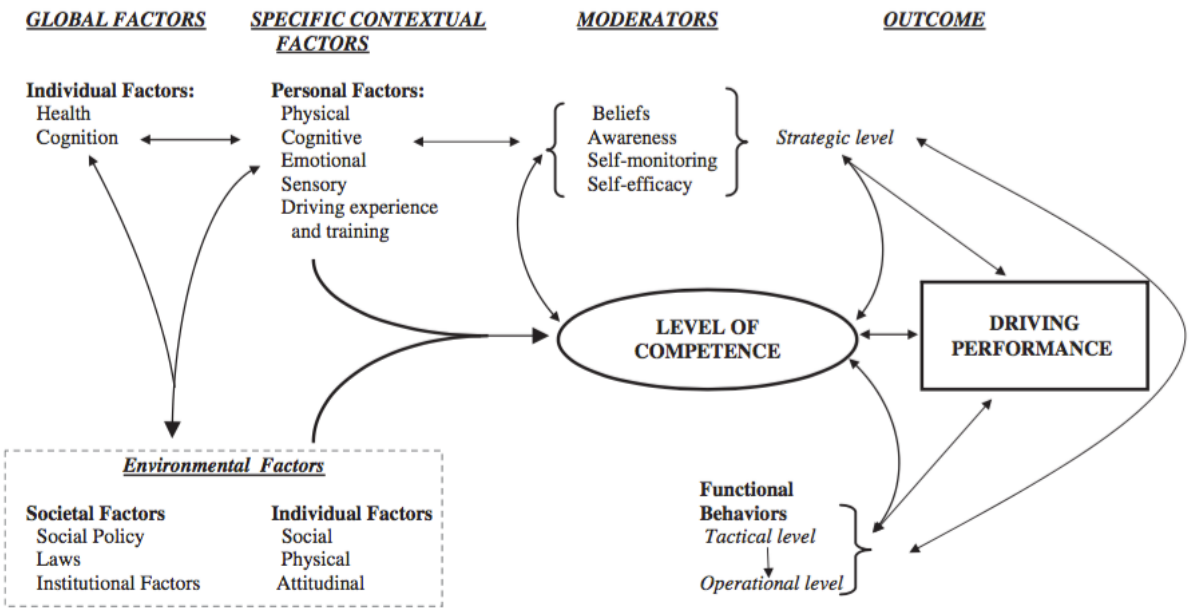


Figure 6 DEC model (Figure adopted from *(56))*

2.2.2 Driving models and imaging

The prefrontal cortex is believed to play a role in executive functioning, working memory, attention, and solving multitask problems. One might hypothesize that the prefrontal cortex would be highly active during driving especially during the performance of strategic level and knowledge based tasks. Antsey (57) suggests that executive function is a necessary component of driving. While the older imaging studies do not show activity in the prefrontal cortex, more recent studies have found activity in the prefrontal cortex that aligns more with the psychological models such as Michon's model. Jeong and colleagues (61) found activity in prefrontal gyrus (BA10) and orbital gyrus (BA11) during an on-road driving course. BA 10 is the anterior-most section of the prefrontal cortex and while it is still not well understood, current research suggests it is involved in memory recall and executive function. BA 11 is involved in reasoning, processing rewards, decision making, and planning. Spires (62)

study involving fMRI during a simulated driving task designed to look like modern London found lateral and medial prefrontal cortical activity when participants had to follow traffic rules. Spires (62) suggested that the reason no activity was found in the prefrontal cortex during the older neuroimaging studies may be because of the "racetrack like" driving courses. His study appears to confirm this hypothesis. Another study that shows activation in the prefrontal cortex is Schweizer and colleagues (71). By using fMRI, they found activation when subjects had to make left handed turns into oncoming traffic while distracted by an audio recording. Other studies using NIRS have also found increases in activity in the prefrontal cortex. Tsunashima & Yanagisawa (72) found similar HbO_2 levels during simulated driving and complex mental tasks. Shimizu and colleagues (73) found HbO_2 in the prefrontal cortex increased proportionally to driving task difficulty. In this study HbO_2 signal was greater during simulated driving on a narrow road with traffic than during routine tasks such as accelerating, decelerating, and stopping. Harada & colleagues (75) and Li & colleagues (74) also both found increased HbO_2 concentrations during driving. In contrast to Harada and Li's findings (74,75) and the other studies mentioned that indicated increased prefrontal cortex activity during driving, Reading and colleagues (18) found decreased HbO_2 during both real urban driving and simulated driving. This finding suggests that when driving begins, arterial vasoconstriction redirects blood flow to more active regions of the brain which include the visual, premotor, parietal, cerebellar areas (61; 62). Due to the disparity in the findings surrounding blood flow to the prefrontal cortex during driving,

more research is warranted in this area to determine the nuerophysiological mechanisms that govern driving.

2.4 Useful Field of View

2.4.1 Information Processing Speed

Information processing speed is an important skill required for competent driving as it allows drivers to react rapidly to stimuli in their environment. There are several variables that can be used to assess information processing speeds. Decision speed is assessed in terms of time to respond to cognitive tests that have moderately complex content. The prefrontal cortex is involved in decision making (63;57). Perceptual speed involves assessing the simple tasks that most people would respond perfectly to if given an unlimited amount of time. Psychomotor speed is the most frequently measured information processing speed and is often recorded as reaction time (RT). Psychophysical speed variables measure decision accuracy with briefly presented visual or auditory stimuli. Lastly, psychophysiological variables attempt to describe the time course of internal responses (64). The UFOV measures visual information processing speed of a psychomotor skill.

2.4.2 Information processing speed and aging

Salthouse's research found a linear correlation between RT and age using a digit symbol substitution task.

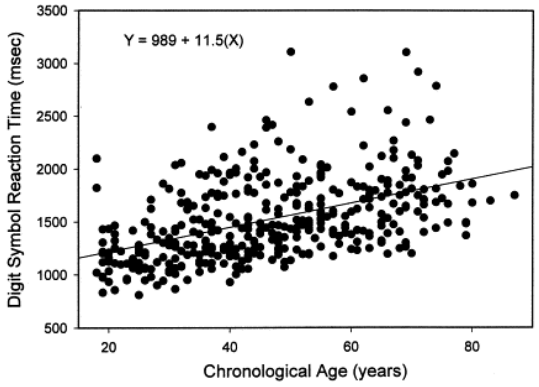


*Figure 7 Digit Symbol Reaction Time vs Chronological Age (*Figure adopted from (*63))*

This type of task performed is a psychomotor task. This decline in RT may be similar to that displayed in automobile drivers. RT would be especially important during defensive driving or responses to unanticipated stimuli and may be lifesaving under certain circumstances. Ranney & Pulling (65) found that in older drivers measures of information processing speed were associated with driving performance and reaction time showed a strong correlation to objective driving measures. The study was completed on a closed course. There are three variables frequently cited as possible moderators of age and information processing speed: health status, experience, and the type of task being performed.

First, health status tends to decline as age increases. However, because of the multidimensionality of health it has been difficult to design research studies that can clearly investigate speed and health. Several studies have attempted to investigate this topic and found that poor health is not a major contributor to age differences in speed (66; 67).

Secondly, experience has been investigated. It appears that the general trend is that most people, regardless of age, improve with practice. This includes studies involving various types of memory and visual search (68). It has been suggested that selective attention skills improve with experience as studies of ball sports such as tennis and cricket have shown that more experienced players are able to pick up on cues that aid them in anticipating opponents' intentions more rapidly than novices (69;70). If automobile drivers are able to process environmental cues pertaining to traffic more quickly and anticipate other drivers' intentions not only will that give them time to react but also it may afford them time to divide their attention to other environmental cues such as traffic lights, signs, pedestrians and so on. Despite the lack of interaction effect between age and experience on speed, unfortunately, older drivers are not our "best" drivers. As illustrated in the DEC model, there are numerous factors that affect driver competency and performance. It is likely other factors associated with age such as cognitive and physical decline eventually overshadow experience.

Thirdly, the type of task appears to be a moderator of age and speed. Certain tasks show no age-related slowing while others do. It appears that tasks relevant to driving may incur slowing.

2.4.3 Useful Field Of View (UFOV)

Useful field of view (UFOV) was introduced by Ball and Colleagues (60) in 1988. Useful field of view is the spatial area over which useful information can be attained quickly within a person's fixation (no eye or head movements). The goal of the test was

to express the vision difficulties experienced by older adults. While standard vision tests evaluate visual acuity, vision field, and colour vision they do not examine higher order cognitive functions and visual processing speeds. Older adults can have difficulty identifying relevant information and/or difficulty dividing attention especially in busy areas where there are many distractions. All of this becomes exponentially more difficult at higher speeds. At this time, it has been suggested that UFOV testing is one the most promising predictor tests for driving ability and crash risk in older adults (76; 77;78). UFOV works by requiring participants to identify and localize targets and taps into their ability to divide attention, process information rapidly, and ignore distractions (79). UFOV performance appears to decline with increasing age in healthy older adults (80; 81; 82;83). However, with relatively little practice the visual field shrinkage that is displayed in numerous older adults can be reversed partially at a minimum (80). High test performance requires the use of higher order cognitive functions. The test can be conceptualized as the ability to rapidly extract information from a cluttered scene. The UFOV test has high test-retest reliability (84). Owsley and colleagues (77) compared maximum UFOV size to traffic accidents in older adults. They used 40% reduction in UFOV size as a cut-off point and found that older drivers with the 40% reductions were 2.2 times more likely to have had an accident in their three-year follow-up period.

2.5 Near Infrared Spectrometry (NIRS)

Near Infrared Spectrometry (NIRS) is a portable non-invasive optical technique that is often used to quantify blood volume and tissue oxygenation levels. NIRS can be

used to interrogate various parts of the human body and was first introduced in 1977 for monitoring human metabolism (85). In order to better understand optical spectroscopy, in particular NIRS, there must be an understanding of the interaction of radiant energy with matter, which in this case is human tissue. Photons, which are just energy in the form of a wave of electromagnetic radiation (86), are emitted into a target matter. The near infrared region is between 700-3000 nm which is just above the visible spectrum. Since photons with long wavelengths have low energy it is safe to use on human tissue.

When photons impinge on material, their behavior depends on a combination of three properties of light: reflectance, absorption, and scattering (87;88). Some of the light photons are absorbed into the molecule of matter that is being interrogated. This depends on the molecular properties of the matter that is in the pathway of the light. Another portion of the light is deflected back; this is known as reflection. Lastly, scattering is the part of the light that is altered and moves in all directions due to the boundaries of the refractive index (89). As the wavelength of light emitted increases, scattering decreases allowing for enough depth of penetration into human tissue (85). Since water and other organic molecules such as bone absorb light at different wavelengths, it is possible to isolate chromophores (light-absorbing substances) in the "medical spectral window" (89) which is between 700-900 nm. In this spectrum, there are oxygenated and deoxygenated derivatives of Hemoglobin (Hb), Myoglobin (Mb) and Cyt_{ax} (90). Thus, it is possible to differentiate between oxygenated blood and deoxygenated blood by emitting different wavelengths of light. Oxygenated

hemoglobin (HbO_2) absorbs more infrared light than deoxygenated hemoglobin (HHb). Typically, a wavelength of 760 nm and 850 nm is used for deoxygenated blood and oxygenated blood respectively. At these wavelengths both oxygenated and deoxygenated blood have their highest absorbency. The difference between these two absorbencies indicates the level of oxygen in the adjacent muscle (91) and the sum of the two absorbencies indicates the total blood volume in that adjacent muscle (92).

Spectrometers all follow the same pattern. They each have a diode that emits light into the tissue being investigated and a receiver diode that measures the intensity of the light that exits the tissue. The absorbency is then calculated using a form of Beer-Lambert Law to account for scattering of light. Beer's law states that for solutions the absorption coefficient is proportional to the concentration of the solute and is described in detail in other articles (86;87;88;93) A modified equation is typically used.

$$[\mathrm{O_2Hb}] = \frac{A^{\lambda_2}\varepsilon_{HHb}^{\lambda_1} - A^{\lambda_1}\varepsilon_{HHb}^{\lambda_2}}{\left(\varepsilon_{HHb}^{\lambda_1}\varepsilon_{\mathrm{O_2Hb}}^{\lambda_2} - \varepsilon_{HHb}^{\lambda_2}\varepsilon_{\mathrm{O_2Hb}}^{\lambda_1}\right)L}$$

$$[HHb] = \frac{A^{\lambda_1}\varepsilon_{\mathrm{O_2Hb}}^{\lambda_2} - A^{\lambda_2}\varepsilon_{\mathrm{O_2Hb}}^{\lambda_1}}{\left(\varepsilon_{HHb}^{\lambda_1}\varepsilon_{\mathrm{O_2Hb}}^{\lambda_2} - \varepsilon_{HHb}^{\lambda_2}\varepsilon_{\mathrm{O_2Hb}}^{\lambda_1}\right)L}$$

Figure 8 Modified Beer Lambert Law (87)

NIRS has been well-established and empirical evidence suggests the reliability and validity of NIRS data (94;95;96). Many studies have shown that NIRS has a high correspondence with other brain imaging techniques such as fMRI (97;98,99). Compared with fMRI, NIRS collection is more straightforward and is more comfortable for participants. There is much less movement restriction and no noise disturbances

involved. The equipment for NIRS is also portable and can be used in the field. NIRS has been used to quantify cerebral blood flow as well as blood oxygenation levels in several studies that involve simulated driving (75;100) and most recently during real urban driving (18). It has also been used to assess cognitive task difficulty (16;101). What were the main findings from these studies? These would be the most relevant to discuss as they are what you are measuring.

2.6 Research Purpose and Questions

2.6.1 Research Purpose

The purpose of the research is investigate differences in the physiological demands placed on three age categories of automobile drivers in both simulated urban and rural driving conditions. The difference in information processing speed and divided attention between age categories will also be explored.

