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Cerebral hemodynamics and behavioral responses during simulated driving with and without hands-free telecommunication: a Near Infrared Spectroscopy study

by

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Abstract

The aims of the present study were to comprehend the behavioral effects of hands-free telecommunication on the hemodynamic responses and examine their relationship with the driving errors during the intervention. To study cerebral hemodynamics (using Near Infrared Spectroscopy) during distracted driving, 26 male participants drove in a simulated urban scenario, without (4 minutes) and with (2 minutes) naturalistic conversation using a hands-free earpiece. Two trials of each intervention were conducted. Driving errors were counted; NIRS and heart rate data were collected. The results indicated that driving with hands-free telecommunication led to an increase in driving errors, neuronal activation of the left frontal lobe (evident by a significant increase in oxy-hemoglobin and decrease in deoxy-hemoglobin) and heart rate compared to driving without telecommunication. Changes in NIRS variables were not correlated with driving errors possibly due to heterogeneity of NIRS data.

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INTRODUCTION

Driving a vehicle is an important activity of daily living and has become the preferred mode of mobility all over the world. However, it comes with a life threatening risk. Lack of attention can impair decision-making during driving and cause expensive accidents, injuries, disability, lost wages and even death. Due to the technological advancements in recent decades, a variety of electronic devices have made their way into our daily lives including automobiles. These electronic devices compete for the attention of drivers and one such device is the mobile or cell phone. Over the last few years, many jurisdictions around the world have imposed legislation that limits the use of hand-held phones while driving. The use of hands-free devices has endured and is considered generally more acceptable than a hand-held device since physical limitations encountered with hand-held device use may not be experienced by the hands-free alternative. In spite of this, a number of studies that have compared the use of hand-held and hands-free devices have consistently reported that the use of hands-free devices also adversely effects driving performance (Beede & Kass, 2006; Ishigami & Klein, 2009; Nunes & Recarte, 2002; Törnros & Bolling, 2005). A review of literature that compared the various measures of driving performance and driving-related errors with the use of hand-held or hands-free device corroborated the extant literature on this issue and concluded that both modes of devices had similar adverse effects on driving (McCartt, Hellinga, & Bratiman, 2006). The relative risks associated with hands-free phone use have not been clearly established, but the experimental evidence strongly suggests that conversations, even if conducted

using fully hands-free voice-activation devices are distracting. This issue clearly affects not only millions of drivers around the world, but also those whose livelihood depends on the multi-tasking abilities to drive and handle calls such as taxi cab operators, policemen, ambulance drivers and emergency response crew. Accidents due to distracted driving cause billions of dollars of damage throughout the world in lost wages and compensation, burden the already limited healthcare resources and negatively impact participation and performance in activities of daily living.

Phone use and driving have a brief history. The late 1980s and early 1990s saw the incorporation of telephones in cars and were advertised as 'car phones'. Car phones looked much like home telephones fixed in place by a cord attached to the driving console. However, when cell phones gained momentum, they effectively replaced car phones as the preferred mode of communication for drivers on the go. Both of these technologies had one common limitation, i.e., one hand was used to hold the phone while the other controlled the steering wheel. This was seen as a major limitation and user-friendly alternatives were sought. More significantly, conversing on hand-held phones affected the performance of driving maneuvers that drivers needed to be able to do, in order to successfully navigate through traffic. As an alternative, hands-free phone technology was invented and encouraged. Hands-free telecommunication enables drivers to keep both their hands on the wheel and enables better physical control of the car while conversing on the phone. However, this technology provides no advantage over hand-held phones to reduce distractions (Ishigami & Klein, 2009).

Telecommunication via any hand-held or hands-free device leads to similar reduction in attention and negative impact on driving performance (Consiglio, Driscoll, White, & Berg, 2003; Rakauskas, Gugerty, & Ward, 2004; Strayer & Johnston, 2001; Törnros & Bolling, 2005). Previous research has demonstrated that driving and simultaneous telecommunication leads to increased reaction time to critical stimuli (Ishigami & Klein, 2009), increased variance in speed (Rakauskas, Gugerty, & Ward, 2004), poor lane control, increased number of accidents and greater number of other driving related errors (Strayer, Drews, & Crouch, 2006; Strayer & Drews, 2007). Number of years of driving experience (Hancock, Lesch, & Simmons, 2003; Patten, Kircher, Östlund, & Nilsson, 2004) and practice had no impact on the ability to handle distractions caused by telecommunication. However, this ability decreased with increasing age putting senior drivers at higher risk (Hancock et al., 2003).

If distraction caused by hands-free phones was simply a product of conversation then it can be reasoned that conversation with an in-car passenger should also cause similar detriments in driving performance. However, prior research indicates the contrary, i.e., conversing with another passenger in the vehicle does not seem to have the same negative impact on driving. This is usually explained by the presence of the person or people in the car that are privy to the prevailing traffic conditions and they either stop talking during difficult traffic patches or even offer positive assistance. This indicates that the problem with telecommunication is not related to where the driver's hands are but where

the drivers mind is, i.e., telecommunication while driving causes distraction and increase in demand for attention.

Limited attention caused by telecommunication and its subsequent effects on driving performance has a neurological basis. This necessitates a clearer picture of the cerebral mechanisms that underlie handling cognitive interference caused by the use of a hands-free device while driving. Several techniques have been used to investigate this phenomenon, including functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), magnetoencephalography (MEG) and Near Infrared Spectroscopy (NIRS). Prior studies using fMRI and PET (Graydon et al., 2004; Horikawa et al., 2005; Uchiyama, Ebe, Kozato, Okada, & Sadato, 2003) have demonstrated that driving and driving distractions leads to an increase in cortical activation in the frontal lobe, parietal lobe, the cingulate gyrus, medial temporal lobe, cuneus, precuneus, and precentral gyrus. Both these technologies have superior spatial resolution but poor temporal resolution. In addition to this, fMRI, PET, and MEG are invasive, expensive and are not feasible to study functional activities that include movement. NIRS offers a valuable compromise with superior temporal resolution but a broad spatial resolution (i.e., measures activity directly from a broad cortical area below it). NIRS is a valid, non-invasive neuroimaging technique that can measure hemodynamic variables, such as concentrations of oxy-hemoglobin (O_2Hb) and deoxy-hemoglobin (HHb) in situ during a functional task. The basic principle behind NIRS is neurovascular coupling. Increased cortical activation (for example during distracted driving) leads to increased neuronal activation.

This necessitates an increase in blood flow to the activated area, which is usually attained by redistribution of cerebral blood flow from the inactive areas. NIRS is based upon the measurement of the difference in the absorption patterns of O_2Hb and HHb in the near infrared range (650-1100 nm). Other advantages of using NIRS include relatively low cost, increased mobility and fewer environmental factors that cause interference with the signal. It is for these reasons that NIRS is preferred for applied research. This technology has a long and elaborate history of use in studying muscle physiology and is gaining momentum as a viable neuroimaging technique. To date, only two studies have used NIRS to evaluate driving performance. This study is aimed at adding to the extant NIRS literature and elaborating on the neural mechanisms and cerebral hemodynamics of interference caused by communicating on a hands-free device while driving.

Specific Purpose

This study aims to elaborate on the physiological mechanisms, specifically cerebral hemodynamics, while participants are driving on a simulator and talking on a hands-free phone simultaneously (versus when they are not). Another goal of this study is to correlate the physiological activity with the number of driving related errors when the participants are driving (without or with a phone conversation) on a virtual driving simulator.

Hypotheses

The specific hypotheses of this study were that: (1) test-retest reliability of driving related errors, cerebral hemodynamic responses, and heart rate will be high when participants drive and engage in hands-free telecommunication

simultaneously; (2) mean number of driving related errors will be significantly higher when driving with hands-free telecommunication compared to without, (3) cerebral hemodynamic variables will be significantly higher when driving with hands-free telecommunication compared to without; (4) the correlation between driving related errors and cerebral hemodynamic changes would be significant; (5) heart rate will be higher when driving with hands-free telecommunication compared to without.

Significance of the study

This study will add to the extant literature on the issue of assessing safety of hands-free communication devices while driving a vehicle. This will be the first study that will use near infrared spectroscopy as the neuroimaging technique to answer this question. This study aims to assess the test-retest reliability of NIRS variables and heart rate in the presence or absence of driving distractions. It also aims to evaluate the difference in the trends of NIRS variables and heart rate in the presence or absence of such distraction. The results of this study can be used to better inform drivers about the risks of driving with a potential distraction such as a hands-free communication device. This knowledge can aid policy makers in developing guidelines or legislation on the use of communication devices while operating a vehicle. Such information is essential for individuals in occupations (such as heavy machinery operators, emergency response workers, police officers, and taxi drivers) where they are expected to handle distraction from communication technologies while operating a vehicle. Besides, if it can be established that the adverse effects of hands-free telecommunication are

associated with changes in cerebral hemodynamics, it could be used as a possible method for screening individuals in such occupations. Apart from this, if NIRS is able to detect subtle changes in the cerebral hemodynamics while driving with or without cell phone, this can initiate further research pertaining to other distractions that drivers face. Findings from this study can add to the public conscience about this issue and perhaps better educate drivers, thus reducing the need for rehabilitation after an accident.

REVIEW OF LITERATURE

Automobile and cell phone usage statistics

Statistics Canada reports that there are more than 21 million licensed drivers in Canada and 26 million registered vehicles including cars, trucks, motorcycles, and buses (Transport Canada, 2008). Similar statistics, proportionate to the population can be reasonably estimated for the United States of America.

As of 2011, there were around 327,577,529 cell phone subscribers in the United States of America (Cellular Telecommunications Industry Association, 2011) and around 24,037,372 in Canada (Canadian Wireless Telecommunications Association, 2011). These figures represent more than 70% of the total population in both countries, suggesting that cell phones are becoming ubiquitous in our lives.

Prevalence of cell phone usage while driving

According to these figures, driving has become the preferred mode of transport for most North Americans. Due to the increased use of cell phones in everyday life, it is not surprising that there is an increase in the number of individuals who talk on their cell phones while driving. To evaluate the rate of concurrent cell phone use while driving, Transport Canada conducted an observational survey in 2006 (Transport Canada, 2008). The primary purpose of this survey was to assess seat belt use in rural and urban communities across Canada. However, they also monitored cell phone use by drivers and correlated this with seat belt use. It was discovered that the national average of concurrent cell phone use while driving was 5.5% which included an average of 2.8% use in