2.6.2 Research Hypotheses

1. Heart rate measures and prefrontal cortex oxygen levels will be elevated in the oldest drving group compared to the young- and mid-aged driving groups. These measures will be higher in urban driving conditions in all age groups.
2. Information processing speed and divided attention scores will be lowest for the older-age driving group. There will be no difference between the young and mid-age driving groups

3.0 Methods

3.1 Participants

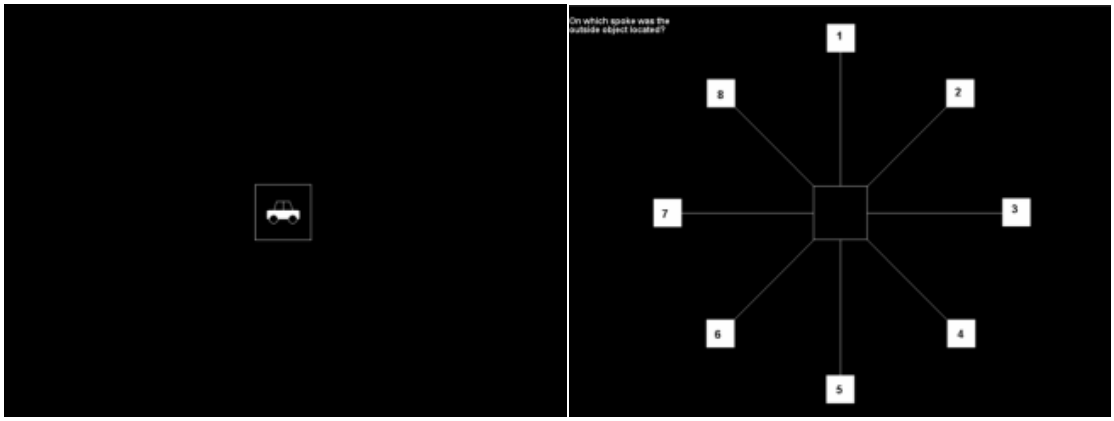
Forty participants, with a valid driver's license, were recruited for this research project in an attempt to create three equally populated experimental groups. Eleven participants were excluded from analysis due to either not completing the full experimental procedure or errors in the data. Respectively, eleven, nine, and nine participants were analyzed for each of the three age groups: 1) young adult (18-25 years-old); 2) mid-aged adult (26-64 years old); and 3) older adult (65+ years old). The young and older adult groups represent highest risk for accidents, while the mid-age adult are at the lowest risk (3). All participants were provided an information sessions where the purpose of the project and the protocol was explained to them. They were provided an opportunity to ask question before signing the University Ethics Review Board approved Informed Consent.

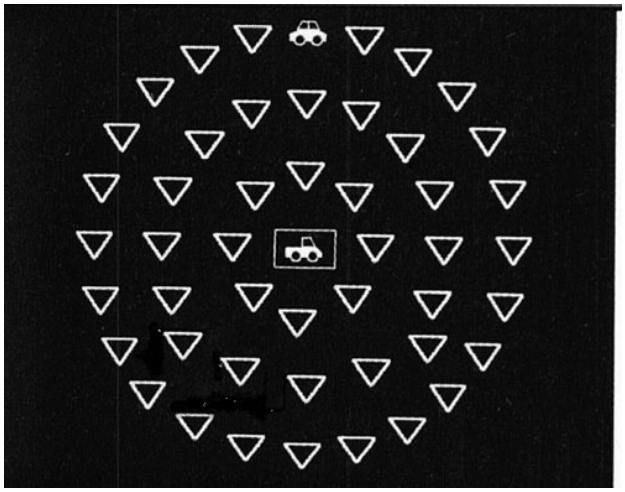
3.2 Protocol

3.2.1 Useful Field of View

Participants completed a useful field of view (UFOV) test prior to simulated driving. UFOV is a tool that assesses visual speed of information processing, selective attention, and divided attention. Information processed during the UFOV test was completed without the participants needing to move their head or eyes. UFOV tests required participants to identify and localize suprathreshold targets during three increasingly difficult subtests. The first subtest required identification of a target (car or truck silhouette) presented in a central location. The second subtest evaluated divided

attention and involved identification of a central target while simultaneously localizing a peripheral target that could appear in one of eight possible locations. The third subtest monitored participants' susceptibility to distractors. It involved both of the prior two tasks except the difficulty was increased by the addition of distractors and locations of targets. Peripheral targets were randomly presented in 24 different locations (10˚, 20˚, 30˚) eccentrically along the previous 8 locations (75).





Figures 9a,b, & c Left is subset 1 Vision/Information processing speed. Right is subset 2 Divided Attention. Bottom is subset 3 selective attention.

3.2.2 Simulated Driving

The driving simulator (VS600M, Virage Simulation, Canada) is a replica of a driver's cabin with three computer screens arranged in a semicircle in front of the driver. The cabin consists of a seat, steering column, brake pedal, accelerator, automatic transmission, and dashboard equipped with a speedometer. A touch screen side display is utilized for transmission control and hand-braking. The three 52" LCD displays provide the driver with an 180˚ front view and is complemented by side view mirrors on the exterior displays. Sensory cues and vibrations for acceleration, deceleration, stopping, obstacles, and turning are provided by electric actuators. Vibrations are transmitted through the steering wheel, seat, and simulator platform via an external air compressor. The VS600M is state of the art! Additonal details of the apparatus are described in Johnson & colleagues (102) as well as Figure 3. Note: Figure 3 is a picture of the truck cabin this study will use a car cabin.

Figures 10a&b: Left is full view that encompasses the entire Virage VS600M driving simulator (three semicircular screens and cabin). (b) Right is a view of the simulator's truck cabin equipped with a steering column, accelerator, brake pedal, dashboard, and side screen for transmission control and hand braking.

Participants completed four simulated drives and a pre and post resting baseline test. For the resting baseline test, participants were seated comfortably in the cabin of the driving simulator. Prior to simulated driving participants completed a 5-minute resting baseline test to establish non-driving baselines. This involved quiet sitting with hands in the lap. In order to establish a baseline for driving, the first drive was a comparatively easy drive with no traffic. This drive lasted 7 minutes and the first and last minute was cut to allow for an accurate baseline free from external factors such as anxiety about participating in a research study. This drive was followed by a 10-minute standardized drive in an urban setting and a 10-minute drive in a rural highway setting. During the driving baseline participants were allowed to drive freely in a highway style course with limited traffic/obstactles. However, during the city and rural drive participants were instructed to follow a standardized course. The city drive course included traffic and a series of turns and the rural drive was a highway drive that included several obstacles such as a car pulling out of a driveway, car on the side of the road, and passing a semi-truck. Following the standardized drives, there was a post-drive baseline of 7 minutes with the first and last minute being cut. Lastly, a post drive 5-minute resting baseline was completed. A 5-minute break was provided

between drives allowing the participant to rest. This break also served as a precaution for motion sickness.

Figure 11 Study Protocol

3.2.3 Outcome Measures

Cerebrovascular Measures using NIRS. A NIRO-200NX spatially resolved near infrared spectroscopic oximeter (Hamamatsu Photonics KK, Hamamatsu City, Japan) was used to record quantitative changes in oxygenation and blood volume in both prefrontal cortices. Optically dense rubber holders housed emitter and detector optodes which were attached with a double-sided adhesive tape to the skin approximately 3 cm from

the midline and just above the supra-orbital ridge (103). To help secure optode holders and wires as well as to provide additional light shielding, a black Lycra® skull cap was placed over the participant's head.

The NIRO-200NX system uses specific, calibrated wavelengths of near-infrared light (775, 810, and 850 nm) and spatially resolved spectroscopy to measure the relative concentration of oxygenated (HbO_2) and deoxygenated haemoglobin (HHb) from the area under interrogation. The relative concentration change of HbO_2 ($\Delta[HbO_2]$) and HHb (Δ[HHb]) will be measured using a differential flight path of 5.93 (104) and with an emitter/detector optode separation distance of 4 cm. It is estimated the measurement depth is at least 2 cm (91).

Total cerebral haemoglobin (cHb) will be calculated by summing the $\Delta[HbO_2]$ and Δ[HHb]. A change in cHb (Δ[cHb]) will indicate either an increase or a decrease in cerebral blood volume (103). The tissue oxygenation index (TOI) reflects the tissue O_2 saturation level and was calculated as follows: $TOI = \frac{[\Delta HbO_2]}{[\Delta HbO_2] + [\Delta HHb]}\ x\ 100.$ TOI will be a major outcome variable for NIRS. Data will be collected at 20Hz.

Electrocardiogram. A 3-lead electrocardiogram (ECG) equipped with Powerlab 8/35 data acquisition device (ADInstruments,USA) was used to determine the participants' heart rates (HR) and heart rate variability (HRV) during data collection. HR is quantified in number of beats per minute (BPM) and HRV is the measurement of the variability in time interval between heartbeats. HRV was calculated using time-domain analysis, frequency domain analysis, and non-linear analysis which are described in Table 1 by Mathieu & Colleagues at the end of this section. Physiological response to physical and

psychological stress have been measured using HR and HRV (106). Table 1 Electrodes were placed in the LEAD II configuration in accordance with Einthoven's triangle (107). Sampling frequency will be 1000 Hz to allow for accurate measures and has been suggested to be the optimum sampling frequency for ECG signal to get an accurate time domain HRV (108). The ECG signal was then filtered to remove noise using LabChart software.

Table 1

Description of heart rate variability (HRV) variables.

Type of analysis	HRV Variables	Description
Time-domain		
	SDNN	Standard deviation time between IBI in milliseconds (ms). SDNN value is commonly used to quantified HRV.
	MeanNN	Mean time between IBI in ms.
	RMSSD	Root mean square of successive differences between IBI in ms.
Frequency-domain		
	LFnu	Normalized measures of LF in percentage (%) (i.e. LFnu = LF / (LF+HF)). LF represent the

		magnitude of low frequency band is considered between 0.04 to 0.15 Hz.
	HFnu	Normalized measures of HF in % (i.e. HFnu = HF / (LF+HF)). HF represent the magnitude of high frequency band is 0.15 to 0.4 Hz.
	LF/HF	Ratio between LF and HF in %.
Nonlinear		
	SD1	Standard deviation of points perpendicular to the line-of-equality.
	SD2	Standard deviation of points along to the line-of-equality.
	SD1/SD2	Ratio between SD1 and SD2.

Adopted from Mathieu & Colleagues

3.2.4 Data Analysis

NIRS data was decimated to 1 Hz by averaging the data recorded over each 1 second interval using Microsoft Excel 2013 (Mississauga ON, Canada). One minute of data was analyzed per five minutes. Data from the resting baselines was averaged and used as a reference values to calculate change scores in HbO_2, HHb, and TOI during the four simulated drives. Change scores from the pre and post simulated drives were compared to change scores from the standardized simulated drive to control for individual variability. The parameter response recorded during identified driving

conditions (eg. urban or highway) will be averaged and compared. The graphs exhibited below in the results section are pertcent change scores versus the ensemble mean of each minute of data. Error bars are one standard deviation (SD) above and below the mean.

NIRS data was visually inspected for errors and outliers that were greater than two SD from the mean. Four participants were excluded from the NIRS Data analysis in the 18-25 age group, three in the 26-64 age group, and five in 65+ for the rural drive. For the city drive five, three, and five were excluded respectively. In four cases for the city drive and three for the rural drive only one sensor collected accurate data. When stats was run in these cases data from the other side was substituted for the other side.

3.2.5 Statistical Analysis

A one way repeated measures analysis of variance (ANOVA) was conducted using the ensemble mean which was calculated for each measured variable for each minute of driving (NIRS) or five minute timepoint (HRV). Driving condition was the independent variable and each measured parameter served as the dependent variable. The baseline simulated drive (pre) served as a control to identify values significantly different from those baselines. Within subject factors included driving timepoint while the between subject factor was age group. Analysis was done for main effects of time and group. A levene's test for homogeneity was conducted and the overall trend was that the timepoints were not significant, however several timepoints were significant. A non-parametric test was conducted and the results were very similar to the

parametric so for simplicity of reporting are not shown in this document. A bonferroni correction was used as a *post hoc* comparison. In all analyses, an alpha level of 0.05 was used to identify statistical differences.

4.0 Results

The mean height, weight, body mass index (BMI), and age for all three groups (18-25; 25-65; 65+) whom completed the entire simulated drive is show in Table (2) below:

Table 2. Partipants Age and Anthropometrics

	18-25	26-64	65+
Height (cm)	166.7±11.1cm	175.7±8.89cm	170.3±6.77cm
Weight (kg)	75.3±10.7Kg	81.0±13.0Kg	81.2±19.6Kg
BMI (kg/m^2)	27.3±4.76kg/m^2	26.1±3.47Kg/m^2	27.8±5.9Kg/m^2
Age (y)	21.4±1.55y	29.2±7.38y	75.0±4.39y

The 18-25 group consisted of 8 females and 3 males. The 25-65 group had 4 females and 5 males and the 65+ group had 2 females and 7 males.

4.*1.1 UFOV Data*

UFOV data, which breaks participants into categories (1-5), placed all but two participants in category 1. As a result no further analysis was performed because it was clear that no statistical significant findings would be found. Interestingly, from observation older adults tended to have slightly slower reaction time during the third part of the UFOV test designed to test selective attention. However, this delayed reaction time was not close to being statistically significant.

4.1.2 HRV Analysis

The repeated measures ANOVAs with a greenhouse-geisser correction for violation of sphericity showed significantly differences for the physiological response variables during the various simulated driving tasks and baseline periods in HR, SDNN, LF, HF, and SD2. These can be viewed graphically below in figures 5 through 13 and more precisely analyzed with the Bonferroni correction post hoc tests (table 3) which compares timepoints. It appears that the City Driving task evoked the greatest physiological response. Time points were broken up into 5 minute segments. The city and rural drives consisted of two 5 minute segments to allow for HRV comparisons. Futhermore, post hoc tests to compare different age groups were also completed but are not described in a table because there were no statistically significant differences were found for HRV; however, there was two statistically significant differences between the groups in HR . The 18-25 age group was significantly different from the 26-64 age group with a mean difference of 12.2%, p=0.012 and the 65+ age group with a mean difference of 11.3, p=0.022.

Table 3. HRV Within Subject Effects over 8 timepoints

Within Subjects Effects			
	F	η^2	*P*
HR	16.1	0.382	**< 0.001**
MeanNN	1.47	0.054	0.239
SDNN	4.538	0.149	**0.001**
RMSSD	1.348	0.049	0.262
LF	2.586	0.090	**0.037**
HF	4.108	0.136	**0.002**
LF/HF	1.969	0.070	0.121
SD1	1.435	0.052	0.235
SD2	4.812	0.156	**0.001**
SD1/SD2	1.983	0.071	0.135

Note: Values in bold: < 0.05 (significant p-value)

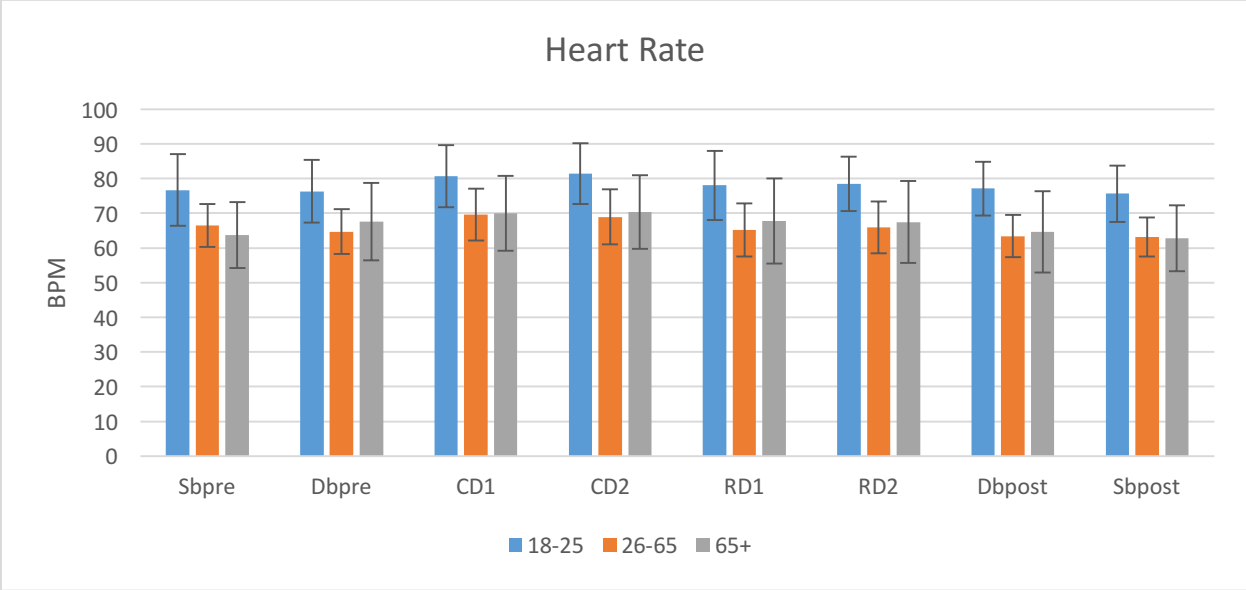


Figure 12 – Heart Rate for three age groups

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

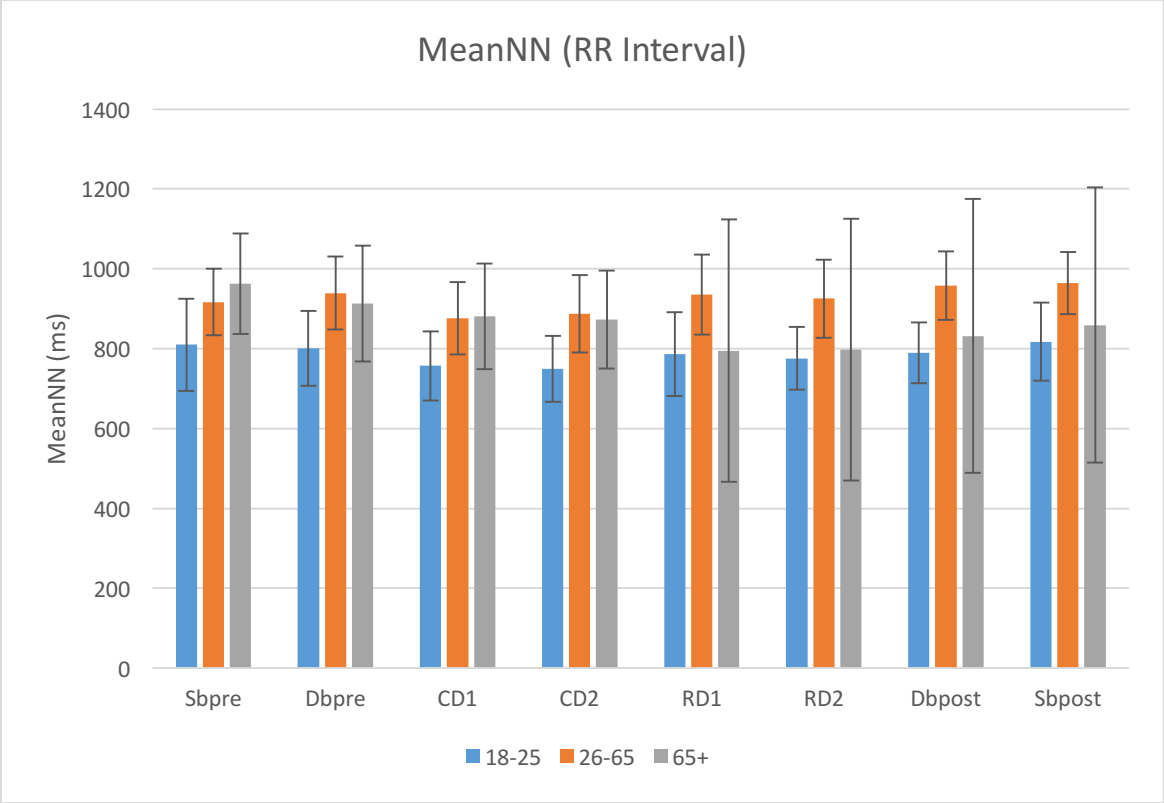


Figure 13 R-R interval for three age groups

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

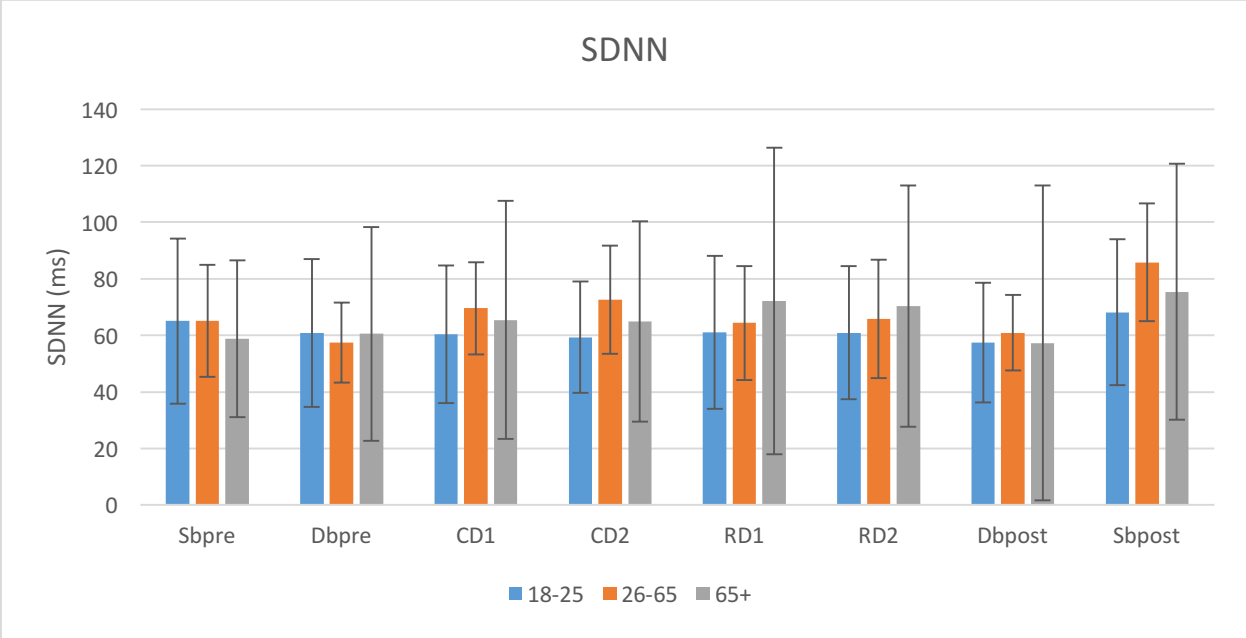


Figure 14 R-R interval Standard Deviation for three age groups

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

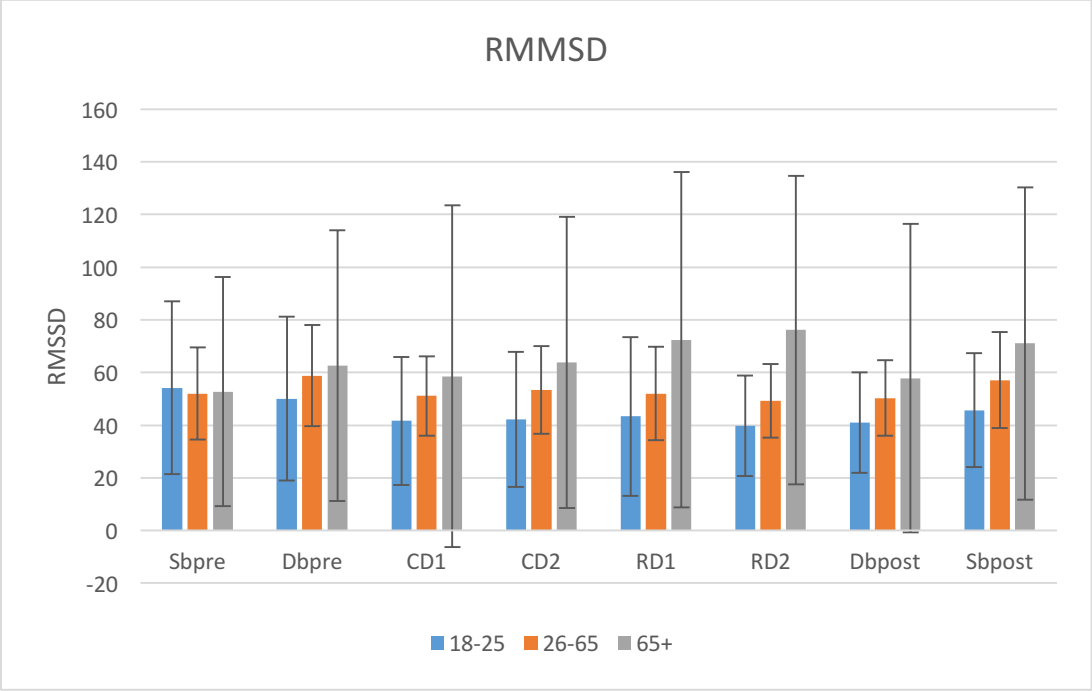


Figure 15 Root Mean Square of Sucessive Differences for RR Interval

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

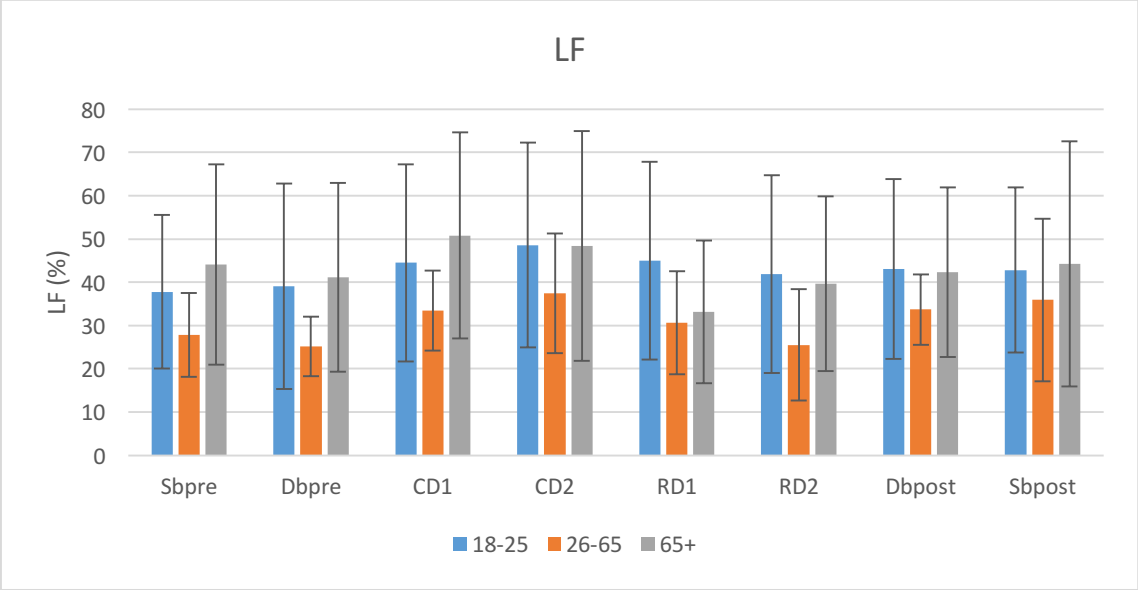


Figure 16 Low Frequency

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

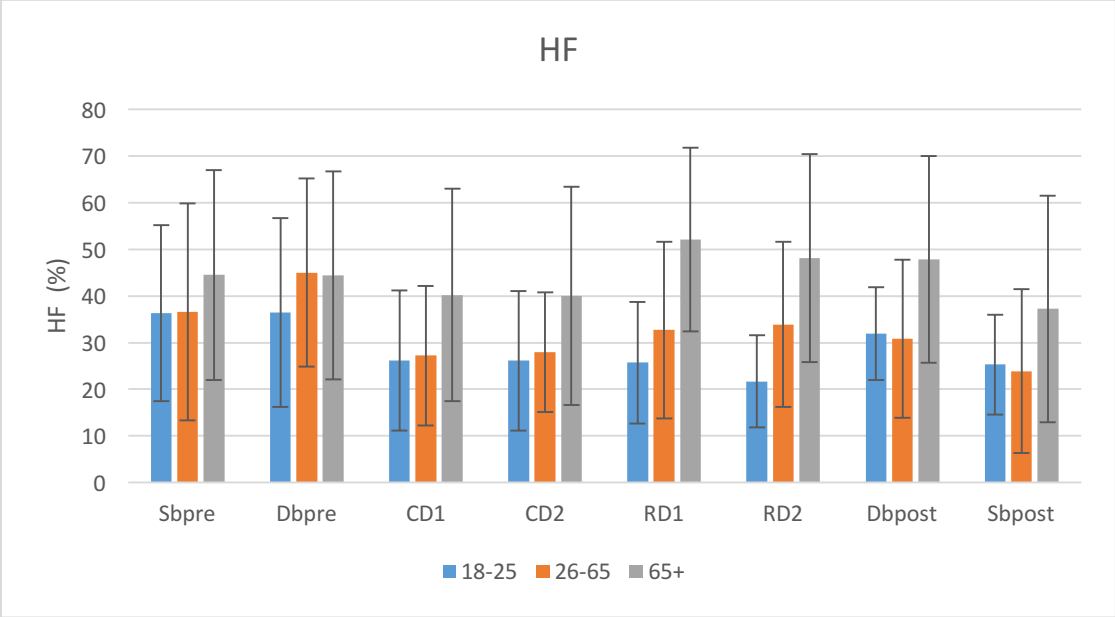


Figure 17 High Frequency

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