rural communities and 5.9% in urban communities. Alberta was higher than the national rural average (4.7%), the leader in national urban average (11.7%) and the leader in national average (10.7%). The study also reported that cell phone use while driving was more prevalent in drivers between the ages of 25 to 49 years (4.5%) and drivers less than 25 years (6.7%). A more concerning statistic was that cell phone users were more likely to not use seat belts (10.8%) than those who were not using cell phones while driving (8.1%). Interestingly, these results were obtained by two separate one-hour long observations that occurred during daylight hours in September 2006. It can be easily speculated that if such a study was to be repeated with longer observation sessions in more than just daylight hours, the results would be more alarming and cell phone use would be reported to be more prevalent. Canadians seem to be aware of the evidence against cell phone use while driving, with majority (66%) thinking that this is a major road safety concern (Vanlaar, Simpson, Mayhew, & Robertson, 2006). However, the awareness of this risk does not seem to have a large impact on behavior. It can be safely assumed that since cell phone use is becoming increasingly common so is the risky behavior of its concurrent use while driving. A 2006 survey by the Traffic Injury Research foundation found that 37% of drivers reported using a cell phone while driving in the past week (Vanlaar et al., 2006). One-fifth of Canadian drivers reported using phones while driving regularly (Beirness, Simpson, & Pak, 2002). Despite the high rates of reported phone use, about half of Canadian drivers surveyed strongly favored a ban on hand-held phone use while driving (Beirness et al., 2002).

Accident statistics/Epidemiological studies

The percentage of fatal car crashes involving driver distraction and resulting in fatalities in the United States has risen from 11 percent in 2004 to 16 percent in 2008 (National Highway Traffic Safety Administration, 2008). In their seminal work on motor vehicle collisions and cell phone use, Redelmeier and Tibshirani (1997) studied the effects of cell phone calls on property damage caused by car accidents. They used a case-crossover design, which is "a technique for assessing the brief change in risk associated with a transient exposure." They used data from 699 drivers in the Greater Toronto Area, who were involved in a motor vehicle collision resulting in substantial property damage but no personal injury. Using cell phone records (for 231 drivers) and self-recall (for 468 drivers), they used a pair-matched analytic approach to contrast a time period on the day of the collision with a comparable period on a day preceding the collision. They included any telephone call occurring during the 10 minutes prior to the collision and 10 minutes at the same time on the day before the collision and contrasted the likelihood of a collision. Only drivers who were confident that they had driven on both days at both times were included in the analysis. Both hand-held and hands-free phone users were included. They reported that the average duration of a call was 2.3 minutes and that 76 percent of phone calls lasted 2 minutes or less. In addition, concurrent cell phone use while driving was associated with a risk of being involved in a motor vehicle collision that was about four times as high as that among the same drivers when they were not using their cell phones. The increase in risk appeared to be greatest for phone use near the time of the

collision. Interestingly, they observed that use of hands-free devices did not provide a safety advantage over hand-held devices, suggesting that the likelihood of collisions was increased due to limited attention and not dexterity. It should be noted that this study did not include serious injuries or fatalities caused by vehicular collisions nor did it assess if the drivers were at fault in collisions. This suggests that perhaps drivers who were concurrently using their cell phones were unable to avoid collisions caused by someone else. The authors also noted that thirty-nine percent of drivers were able to contact emergency services immediately after a collision suggesting that having a cell phone may have been advantageous in the aftermath of an event.

In a follow-up study looking at the increased likelihood of personal injury due to a collision while engaging in cell phone use, McEvoy et al. (2005) used a case-crossover design to compare a driver's use of a cell phone at the estimated time of a collision with the same driver's use during another time period before the collision. The authors accessed cell phone usage data of the participants for two hours before and after the crash as well as for the same time window during the control periods (24 hours, 72 hours and 7 days). Cell phone activity was defined as calls made or received and text messages sent. Of the 456 drivers who met the inclusion criteria (cell phone use at the time of the collision and at least once control period), the authors reported that a person using a cell phone concurrently while driving was 4.1 times more likely to have a collision that would result in personal injury and hospital attendance. Using phone records they also found out that 9% of the drivers were using a cell phone during or up to 10

minutes before the crash. Since they were trying to assess the seriousness of the injury caused by the collision, they discovered that almost all had at least one injury and almost half had two or more. Injuries included but were not limited to, sprains, bruises, lacerations, dislocations, fractures, minor head injuries, internal organ injuries to chest/abdomen and spinal cord injuries. They acknowledged that their findings were similar to those reported by Redelmeier and Tibshirani (1997); however, they claim to have been more persistent in reconciling self-recall and cell phone records. Unlike Redelmeier and Tibshirani (1997), they were also able to estimate the risk of collisions associated with hand-held and hands-free use. Remarkably, they reported that the collision risk while using hands-free devices (3.8 times) was comparable to hand-held devices (4.9 times), supporting a previous claim (Redelmeier & Tibshirani, 1997) that the use of hands-free devices does not seem to confer any safety advantage to the driver.

The results of the two studies (McEvoy et al., 2005; Redelmeier & Tibshirani, 1997) motivated Farmer, Braitman, and Lund (2010) to conduct a landmark study in which they calculated crash risk directly associated with cell phone use while driving that they termed, 'Population Attributable Risk'. Using telephone interviews with 1219 drivers, they computed percentage of driving time on cell phone distributed by demographic features such as age and sex. They discovered that males spent 7.0 percent and females spent 6.4 percent of driving time while concurrently using a cell phone. Individuals between 18-29 years, 30 to 59 years, and older than 65 years of age spent 16.4%, 7.1%, and 2.5% respectively of driving time while using a cell phone. Across age and sex, 6.7% of

driving time was spent in using a cell phone simultaneously. Using these base rates, the crash risk figures of Redelmeier and Tibshirani (1997) and McEvoy et al. (2005), national car accident statistics provided by Fatality Analysis Reporting System and General Automotive Samples of the National Automotive Sampling System, the 'Population Attributable Risk' was calculated. This was defined as the proportion by which crash risk would be expected to decrease if cell phones were never used while driving. Astoundingly, they reported that 19% of fatal crashes, 23% of collisions leading to injuries and 22 percent of collisions leading to property damage could have been avoided if there were no drivers talking on their cell phones. In actual numbers this would mean that 1.3 million out of 5.8 million crashes in the United States in 2008 could have been avoided if cell phone use while driving was avoided.

Studies on cell phone use and driving performance

Behavioral studies focusing on understanding the effects of cell phone use (hand-held or hands-free) on driving ability are primarily divided into three categories: on-the-road driving, simulated driving, and non-driving (cognitive). On-the-road testing, which is the accepted standard for driving assessments, has many benefits because it represents actual driving in a real-world context (Korner-Bitensky, Sofer, Kaizer, Gelinas, & Talbot, 1994). However, on-the-road testing is time consuming (Di Stefano & Macdonald, 2005), not always safe, expensive (due to liability insurance, track rental fee or course development), and may have adverse effects that could lead to dangerous driving situations (Lee, Lee, & Cameron, 2003). In addition, researchers cannot control for environmental

conditions such as light and weather or task conditions such as traffic and pedestrians. Thus, on-the-road testing may pose ethical problems including risking the safety of participants, passengers, pedestrians and other road users. In contrast, driving simulation provides a convenient and safe method for assessing driving behaviors. Driving simulators also allow for assessment under well-controlled and repeatable conditions and efficient data acquisition (Gruening, Bernard, Clover, & Hoffmeister, 1998; Reed & Green, 1999), which makes them a promising evaluation and research tool. Driving simulators are becoming more commonplace due to their increased fidelity and reduced cost (Rizzo, Jermeland, & Severson, 2002); thus, they are being used more frequently in both research and clinical settings (Brown, Ticker, & Simmonds, 1969). There are some limitations to using driving simulators. Firstly, a simulator is an estimation of reality. It is impossible to accurately reproduce reality due to technological limitations as well as cost and time constraints. The driving environment is simpler in simulators than in the real world, where drivers must cope with a large number of events. Secondly, there are no serious consequences of subjects' driving errors and it is unknown whether drivers would make the same decisions when driving with their own vehicles. Thirdly, driving simulation may lead to SAS as discussed on page 24 of this literature review. In spite of these limitations, a driving simulation is safe and relatively inexpensive technique in comparison with the alternative (on-the-road testing).

Behavioral effects and driving errors during cell phone use

Earlier studies were conducted using on-the-road driving but with the evolution of computer technology, simulation studies are becoming a standard for behavioral and neuroimaging driving research. In one of the initial studies (Brown et al., 1969) on this topic, using a radiophone (pre-cursor to hands-free communication devices) minimally interfered with on-the-road driving tasks, but severely impacted the drivers' perception and decision-making process (judging whether to drive through gaps which might be larger or smaller than the car). This was the first report on the effects of a 'hands-free' device on driving performance. Interest in this area of cognition increased with the increasing number of cellular devices in the last 20 years.

Brookhuis, deVries, and deWaard (1991) sought to compare the effects of hand-held versus hands-free devices on driving ability in three on-the-road driving conditions. They used a verbal mathematical task (Paced Serial Addition Task) over hand-held or hands-free phones while participants completed a car following maneuver. They reported that using a telephone while driving decreased the number of times the rear view mirrors are checked, which led to delayed adaptation to the speed of the car in front, significantly increased reaction time to speed variations by 22.6%, and increased heart rate (as measured by ECG). This increase in reaction time to speed variations could cause rear-end vehicle collisions, if the driver of the vehicle was using a cell phone simultaneously while driving. Driving performance was worse with hand-held devices, and therefore, use of hands-free device (with voice dialing) was suggested. Another study

employing on-the-road testing used a closed-circuit track to test stopping time, distance and accuracy in response to a red traffic light when participants were driving and interacting with a simulated hands-free phone (Hancock et al., 2003). They sought to compare performance on the variables listed above between genders and age. They reported that drivers involved in a phone call had significantly slower response to change in traffic lights and stopped at a red light 15% less often than when they were not on the phone. Moreover, older drivers were significantly disadvantaged by the driving and concurrent cell phone task. Also, the brake response time and stop light compliance was more negatively affected in females. Patten et al. (2004) studied driving performance (namely Peripheral Detection Task and Speed Maintenance) in experienced cab drivers on the real roads while they were concurrently involved in a simple or complex conversation using a hand-held or hands-free phone. They discovered that response times on the peripheral detection task increased and correct responses decreased for phone tasks when compared to control conditions, and for complex versus simple phone calls. There was no difference in performance between phone type (hand-held versus hands-free) and surprisingly, the mean speed was significantly higher when using hands-free versus hand-held phones. Maintaining a speed lower than baseline when using hand-held devices seems to have been a compensatory mechanism.