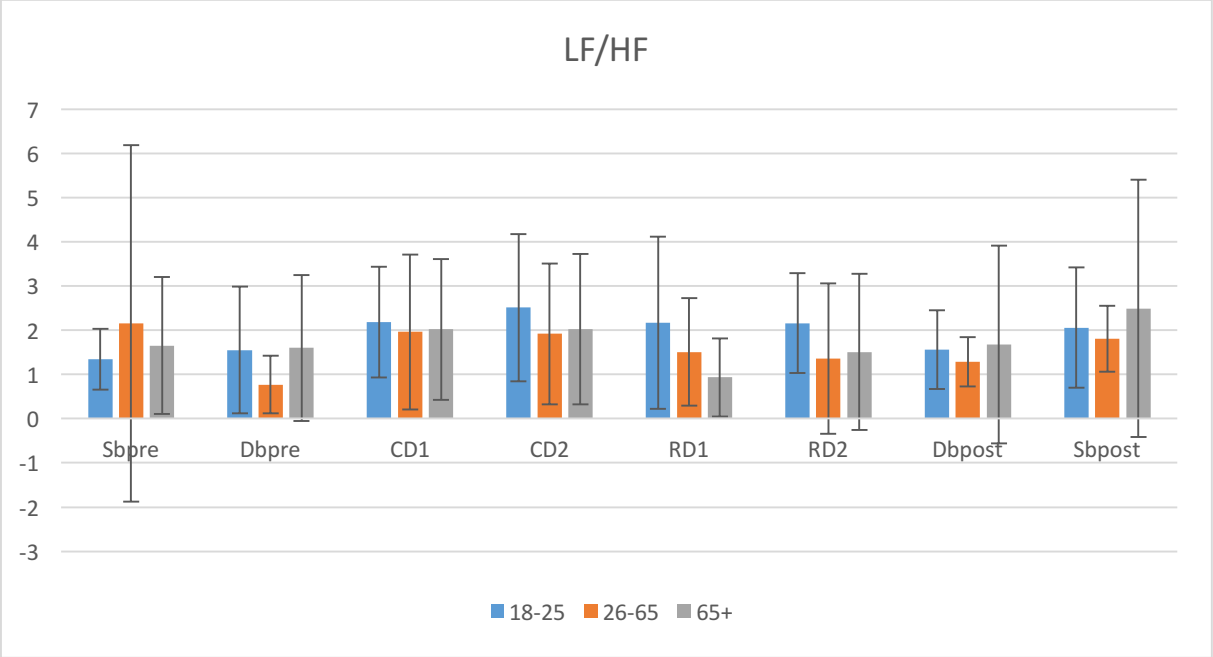


Figure 18 Low frequency vs high frequency ratio

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

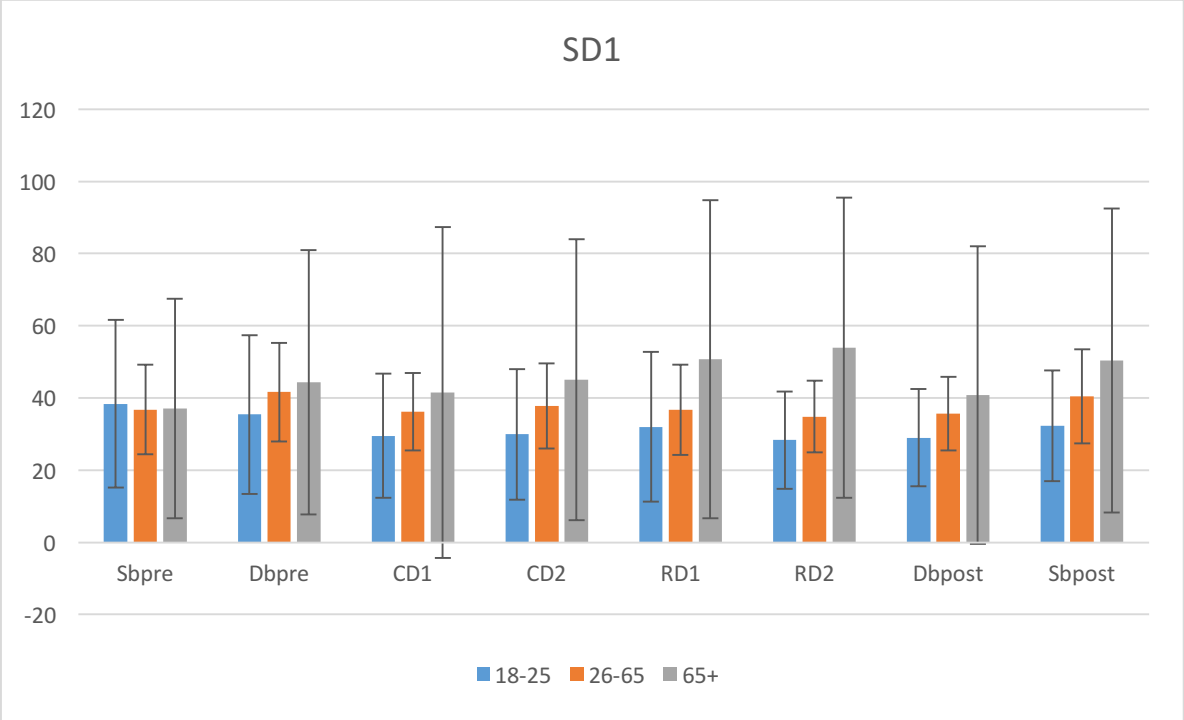


*Figure 19*_ Standard Deviation of points perpendicular to the line of equality

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

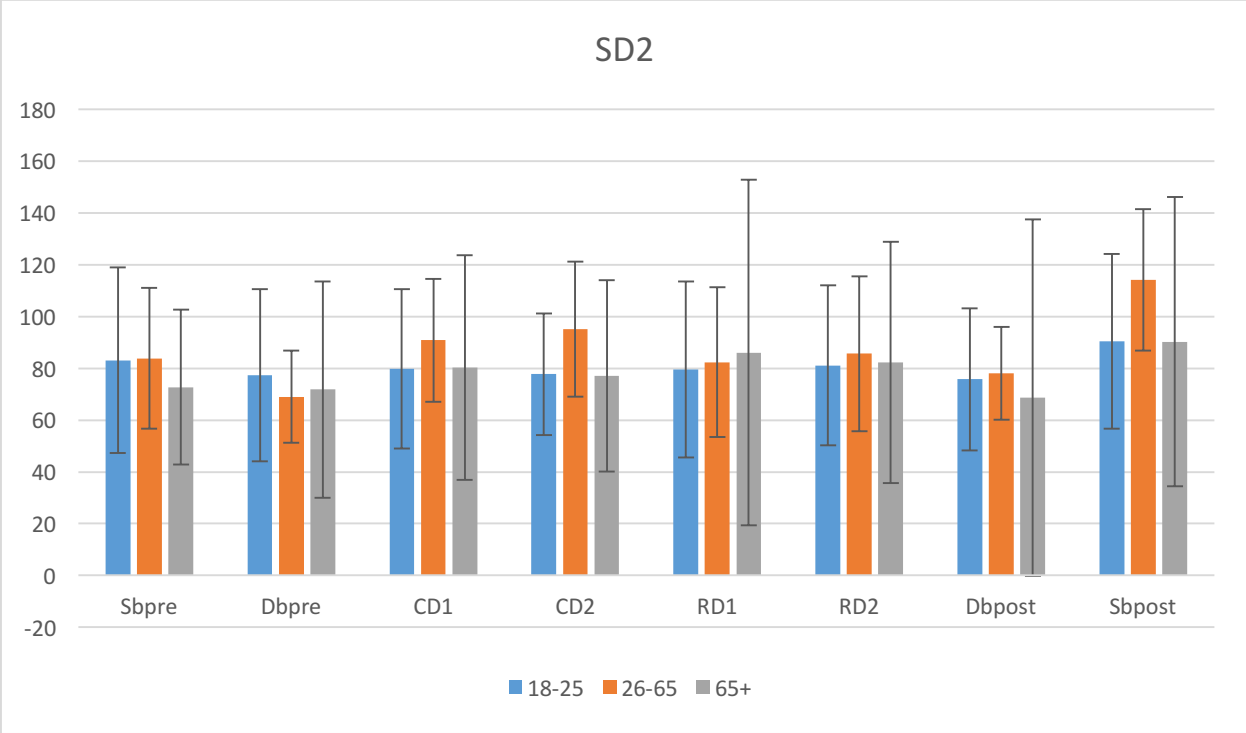
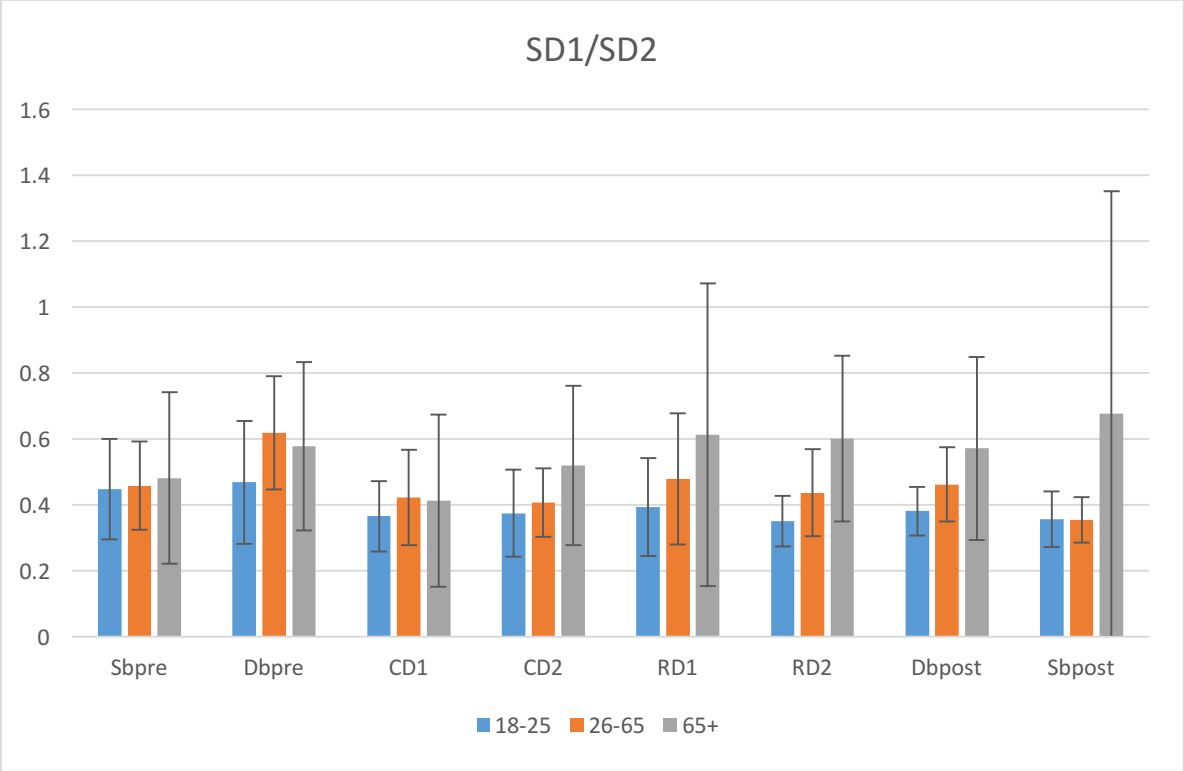


Figure 20 Standard Deviation of points along the line of equality

Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post



Note: SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

Table 4 – HR and HRV timepoint comparison all three groups combined –

Post-Hoc Tests

Mean

p-value

		HR	MeanNN	SDNN	RMSSD	LF	HF	LF/HF	SD1	SD2
SBpr	DBpr	70.0 1.00	884.6 1.000	59.6 1.000	56.6 1.000	35.4 1.000	41.6 1.000	1.33 1.000	40.1 1.000	73.0 1.000
	CD1	73.9 **<0.001**	838.2 **<0.001**	65.1 1.000	49.8 1.000	43.0 1.000	30.8 .876	2.06 1.000	35.3 1.000	83.3 1.000
	CD2	74.1 **.001**	836.6 **<0.001**	65.6 1.000	52.4 1.000	45.1 1.000	31.0 1.000	2.18 1.000	37.1 1.000	82.9 1.000
	RD1	70.8 1.000	838.9 1.000	65.9 1.000	43.3 1.000	36.9 1.000	36.1 1.000	1.58 1.000	39.3 1.000	82.4 1.000
	RD2	71.1 1.000	833.0 1.000	65.7 1.000	54.0 1.000	36.1 1.000	33.7 1.000	1.71 1.000	38.3 1.000	82.9 1.000