The effects of cell phone use on driving performance have also been studied using the meta-analytic technique. In the first meta-analysis, Horrey and Wickens (2004) analyzed data from 16 studies (3 on-the-road, 1 test track, and 12

simulator studies) on response time and lane maintenance. They examined the possible differences between hand-held versus hands-free, naturalistic conversation versus information processing tasks, passenger versus remote conversation, and simulator versus on-the-road testing. Significant decrement in driving performance associated with phone use while driving was primarily observed in increased response time to critical hazards or stimuli. Lane maintenance was not reported to be significantly impaired while driving and using a phone. This could be because lane control is primarily vision and not attention based. Performance on hands-free versus hand-held use, phone versus passenger conversations, or simulator versus on-the-road were not significantly different. This lends support to the notion that hands-free phone use may be just as distracting as hand-held and that performance on simulator studies is similar to on-the-road studies. Lastly, this study reported significantly more distraction during conversation (discussion of current events) versus information processing (word games, mathematical tasks, etc.). This suggests that conversation should be used to simulate real-world driving conditions when the goal is to study the effects of distraction. These researchers followed up on and replicated their findings in another meta-analysis of 23 studies evaluating at the driving measures listed above and comparing the same variables(Horrey & Wickens, 2006). Another meta-analysis (Caird, Willness, Steel, & Scialfa, 2008) reported similar results. Using 33 studies (7 on-the-road, 9 lab, and 17 simulator based), this group concurred with the previous meta-analysis and concluded that there was a significant increase in reaction time to stimuli in the presence of a phone and that

hands-free phone users drove at higher speeds than hand-held users. They also found no significant differences in lane control, the gap maintenance between two cars when driving with a cell phone conversation, and use of hands-free versus hand-held device.

Hands-free versus hand-held telecommunication and driving

Research has demonstrated that the adverse effects of driving while talking are most likely not related to the motor control issues of manipulating a hand-held phone or driving experience. Rather, it is believed that the effects are a result of competition of limited cognitive resources. It is well established that people have a limited amount of attentional resources, and focusing attention on one task (e.g., the cognitive load of a phone conversation) reduces the capacity to process information needed to perform other tasks (e.g., driving). Strayer and Johnston (2001) compared the effects of driving without a phone call or with a phone call using a hand-held device or hands-free device on a pursuit-tracking task. Participants were instructed to continue the task on a computer display if the light on the screen was green but make a braking response when the light turned red. Response time and probability of missing the red light was measured. Their results indicated that response time was longer and probability of missing the red lights was higher in the phone condition than the no phone control condition. They reported no significant difference between hand-held or hands-free groups.

A similar study conducted by Consiglio et al. (2003) evaluated the effect of listening to music on the radio, conversing with a passenger, using hand-held or hands-free phones on a braking response task. Participants were asked to release

the simulated accelerator and depress the brake pedal as quickly as possible following activation of a red brake lamp located in front of them. Their results indicated that response time was slower in the phone conditions but no significant difference in hand-held and hands-free conditions. In contrast to Consiglio et al. (2003) who used straightforward question-answer format of conversation, Rakauskas et al. (2004) studied the effects of naturalistic conversation on simulated driving performance using hands-free modality. They measured aspects of vehicle control (such as, speed, lane maintenance and crash avoidance) while participants engaged in a low difficulty conversation (questions requiring one-word to one-phrase answers), high difficulty conversation (questions requiring a well-considered, opinion based answer) or no conversation. They reported that conversation type had no effect on driving performance measures; however, conversing on hands-free led to a significant decrease in speed and increased speed variability. Similarly, Törnros and Bolling (2005) reported a significant reduction in speed when driving along with conversing on the phone as compared to driving without conversing. This effect, however, was more pronounced for hand-held phone use. Participants in this study drove in a simulated route that included rural and urban environments. They also completed peripheral detection task and paced serial addition task via hand-held or hands-free modality. The researchers reported that lane control was better during the phone condition than control. Response time and percentage of missed signals were higher in the peripheral detection task during the phone conditions. They reported no significant differences in hand-held versus hands-free modality in response time

and percentage of missed signals. Speed reduction seems to be a compensatory mechanism to deal with the added attentional load levied by the phone conditions. Since this effect was greater in hand-held than hands-free, perhaps drivers are underestimating the risks associated with conversing with the hands-free phones. Ishigami and Klein (2009) conducted a thorough review of literature to compare the difference in driving performance when drivers were using a hand-held versus a hands-free device. Summarizing the findings of ten studies (2 non-driving, 4 simulation based, 2 field driving and 2 epidemiological), they reported that hands-free phone use seems to confer no attention or safety advantage over hand-held phones. As well, phone usage while driving leads to an increased probability of missing critical signals and an increased reaction time.

Beede and Kass (2006) showed similar decrements in driving performance when drivers were driving on a simulated route and simultaneously conversing on a hands-free device. Participants in this study were required to drive through a semi-urban/urban environment (where other cars, pedestrians, cyclists and signals were present) and participate in a phone conversation task and/or a signal detection task. They reasoned that since driving involves both focal and peripheral attention, the effects of a hands-free conversation task should be studied on both these parameters. They reported that drivers involved in the conversation task committed more violations, changed lanes less often and performed poorly on the signal detection. Also, drivers drove at a higher average speed and had higher response times when conversing on a hands-free phone and detecting peripheral signals simultaneously. They concluded that drivers coped with the demands of

the phone call by narrowing their attention, shedding the peripheral task (such as signal detection) and focused on more immediate tasks.

In a landmark study, Strayer et al. (2006) compared the effects of phone conversation and driving at the legal limit for alcohol intoxication on driving performance. Participants in this study drove in a simulated multilane freeway while following a pace car that would stop at random intervals, thus requiring a brake response from the driver. Driving speed, following distance, brake reaction time and collision statistics were measured when the same group of drivers either drove in control condition, drove with a simultaneous phone conversation (hand-held and hands-free) or drove under the influence of alcohol (at legal blood alcohol level of 0.08%). Intuitively, they found that drivers driving under the influence of alcohol had a more "aggressive" driving style characterized by hitting the brake with greater force and following closely. However, when driving in phone condition, participants reaction time was greater, they had longer following distance and took longer to recover their speed following braking and were involved in more rear-end accidents (compared to control). They concluded that the impairments associated with driving and simultaneously conversing on a phone may be as great as driving under the influence of alcohol and there were no observed differences when driving with either hand-held or hands-free phone use. Additionally they commented on how the longer following distance and slower recovery time after braking might negatively influence a smooth traffic flow.