	DBpo	69.0 1.000	859.5 1.000	58.5 1.000	49.1 1.000	39.9 1.000	36.5 1.000	1.51 1.000	34.7 1.000	74.2 1.000
	SBpo	67.8 1.000	880.2 1.000	76.4 **.005**	57.1 1.000	41.1 1.000	28.5 .521	2.11 1.000	40.4 1.000	97.8 **.009**
DBpr	SBpr	69.5 1.000	896.5 1.000	63.0 1.000	53.0 1.000	36.7 1.000	38.9 1.000	1.68 1.000	37.5 1.000	80.1 1.000
	CD1	73.9 **<0.001**	838.2 **<0.001**	65.1 1.000	49.8 .863	43.0 .317	30.8 **.023**	2.06 .102	35.3 .837	83.3 .142
	CD2	74.1 **.003**	836.6 **.004**	65.6 .701	52.4 1.000	45.1 **.004**	31.0 **.002**	2.18 **.008**	37.1 1.000	82.9 .168
	RD1	70.8 1.000	838.9 1.000	65.9 1.000	43.3 1.000	36.9 1.000	36.1 1.000	1.58 1.000	39.3 1.000	82.4 1.000
	RD2	71.1 1.000	833.0 1.000	65.7 1.000	54.0 1.000	36.1 1.000	33.7 .443	1.71 1.000	38.3 1.000	82.9 .927

	DBpo	69.0 1.000	859.5 1.000	58.5 1.000	49.1 .412	39.9 1.000	36.5 1.000	1.51 1.000	34.7 .373	74.2 1.000
	SBpo	67.8 .185	880.2 1.000	76.4 **.001**	57.1 1.000	41.1 1.000	28.5 **.05**	2.11 .357	40.4 1.000	97.8 **.001**
CD1	SBpr	69.5 **<0.001**	896.5 **<0.001**	63.0 1.000	53.0 1.000	35.4 1.000	38.9 .876	1.68 1.000	37.5 1.000	80.1 1.000
	DBpr	70.0 **<0.001**	884.6 **<0.001**	59.6 1.000	56.6 .863	36.7 .317	41.6 **.023**	1.33 .102	40.1 .837	73.0 .142
	CD2	74.1 1.000	836.6 1.000	65.6 1.000	52.4 1.000	45.1 1.000	31.0 1.000	2.18 1.000	37.1 1.000	83.0 1.000
	RD1	70.8 **.001**	838.9 1.000	65.9 1.000	43.3 1.000	36.9 .987	36.1 1.000	1.58 1.000	39.3 1.000	82.4 1.000
	RD2	71.1 **.01**	833.0 1.000	65.7 1.000	54.0 1.000	36.1 .144	33.7 1.000	1.71 1.000	38.3 1.000	82.9 1.000

	DBpo	69.0 **<0.001**	859.5 1.000	58.5 1.000	49.1 1.000	39.9 1.000	36.5 1.000	1.51 1.000	34.7 1.000	74.2 1.000
	SBpo	67.8 **<0.001**	880.2 1.000	76.4 .226	57.1 1.000	41.1 1.000	28.5 1.000	2.11 1.000	40.4 1.000	97.8 .433
CD2	SBpr	69.5 **.001**	896.5 **<0.001**	63.0 1.000	53.0 1.000	35.4 1.000	38.9 1.000	1.68 1.000	37.5 1.000	80.1 1.000
	DBpr	70.0 **.003**	884.6 **.004**	59.6 .701	56.6 1.000	36.7 **.004**	41.6 **.002**	1.33 **.008**	40.1 1.000	73.0 .168
	CD1	73.9 1.000	838.2 1.000	65.1 1.000	49.8 1.000	43.0 1.000	30.8 1.000	2.06 1.000	35.3 1.000	83.3 1.000
	RD1	70.8 **<0.001**	838.9 1.000	65.9 1.000	43.3 1.000	36.9 .376	36.1 1.000	1.58 .696	39.3 1.000	82.4 1.000
	RD2	71.1 **.001**	833.0 1.000	65.7 1.000	54.0 1.000	36.1 .298	33.7 1.000	1.71 1.000	38.3 1.000	82.9 1.000

	DBpo	69.0 **<0.001**	859.5 1.000	58.5 1.000	49.1 1.000	39.9 1.000	36.5 1.000	1.51 1.000	34.7 1.000	74.2 1.000
	SBpo	67.8 **<0.001**	880.2 1.000	76.4 .214	57.1 1.000	41.1 1.000	28.5 1.000	2.11 1.000	40.4 1.000	97.8 .216
RD1	SBpr	69.5 1.000	896.5 1.000	63.0 1.000	53.0 1.000	35.4 1.000	38.9 1.000	1.68 1.000	37.5 1.000	80.1 1.000
	DBpr	70.0 1.000	884.6 1.000	59.6 1.000	56.6 1.000	36.7 1.000	41.6 1.000	1.33 1.000	40.1 1.000	73.0 1.000
	CD1	73.9 **.001**	838.2 1.000	65.1 1.000	49.8 1.000	43.0 .987	30.8 1.000	2.06 .696	35.3 1.000	83.3 1.000
	CD2	74.1 **<0.001**	896.5 1.000	65.6 1.000	52.4 1.000	45.1 .376	31.0 1.000	1.68 1.000	37.1 1.000	82.9 1.000
	RD2	71.1 1.000	833.0 1.000	65.7 1.000	54.0 1.000	36.1 1.000	33.7 1.000	1.71 1.000	38.3 1.000	82.9 1.000

	DBpo	69.0 .117	859.5 .281	58.5 1.000	49.1 1.000	39.9 1.000	36.5 1.000	1.51 1.000	34.7 1.000	74.2 1.000
	SBpo	67.8 .054	880.2 **.02**	76.4 .396	57.1 1.000	41.1 1.000	28.5 1.000	2.11 1.000	40.4 1.000	97.8 .216
RD2	SBpr	69.5 1.000	896.5 1.000	63.0 1.000	53.0 1.000	35.4 1.000	38.9 1.000	1.68 1.000	37.5 1.000	80.1 1.000
	DBpr	70.0 1.000	884.6 1.000	59.6 1.000	56.6 1.000	36.7 1.000	41.6 .443	1.33 1.000	40.1 1.000	73.0 .916
	CD1	73.9 **.01**	838.2 1.000	65.1 1.000	49.8 1.000	43.0 .144	30.8 1.000	2.06 1.000	35.3 1.000	83.3 1.000
	CD2	74.1 **.001**	896.5 1.000	65.6 1.000	52.4 1.000	45.1 .298	31.0 1.000	1.68 .100	37.1 1.000	82.9 1.000
	RD1	70.8 1.000	838.9 1.000	65.9 1.000	54.0 1.000	36.9 1.000	36.1 1.000	1.58 1.000	39.3 1.000	82.4 1.000

	DBpo	69.0 **.006**	859.5 **.007**	58.5 1.000	49.1 1.000	39.9 1.000	36.5 1.000	1.51 1.000	34.7 1.000	74.2 1.000
	SBpo	67.8 .069	880.2 **.014**	76.4 .263	57.1 1.000	41.1 1.000	28.5 1.000	2.11 1.000	40.4 1.000	97.8 .177
DBpo	SBpr	69.5 1.000	896.5 1.000	63.0 1.000	53.0 1.000	35.4 1.000	38.9 1.000	1.68 1.000	37.5 1.000	80.1 1.000
	DBpr	70.0 1.000	884.6 1.000	59.6 1.000	56.6 .412	36.7 1.000	41.6 1.000	1.33 1.000	40.1 .373	73.0 1.000
	CD1	73.9 **<0.001**	838.2 1.000	65.1 1.000	49.8 1.000	43.0 1.000	30.8 1.000	2.06 1.000	35.3 1.000	83.3 1.000
	CD2	74.1 **<0.001**	896.5 1.000	65.6 1.000	52.4 1.000	45.1 1.000	31.0 1.000	1.68 1.000	37.1 1.000	82.9 1.000
	RD1	70.8 .117	838.9 .281	65.9 1.000	55.0 1.000	36.9 1.000	36.1 1.000	1.58 1.000	39.3 1.000	82.4 1.000

	RD2	71.1 **.006**	833.0 **.007**	65.7 1.000	54.0 1.000	36.1 1.000	33.7 1.000	1.71 1.000	38.3 1.000	82.9 1.000
	SBpo	67.8 1.000	880.2 .758	76.4 **.001**	49.1 .185	41.1 1.000	28.5 .218	2.11 .372	40.4 .171	97.8 **.003**
SBpo	SBpr	69.5 1.000	896.5 1.000	63.0 **.005**	53.0 1.000	35.4 1.000	38.9 .521	1.68 1.000	37.5 1.000	80.1 **.009**
	DBpr	70.0 .185	884.6 1.000	59.6 **.001**	56.6 1.000	35.4 1.000	41.6 **.05**	1.33 .357	40.1 1.000	73.0 **.001**
	CD1	73.9 **<0.001**	838.2 1.000	65.1 .226	49.8 1.000	43.0 1.000	30.8 1.000	2.06 1.000	35.3 1.000	83.3 .433
	CD2	74.1 **<0.001**	896.5 1.000	65.6 .214	52.4 1.000	45.1 1.000	31.0 1.000	2.18 1.000	37.1 1.000	82.9 .216
	RD1	70.8 .054	838.9 **.02**	65.9 .396	55.0 1.000	36.9 1.000	36.1 1.000	1.58 1.000	39.3 1.000	82.4 .216

	RD2	71.1 .069	833.0 **.014**	65.7 .263	54.0 1.000	36.1 1.000	33.7 1.000	1.71 1.000	38.3 1.000	82.9 .177
	DBpo	69.0 1.000	859.5 .758	58.5 **.001**	49.1 .185	39.9 1.000	36.5 .218	1.51 .372	34.7 .171	74.2 **.003**

Note: Values in bold: Significant p-value(<0.05); SBpr: Resting Basline pre; DBpr: Driving Baseline pre; CD1: City Drive first half; CD2: City Drive second half; RD1; Rural Drive first half; RD2: Rural Drive second half; DBpo: Driving baseline post; SBpo: Resting baseline post

4.1.3 NIRS Data

NIRS data was analyzed using repeated measures ANOVAs with a greenhouse geisser correction for violation of sphericity found one statistically significant difference for driving condition which was in the left PFC for city drive which is show below in Table 4. Post Hoc tests using a bonneferroni correction for between subject effects to compare groups showed only one statistically significant effect for all repeated measures ANOVAs. It was between the 25-64 age group and the 65+ age group in the HHb in left PFC for the city drive with a mean difference of 49.6%, p=0.034. For simplicity of presentation post-hoc tests for between subject effects are not shown in a table.

Table 5 NIRS Timepoint comparison for driving condition

	Within Subjects Effects		
	F	η^2	*P*
Rural HbO_2 Right	0.637	0.043	0.482
Rural HHb Right	0.960	0.064	0.407
Rural TOI Right	0.477	0.043	0.477
Rural HbO_2 Left	0.677	0.049	0.505
Rural HHb Left	0.459	0.034	.577
Rural TOI Left	0.640	0.047	0.506
City HbO_2 Right	0.592	0.044	0.532
City HHb Right	0.884	0.052	0.437
City TOI Right	0.735	0.053	0.507
City HbO_2 Left	0.654	0.048	0.528
City HHb Left	1.152	0.081	0.335
City TOI Left	5.644	0.303	**0.005**

Note: Values in bold: < 0.05 (significant p-value)