Elaborating on this, Strayer and Drews (2007) offered a plausible hypothesis termed 'inattention blindness' to explain the negative effects of driving while

conversing on a phone call. This was defined as a failure to see/perceive objects in the driving environment when a driver is talking on the phone. To test this hypothesis, they conducted two similar experiments in which a driver drove in a simulated city environment (with and without naturalistic conversation via hands-free phone) and memory for the objects from that environment were surprise tested using an incidental-recognition memory paradigm (study 1) or a two-alternative forced-choice recognition memory paradigm (study 2). In both studies, the participants were twice as likely to recognize roadway signs encountered when they were driving only than when they were driving and conversing on a hands-free phone. This difference was not affected by how long participants had fixated on the object (study 2), as the experimenters had ensured that participants looked at objects (targets and foils) for the same amount of time.

Another study found that a conversational task using a hands-free device reduced visual attention, as measured by the useful field of view (Atchley & Dressel, 2004). It was concluded that the combination of phone usage and decision-making in demanding driving situations created a potentially hazardous competition for a driver's attention. Performance degradations may result even when two tasks use different senses. A study on cortical activity during shifts of attention between visual and auditory stimuli suggests that when attention is focused on listening, the ability to process visual stimuli may be hindered (Shomstein & Yantis, 2004).

Hands-free versus conversation with a passenger while driving

If one cause of driver distraction is the act of communicating, then this should also apply to communication with passengers in the car as well. This would mean that conversation itself is detrimental to driving performance. Several studies (Charlton, 2009; Drews, Pasupathi, & Strayer, 2008) have reasoned that passengers in the car modify their behavior and the conversation in response to the changing needs of the traffic and as such may even help the driver to navigate through challenging areas. As conversation with fellow passengers in the car cannot be reasonably controlled, it should be ascertained if passenger conversation indeed has the same effects on driving performance as hands-free telecommunication. Crundall, Bains, Chapman, and Underwood (2005) provided initial evidence on this issue. They conducted an on-the-road study to test the hypothesis that drivers and in-car passengers will suppress conversation when the attentional demands of the road become too great and on the contrary interlocutors on hands-free phones will make no such adjustment as they are not privy to the driving conditions. Measures of conversation pace (number and length of utterances) were monitored for both the driver and the interlocutor (passenger or hands-free) as drivers drove through rural, intra-city highway, suburban and urban road segments. Each of these segments offers slightly different challenges. Participants played a verbal game where the goal was that the interlocutor (who was provided with a list of words) had to provide clues and engage in a conversation that would lead the driver to guess the word on the list. An interlocutor in this study was either a passenger in the car (with or without

blindfold) or a hands-free device. Their results confirmed their hypothesis that passenger conversations were suppressed during more demanding urban driving and that conversation suppression only occurred when both driver and the passenger could see the road ahead (blindfolded passengers had a similar conversation pace as hands-free). Following this, another group (Drews et al., 2008) monitored lane control, following distance, average speed, and navigational accuracy (if the correct exit was taken) while participants drove in a simulated freeway. Drivers maintained a naturalistic conversation with either an in-car passenger or over hands-free device about a personal experience. Their results showed that drivers in the hands-free phone condition showed more lane keeping variability and tended to drift, maintained a larger following distance from the car in front, and were four times more likely to fail in taking the correct exit as compared to the in-car passenger group. They reported no significant changes in speed maintenance and that in-vehicle passengers took an active role in supporting the drivers as surrounding traffic also became a topic of conversation. Another study by Charlton (2009) with a similar paradigm noted slightly different results as far as speed maintenance was concerned. They reported that drivers talking to in-car passengers were more likely to anticipate hazards and reduce their speeds performing nearly as well as a no-conversation control group. In contrast, drivers talking on a cell phone often failed to take action to reduce their speed as they approached hazards, resulting in higher crash rates. The author suggested that the driver's concern about the welfare of their passenger motivates a more conservative driving style. The finding that drivers involved in a hands-

free phone conversation perform poorly on navigational tasks was previously reported in Strayer and Drews (2007). They had reported that only 50% of drivers who were talking on the hands-free device were able to navigate to a rest stop on a simulated multilane freeway as opposed to 88% of drivers who were conversing with an in-car passenger.

Simulation Adaptation Syndrome

A significant limitation to using driving simulators as opposed to on-the-road testing is the presence of Simulation Adaptation Syndrome (SAS) or simulation sickness. Symptoms of SAS include (Kennedy, Lane, Berbaum, & Lilienthan, 1993) oculo-motor disturbance (fatigue, headache, eyestrain, difficulty focusing), disorientation (dizziness, vertigo), and nausea (increased salivation, sweating, stomach awareness, emesis). Some level of SAS occurs in participants in any simulated environment. The rate of SAS can range from 20% in a high-fidelity simulator to 60% in a low-fidelity one(Kennedy & Fowlkes, 1992); however, for driving simulators the rate of SAS is approximately 10% (Freund & Green, 2006; Lee, Cameron, & Lee, 2003). SAS can occur even in simulations that do not have any other traffic(Brooks et al., 2010). Most people overcome the SAS by adapting to the simulated environment in a few sessions; however 3-5% never adapt and continue to experience SAS (Johnson, 2005).