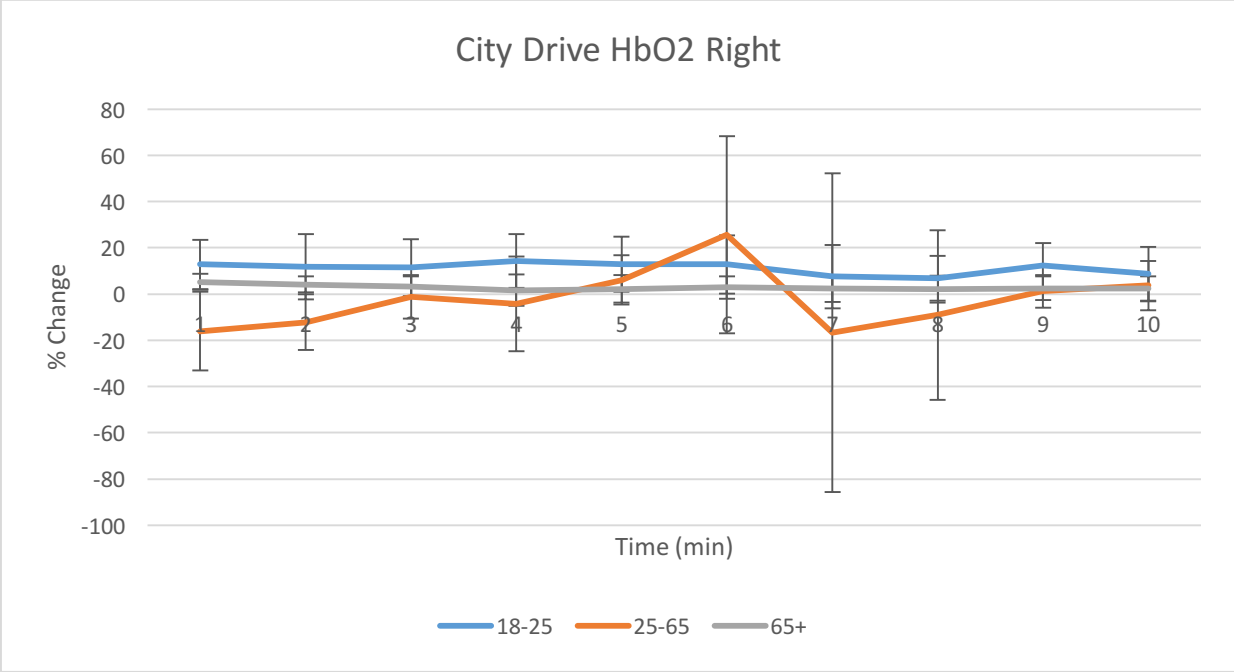


Figure 22 Percent change of deoxygenation in right PFC across three age groups

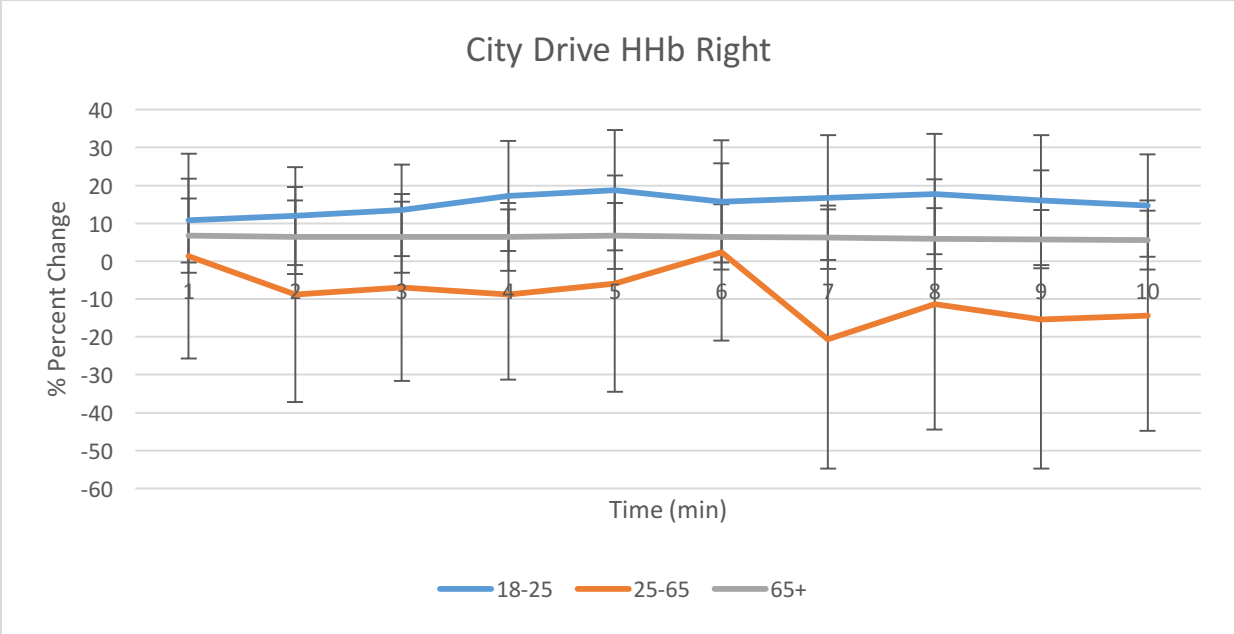


Figure 23 Percent change of tissue oxygenation index in right PFC during

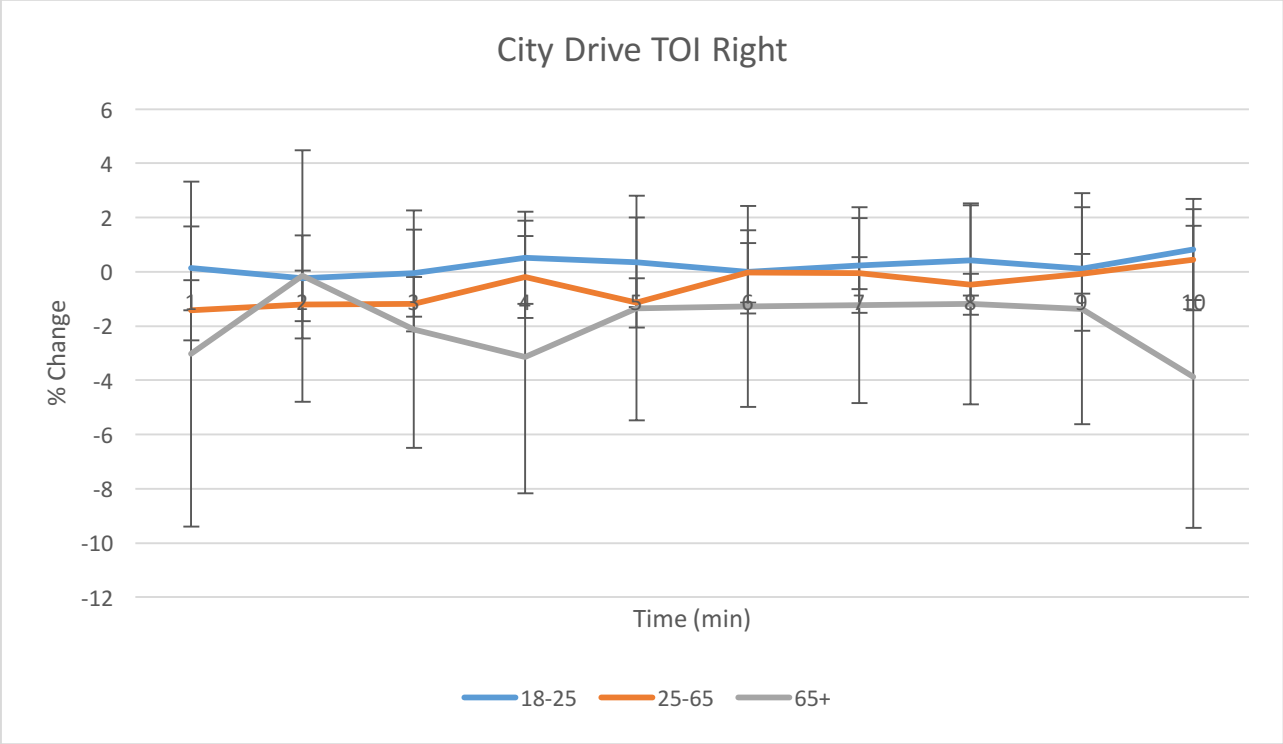


Figure 24 Right Total Oxygen Index for City Driving

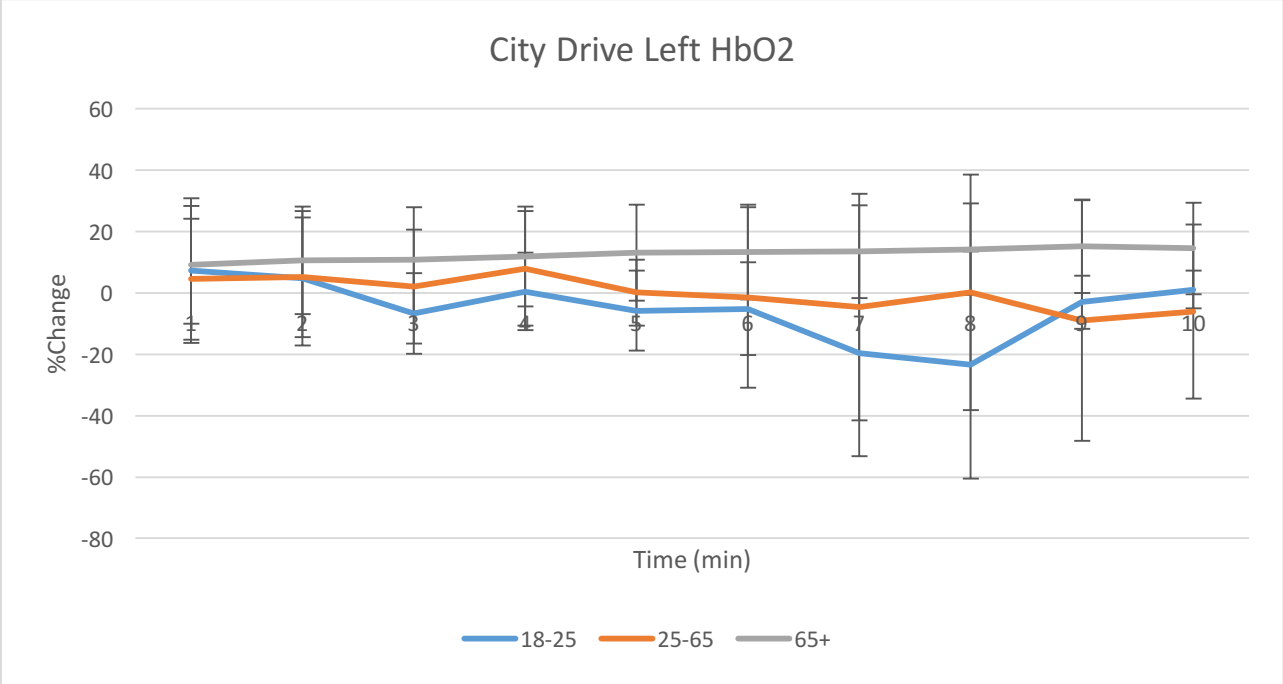


Figure 25 Left Total Oxygen Index for City Driving

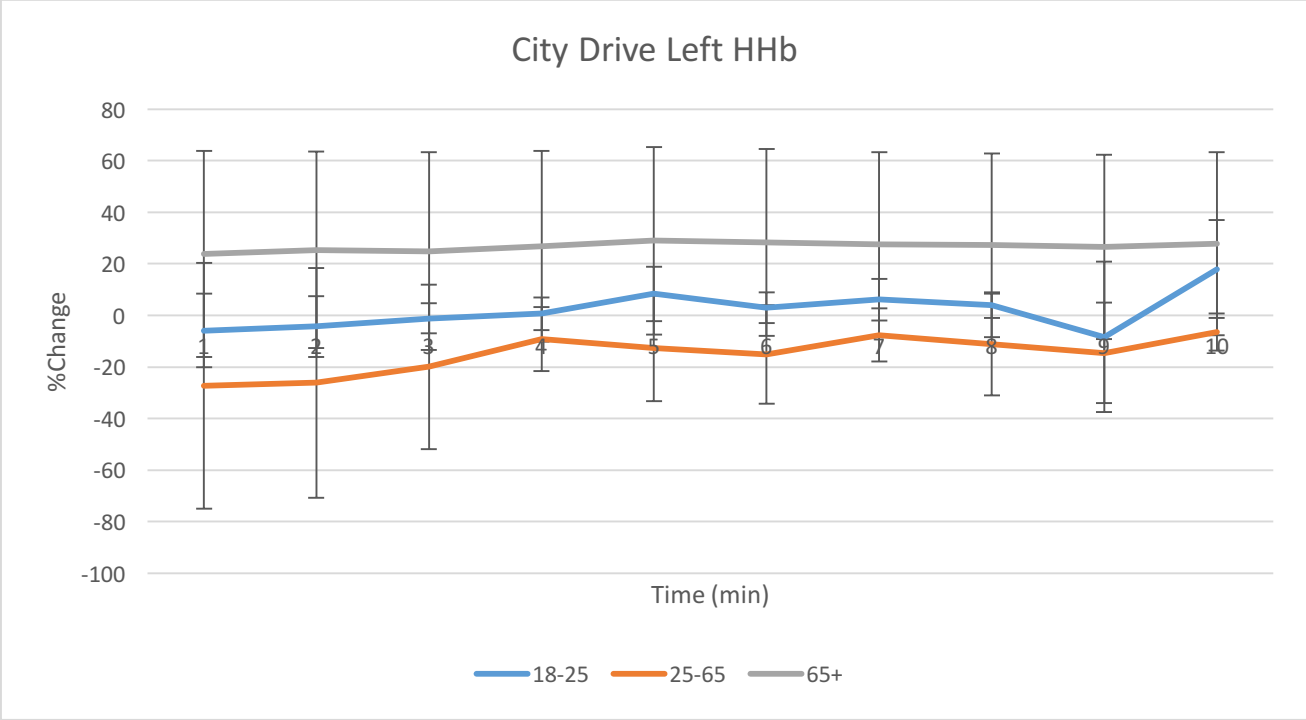


Figure 26 Left HHb for City Driving

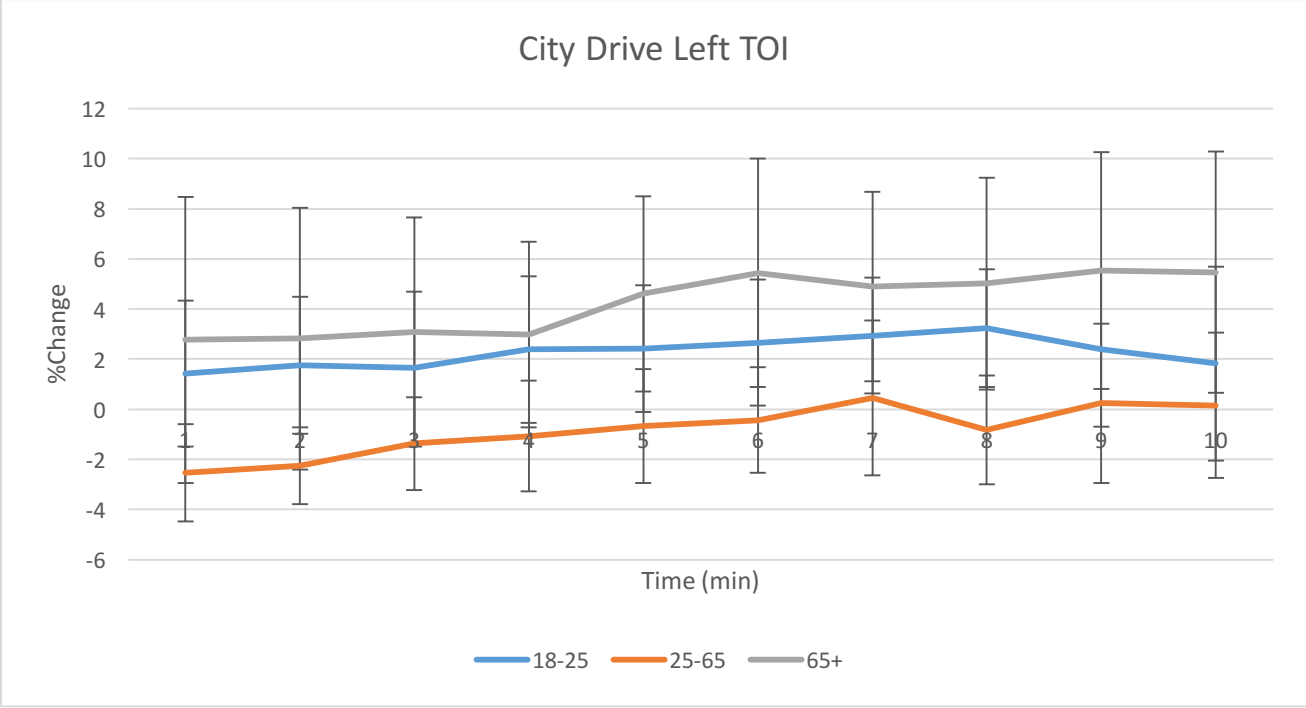


Figure 27 Left Total Oxygen Index for City Driving

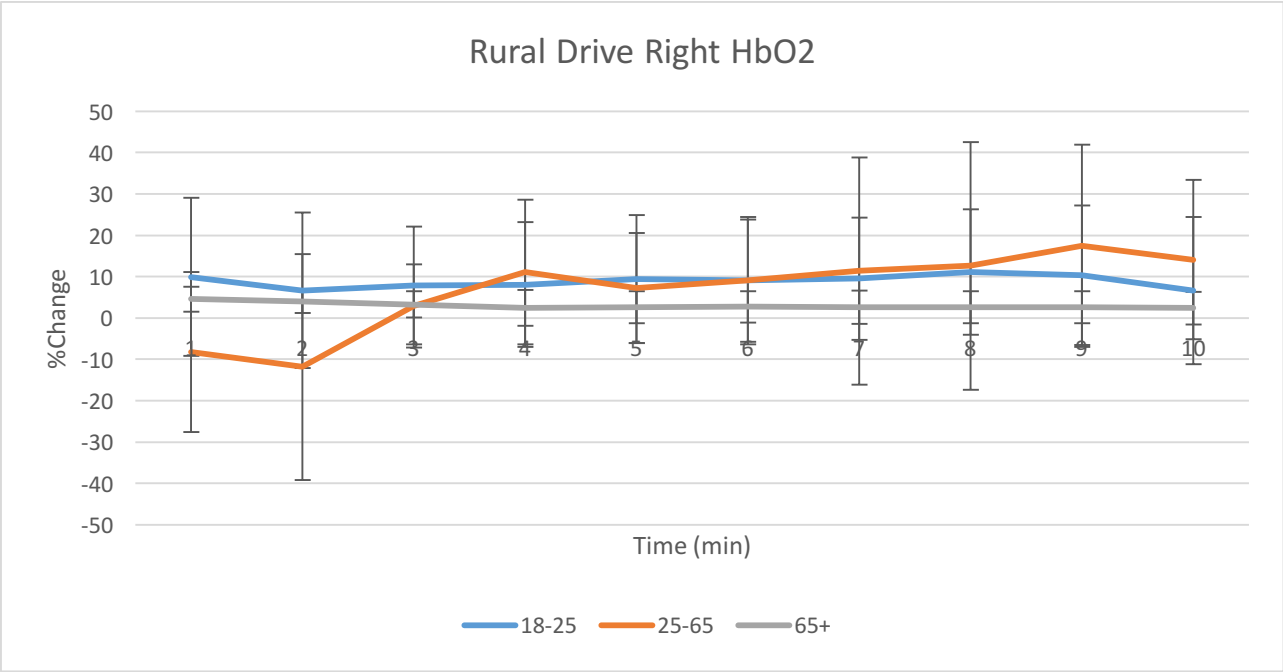


Figure 28 Right HbO_2 for Rural Driving

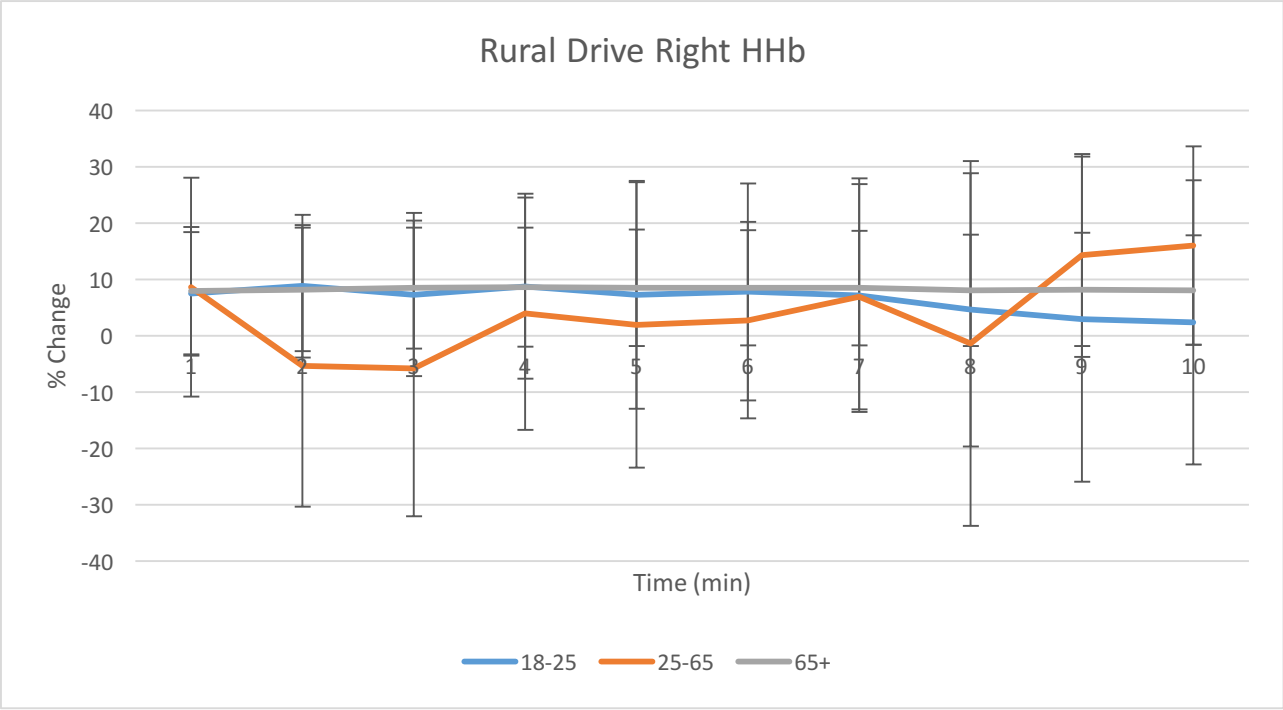


Figure 29 Right HHb for Rural Driving

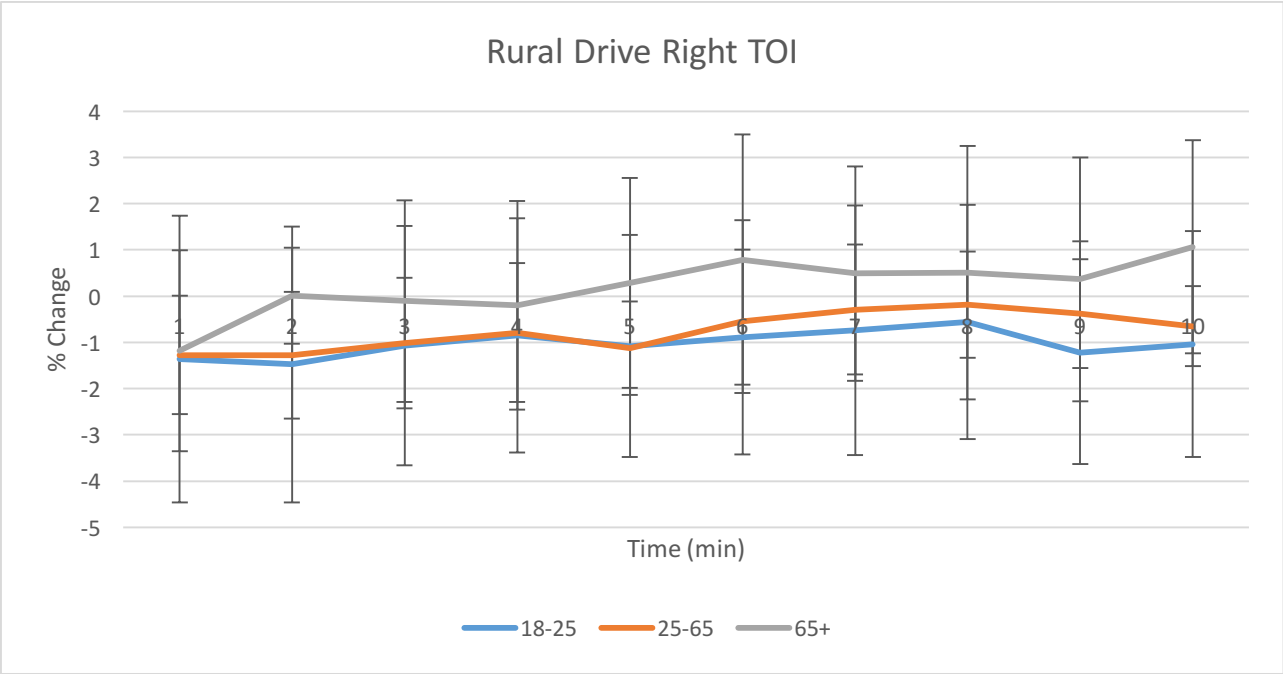


Figure 30 *Right Total Oxygen Index for Rural Driving*

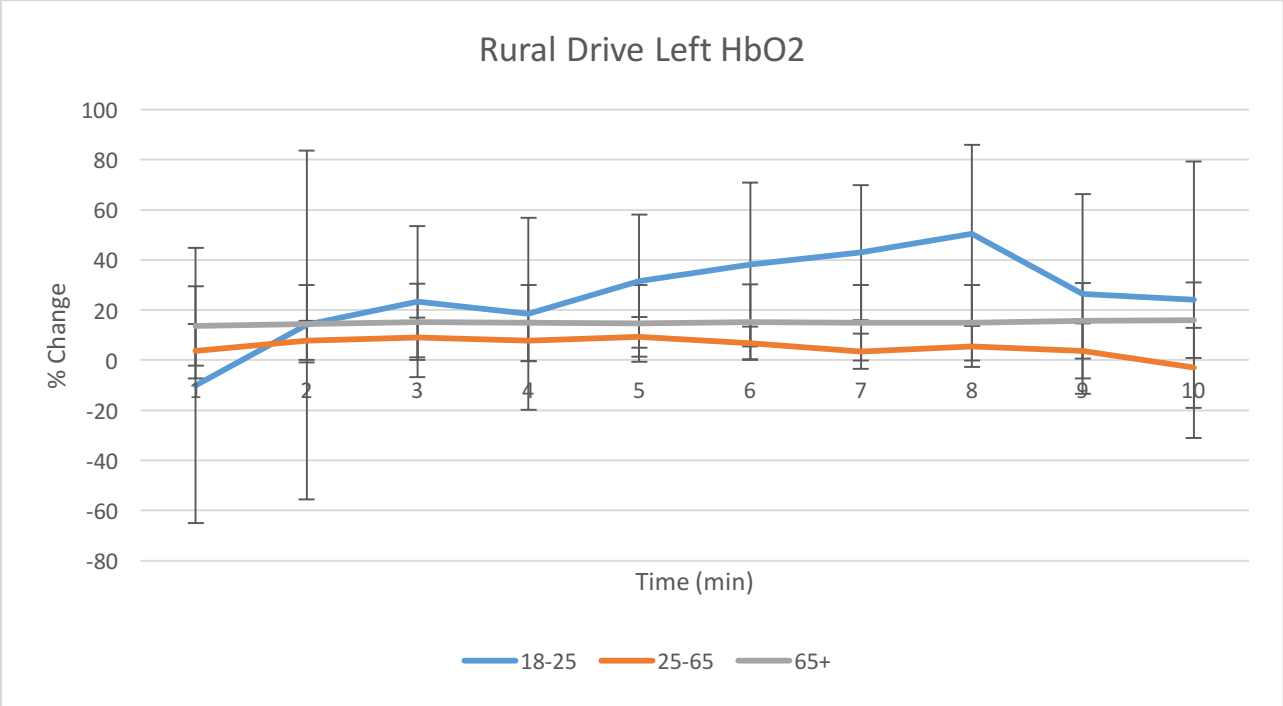


Figure 31 Right HbO_2 for Rural Driving

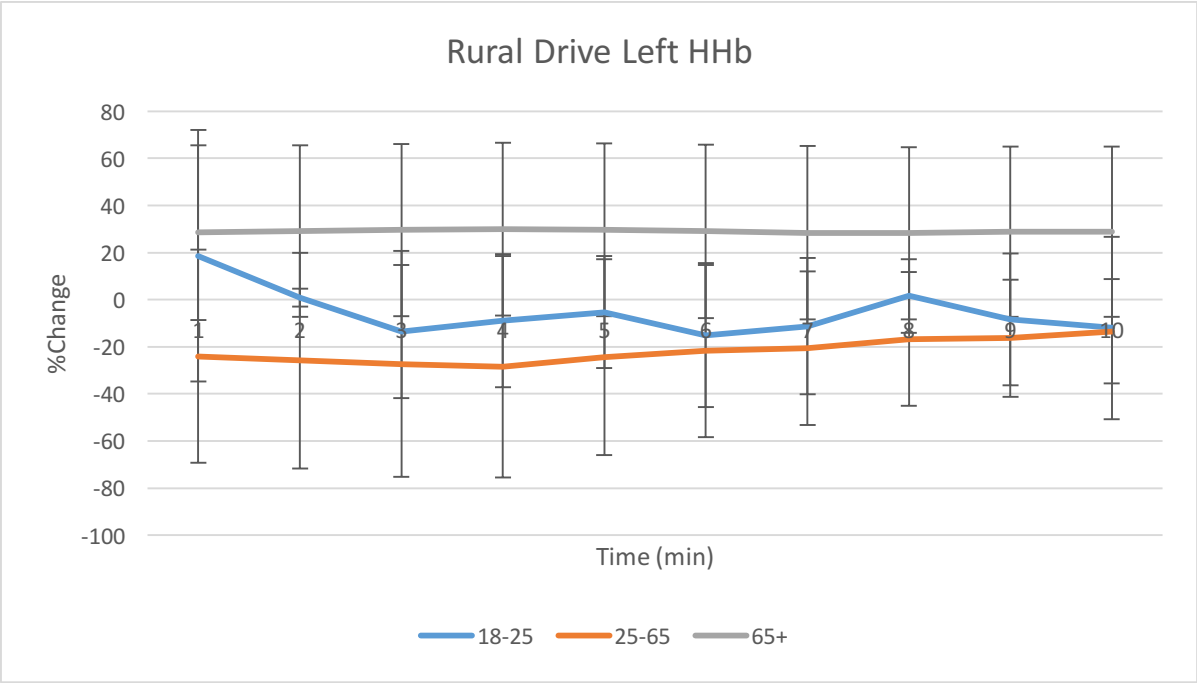


Figure 32 Right HHb for Rural Driving

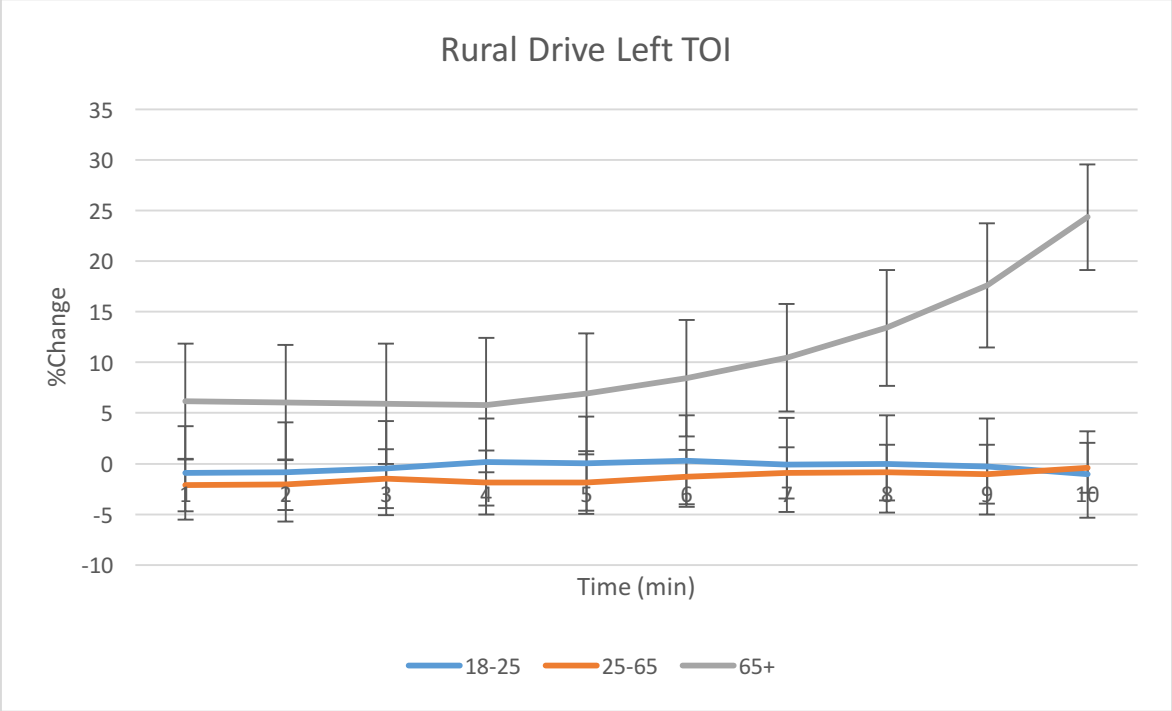


Figure 33 Left TOI for Rural Driving

5.0 Discussion

This study offers novel insights into the physiological and cerebrovascular responses that occur in different age demographics while operating automobiles on various simulated roadways. Several surprising findings are outlined in the present study.

Firstly, the TOI for the 25-64 age group was reduced in both hemispheres of the prefrontal cortices during both the city and rural drives. Despite challenging driving conditions (busy urban area) in the city drive and various obstacles in the rural drive (e.g. passing a truck, car pulling out onto highway) the NIRS signal for TOI remained below or at baseline levels. This suggests that for experienced drivers under 65 years of age prefrontal cortices are less active during driving tasks than at rest despite their suggested role in executive function, decision making, and information processing. Secondly, the TOI for the 65+ age group was elevated above the baseline for both the city drive and the rural drive particularly in the left hemisphere. It is possible that older drivers have more activity in the prefontal cortex during driving tasks and have to utilize more attentional resources when driving than their younger counterparts. Lastly, TOI for the 18-25 age group remained near the baseline values. This suggests that experience did not play a large role in cerebrovascular responses to driving. The younger drivers in this group had a mean years of driving experience of 3.8±2.71. It is likely that these drivers had sufficient practice to develop the automaticity that Michon (28) alludes to in his paper. All of the drivers in this study were over the age of 20. It is

likely that the learning curve for driving tasks such as motor control for steering, accelerating, and braking along with dividing attention to process external cues (signage, pedestrians, other motorists) is shorter than three years. Future research in this area should focus on drivers with less than three years of experience.

Several studies have shown increased HbO_2 levels during complex driving tasks (71,72,74). Tsunashima (71) found increased HbO_2 levels using fMRI when drivers were asked to manually control the gap between the car in front of them as opposed to using cruise control. This study had four participants all in their 20s. Simizu & colleagues (72) found increased PFC activity using fMRI and fNIRS in simulated driving conditions that were subjectively perceived as more difficult. They also found increased PFC activity when drivers navigated narrow roads that required more attention. Participants in this study ranged between the ages of 22-56. Harada & colleagues (75) found a slight increase in HbO_2 during driving compared to a resting baseline in both young drivers and elderly drivers in their late 60s in non-simulated driving using NIRS. They also found that elderly drivers and more experienced drivers had less variation in NIRS signals during the drive.

The present study found that the HbO_2 for the 26-64 age group was elevated above baseline during the rural drive but remained close to the baseline during the city drive. This is a suprising result because both intuitively and by looking at previous research it was expected that the city drive would supply greater cognitive stress. However, obstacles in the rural driving course in the present study included a car parked at the side of the road, passing a truck, and negotiating with a car merging onto

the roadway. It is possible that these stimuli are more infrequent driving stimuli that participants do not encounter on their everyday commutes whereas navigating an urban center is much more common. Since it is likely that drivers perform maneuvers such as stopping at traffic lights and making left hand turns with oncoming traffic on a regular basis, it is likely that they have developed automaticity with these tasks. The simulations selected for this study included difficult driving conditions as previous research (61) have shown decreased PFC activity during driving with little to no obstacles, traffic, or turns. (The HbO2 was elevated for the 65+ age group above the baseline for both the rural and city drives. This is in alignment with increased TOI and suggests that it is likely that older adults utilize more attentional resources