One of the most widely accepted theories of SAS is the *Sensory Conflict Theory* (Reason & Brand, 1975). According to this theory, when a person drives a real car on the road, the eyes and the vestibular system of the driver track his/her movement in space and sense changes in acceleration. However, when a person

drives in a simulated environment, the conflict between the sensory systems, i.e., perceived motion (by the eyes) but no acceleration (as sensed by the vestibular systems) causes SAS and its associated symptoms.

Symptoms of SAS are observed more often and are more serious in a city simulation (with many sharp turns and other traffic) than in highway, suburban or rural simulations (Mourant, Rengaraja, Cox, Lin, & Jaeger, 2007). Some studies (Freund & Green, 2006; Jaeger & Mourant, 2001; Mourant & Thattacherry, 2000) have reported that women are more likely to experience symptoms of SAS than men. Older adults tend to be more susceptible to SAS than younger participants (Roenker, Cissell, Ball, Wadley, & Edwards, 2003). Several individual variables increase susceptibility to SAS; these include, but are not limited to: certain medications, poor health, sleep deprivation, limited experience in simulated environment and history of motion sickness (Crowley, 1987; Johnson, 2005; Kennedy & Fowlkes, 1992; Lerman et al., 1993).

Brooks et al. (2010) established guidelines on how to deal with SAS in experimental settings. They recommend that the testing facility be well ventilated and equipped with light drinks, snacks, bags (in case of emesis), plastic gloves and cleaning products. They also encourage that in case of SAS, participants must stay in the testing facility for a minimum of one hour. Mullen, Weaver, Riendeau, Morrison, and Bedard (2010) reported that participants who experienced significant SAS and were unable to complete a simulated drive performed better during on-the-road testing. This alternate form of testing alleviates the concern

that SAS prevents examination of those who might need it the most (e.g., elderly drivers).

Neuroimaging of driving

In order to fully comprehend the nature of interference that the use of cell phones causes while driving, one needs to understand the neural basis of driving and interference handling while driving. In one of the first studies on this topic, Walter et al. (2001) used functional Magnetic Resonance Imaging (fMRI) to differentiate neural activation when participants actively drove or passively viewed a scene in a simulation. It was reported that simulated driving engages mainly areas concerned with perceptual-motor integration and does not engage areas involved in higher cognitive functions. Amongst areas where increased activity was observed were left sensorimotor area and cerebellar regions. These areas are mainly necessary for steering the car with the right hand. Some of the limitations of this study were the absence of other traffic and pedestrians on the road, the relatively short blocks of driving (10 blocks of 32 seconds each) and driving on a straight path (no turns or other maneuvers). The results of this study paved way for other studies in neuroimaging of driving behavior. Another fMRI study by Calhoun et al. (2002) recognized that the driving consisted of complex interactions between the processing of sensory information, attention, and vigilance, decision-making and motor skills. They used independent component analysis to discover the dynamic changes in the cortical areas underlying these tasks. Using a simulated driving scenario, they reported that increased activation in the anterior cingulate cortex was associated with error monitoring and

inhibition, posterior cingulate cortex during spatial attention; however, both anterior and posterior cingulate cortex were active when participants demonstrated vigilance. In addition to these, frontal and parietal regions were involved in selective and divided attention during simulated driving. The authors also tested whether the driving speed modulates neural correlates differently. They did so by changing the speedometer display units from kilometers per hour to miles per hour for some participants, resulting in an actual speed range of 160-224 KPH (when drivers attempted to drive between 100-140). Driving at a higher speed exhibited an exponential decline in anterior cingulate cortex activity (associated with error monitoring and inhibition) and fronto-parietal regions (associated with vigilance). Increases in cerebellar and occipital areas during driving was presumably related to complex visuomotor integration, but not associated with driving speed.

Exploring another dimension of driving ability, Uchiyama et al. (2003) studied the neural underpinnings of maintaining safe distance while driving in a simulated environment using fMRI. The researchers compared the activity between rest, driving behind a car and actively maintaining a safe distance by decelerating or accelerating, and passively viewing a car 5m in front travelling at 50 KPH. Their results indicated that the driving task activated bilateral cerebellum, basal ganglia, ventral and dorsal premotor cortex, inferior parietal lobule, left primary sensorimotor cortex, supplementary motor area and anterior cingulate cortex. Interestingly, they reported that the activity in anterior cingulate cortex was negatively correlated with task performance and absent at rest. They

concluded that co-activation of the basal ganglia, thalamus and premotor cortex was related to movement selection. Activation of a premotor-parietal network is related to visuo-motor coordination and that the anterior cingulate cortex is primarily involved in error detection, response selection and choice between conflicting options. Further studying attentional processes using fMRI, Graydon et al. (2004) looked at visual event detection in simulated driving. Detecting visual events such as brake lights, traffic signs, traffic lights and passing vehicles and appropriately responding to them is critical for driving safely. Drivers in this study drove in a simulated environment and were instructed to respond when they saw a red dot on the screen. The results of this manipulation indicated that fronto-parietal region, premotor area, cerebellum and basal ganglia showed increased activity in addition to anterior and posterior cingulate cortex. The authors concluded that several fronto-parietal networks are believed to be important in the control and allocation of attentional resources.