than younger people. UFOV scores for this study had all but two participants scoring in category 1. Two other participants scored in category 2 one of which was included in the NIRS data for the 65+ age group. Since the UFOV scores did not show much variation no statistical analysis was performed. With all participants scoring well on the UFOV it may not be a sensitive enough test/prediction of driving performance in older adults. This study had the intention of grouping pariticpants based on their UFOV category to see the effects of attention and information processing speeds on cerebrovascular responses during driving; however, nearly all participants scored in the same category. If in future research a similar design is attempted, it may be possible to group participants based on selective attention/information processing scores from subset 3 (the most difficult subset in the UFOV test). While nearly all participants scored in the top category, information processing speeds during subset 3 were

observed to be longer in older drivers. Despite more research being needed, results of the present study suggest that although more time consuming and less affordable, NIRS could be a valuable tool to evaluate older drivers.

Since increased Oxygen and metabolic substrate delivery is completed by vasoactive control mechanisms that distribute blood flow from low activity levels to high activity level areas, using the measurements of HbO_2 and TOI can provide insight into the level of activity of a certain area of the brain (e.g. prefrontal cortex). HbO_2 sheds light on oxygen delivery to that brain area whereas TOI indicates substrate utilization. Pippa & Kirkpatrick (110) found the threshold for cerebral ischemia to be -13 % Δ TOI from baseline and thus one could assume that when percentages approach this magnitude drastic changes in hemodynamics are occurring. In the present study, TOI for all age groups remained within two or three percentage points from baseline with the exception of the 65+ age group left PFC which seem to level off around 5% for both drives and seemed to explode in the last three minutes of the rural drive reaching as high as high as 25%. At this point in the course most participants are driving down a two lane highway where an obstacle presents itself. Drivers are required to slow down to allow for an oncoming car attempting to pass a truck to return to its lane. Since speed varied between participants this event generally occurred between eighth and tenth minute and could account for the drastic increase in HbO_2. As for HbO_2 the general trend for all age groups was an increased HbO_2 for both city and rural driving consistent with previous research (74,75) showing elevated levels of oxygen in the PFC. However, the results do show some points in time where levels are below baseline

indicating participants' PFCs were diminished Since previous research has shown increases in HbO2 when mental load has increased, for example Spires & Colleagues (62) found increases in PFC activity when drivers followed traffic signs but noted no activity when drivers maneuvered vehicles around a track, it is possible that during normal everyday driving conditions the prefrontal cortex turns off and only activates during complex and defensive driving situations. This would be congruent with Reading & Colleagues (18) who found a six fold increase in HbO2 and cHb occurring 5 seconds before impact. This study used a computer simulated urban track which was programmed to test drivers' hazard perception for both urban and rural drives. With improved technology and NIRS being portable a more effective, design for future research could be done in a real life setting. It is possible that HbO2 would be lower due to less frequency of "threatful" hazards.

Stress is a physiological response produced by the body to combat physical, mental, emotional challenges that are placed on it. Stress responses are measureable through physical responses that include VO2max, HR, HRV, and blood pressure (111; 112). Manuevering a vehicle through an urban center within the confines of traffic laws and abiding by signage should create a substantial dynamic mental stress load as the driver must remain vigilant, divide his/her attention, and pick up pertinent environmental cues all while simultaneously correctly planning and executing appropriate courses of action to maneuver the vehicle safely.

For this study, data of energy expenditure rate was not collected; however, previous literature has suggested that it is around 2 METs (12) or even slightly lower as

Johnson & colleagues (102) reported 1.5 METs in simulated and on-road driving in participants between the ages of 21-57 years. With this slight increase in metabolic rate, one might expect a corresponding slight increase in HR; however, this was not the case in the present study. Reading & colleagues (18) found an increased cardiovascular response within the first one to two minutes of driving followed by the response resolving itself. They attributed this elevated response to possible anticipation or anxiety from participating in a research study. In the present study the first minute of driving was not analyzed to account for this phenomenon. There was no significant difference (p=1.000) between the resting baseline and driving baseline pre. Mean heart rate during a driving task for the present study was between 69.0-74.1 (depending on the timepoint) which is comparable to previous studies (75 & 80;(102), 70 (113), and 75(113)). Interestingly, the present study found a statistically significant difference in mean heart rate between the city drives and all other timepoints. This is in contradiction with Reading & colleagues (18) who found no significant effect on mean heart rate during complex driving situations such as driving through the downtown core or through a busy shopping plaza parking lot. Despite being statistically significant the elevation in heart rate during complex urban driving appears to be very minimal. Additionally, Reading & Colleagues (18) found the energy expenditure during highway driving (1.7METs) to be lower than when entering traffic (2.3 METs). It is likely that this ~3 BPM increase in mean heart rate while navigating busy urban traffic could be presumably due to the slightly higher energy demands of driving in traffic.

HRV has been used to quantify the physiological response of the body to physical and psychological stress (107). Table (2) shows statistically significant differences for SDNN, LF, HF, and SD2. SDNN is often used to quantify HRV as it represents the variability in the R-R intervals. Bonnferroni post-hoc test shows no significant differences in SDNN during driving tasks and only shows statistically significant differences amongst the various baseline periods. This indicates the decreasing HRV during driving tasks which is indicative of greater physiological responses. LF and HF represent frequency domain analysis of HRV which uses a Fast Fourier Transform to quantify the magnitude of signal literature (114). HF is a reflection of vagal activity as well as parasympathetic activity. LF is modulated by more factors but is more complicated than HF because it is affected by both sympathetic and parasympathetic outflows. LF/HF ratio, which was not significant in this study, is a description of the interplay between the sympathetic and parasympathetic activity (116). The current study shows statistically significant differences in between CD2 and the driving baseline in LF and HF. It does appear that sympathetic activity does increase slightly during the city drive and parasympathetic decreases slightly in turn as a percentage of the total power spectrum. However, the bonneferroni post hoc tests do not show consistent statistically significant differences between city driving and other timepoints. These results mirror the finding in HR in the fact that there is a statistically significant difference but the change in physiological response to the task is slight.

Limitations

This study had several limitations. Firstly, despite the participants all following the same standardized course in both the rural and city drives, participants each drove at different speeds and therefore were at different places in the course at each timepoint. Participants were instructed to drive how they would in real life and to abide by the traffic laws; however, it is possible that some may have exceeded the speed limit knowing that there would be no penalties since the study was on a driving simulator. Secondly, the study had unequal groups. The goal during participant recruitment was to obtain ten to twelve participants in each group; however, due to time constraints this was not met. Although forty participants did participate in the study, many were lost either to error readings in NIRS data or motion sickness. Thirdly, participants were not excluded due to medical history. It is possible that the older participants were on heart medications (eg. Beta blockers) that could affect HR, HRV, and blood pressure. These were not contraindicated for the study because of the need for participants. Thirdly, with NIRS data large sample sizes is especially important because of individual variability in hemodynamic responses. The graphs in this study have large error bars which are likely due to the great individual variability seen with NIRS data. Lastly, UFOV had observed “ceiling effect” nearly all the participants scored in Category 1. As a result the study was unable to group participants based on their ability to process information or focus/utilize their attentional resources.

6.0 Conclusion

The present study is the first study to our knowledge to compare different age groups cerebrovascular and cardiorespiratory responses to simulated driving. The finding were similar UFOV scores amongst all three age groups which indicated that age was not a substantial factor in visual information processing and divided attention. Additionally HR, HRV, and PFC oxygenatation was not significantly different amongst different aged participants.

Overall, there was a slight physiological response to the vigors of driving including decreased HRV, slightly increased HR (~3BPM in city driving) and increased HbO_2. There were periods of reduced PFC activity interspearsed with increased PFC activity which was likely due difficult driving situations employed by the computer simulations. It's possible that these computer simulated driving situations added to the high variance of cerebrovascular measures found in this study. With NIRS equipment being portable, future research should follow a similar design but be completed in the field to better represent everyday driving conditions.

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