Positron Emission Tomography (PET) evidence indicates that similar structures, with the addition of medial temporal and occipital gyrus, cuneus, precuneus and precentral gyrus were involved in maintaining simulated driving performance(Horikawa et al., 2005). The authors also reported that the number of crashes was negatively correlated with posterior cingulate gyrus activity and concluded that this area, in conjunction with frontal and parietal cortices, has been identified as a major component in the network of visuospatial attention. The results of this PET study are consistent with the results of Uchiyama et al. (2003).

In EEG research, P300 is an event-related potential that is detected as a positive deflection in voltage with a latency of roughly 250-600ms. Prior EEG research has found that the amplitude of the P300 component of the event-related brain potential (ERP) is sensitive to the attention allocated to a task (Sirevaag, Kramer, Coles, & Donchin, 1989; Wickens, Kramer, Vanasse, & Donchin, 1983). Also, memory performance is superior for objects eliciting a larger-amplitude P300 during encoding (Fabiani, Karis, & Donchin, 1986; Otten & Donchin, 2000). According to this line of thought, if impairments in memory are due to poor encoding, then P300 amplitude should be smaller in tasks where distraction occurs during the task. Strayer and Drews (2007) used EEG to distinguish between cerebral electrical activity when participants drove in a high fidelity driving simulator and performed a memory task in presence of hands-free cell phone call. They reported that drivers using a cell phone while driving performed poorly on the memory task. This could be explained by poor encoding, as the P300 amplitude elicited during conversation was half of that compared to the no hands-free cell phone call while driving. This indicates that drivers using a cell phone fail to see information in the driving scene and do not encode it in their memory as well as they do when they are not distracted by the cell phone conversation.

In all of the studies described thus far, the simulations were simplistic (race track like). However one fMRI study combined neuroimaging with an accurate, high-fidelity simulation of the city of London (Spiers & Maguire, 2007). Using 28 male, highly experienced London taxicab drivers as participants, this

study aimed to find the neural correlates (using fMRI) of the different aspects of simulated driving such as planning and performing a prepared action, reaction to unexpected events, following traffic regulations and navigation through busy roads with many other cars and pedestrians on the road. By exposing the participants to very realistic simulation of their natural work environment, this group aimed to study different cognitive functions such as perception, attention, motor control, working memory and decision making while driving. The results of this study were fascinating, as they demonstrated that a network of areas in the brain correlate to the different demands placed on a driver. They reported that prepared actions increased activation in the cerebellum, pre-supplementary motor area (pre-SMA), supplementary motor area (SMA), and posterior cingulate, medial parietal, medial and lateral occipital cortex. A complex maneuver such as turning at an intersection activated the dorsolateral precentral gyrus and a large area extending from the occipital cortex dorsally to the superior parietal cortex and laterally in the right posterior middle temporal gyrus. Unprepared and unexpected actions correlated with activity in the cerebellum, medial occipital gyrus and posterior middle temporal gyrus. Attempts to avoid collisions were additionally associated with activation in the mid and anterior cingulate, precuneus, posterior parietal cortex, bilateral ventrolateral PFC and left insula. Planning an action with respect to rule following (such as a traffic rule or one-way system) was associated with significantly increased activity in the pre-SMA, cerebellum, lateral occipital, superior parietal cortices, precuneus and right lateral PFC. Overall, the cerebellum features in almost all of these maneuvers and tasks.

This is intuitive, as the cerebellum is thought to be important for fine control during movement execution that accompanies any driving task (Home & Butler, 1995). The activation of pre-SMA and SMA seems to correlate with actions in prepared movement execution (Cunnington, Windischberger, Deecke, & Moser, 2002; Deiber et al., 1991; Grafton, Hazeltine, & Ivry, 1998). One of the most interesting findings of this study was the increased activity in the right lateral prefrontal cortex and medial prefrontal cortex when participants were considering traffic regulations and rule obedience. Lateral prefrontal cortex has previously been implicated in rule retrieval and maintenance (Bunge, Kahn, Wallis, Miller, & Wagner, 2003; Donohue, Wendelken, Crone, & Bunge, 2005) and medial prefrontal cortex in altering responses to adapt to challenges in the environment (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004).

To elaborate on the neural structures that contribute to decision making while driving, Callan, Osu, Yamagishi, Callan, and Inoue (2009) reported increased activation in the frontal cortex, anterior cingulate gyrus and amygdala. Bowyer et al. (2007) and Bowyer et al. (2009) studied the effects of conversation while driving using magnetoencephalography (MEG) and reported primarily increased activity in the frontal lobe and right parietal lobe.

To summarize, driving alone increases activity in the frontal cortex (due to executive processes such as deciding to stop or take a turn and interference handling or planning a route), occipital lobe (for vision), parietal lobe (for spatial navigation) and cerebellum (for motor aspects of manipulating a vehicle). However, driving with a phone conversation has been known to increase activity

in the frontal lobe significantly over other areas in the brain. This may be due to the increased effects of interference from the conversation and an increased cognitive load. In spite of this, little is known about the complex cerebral oxygenation of the frontal lobe while handling interference while driving and using a cell phone simultaneously.

Near Infrared Spectroscopy

Introduction and current uses

Near infrared spectroscopy is a valid non-invasive optical method of measuring relative changes in cerebral oxygenation and blood volume in humans (Simonson & Piantadosi, 1996; Villringer, Planck, Hock, Schleinkofer, & Dirnagl, 1993). Biological tissue is relatively transparent to light (Jöbsis, 1977). The oxygenation patterns of most biological tissues including the brain can be studied using NIRS. To comprehend how NIRS measures oxygenation patterns, one must first understand some basic concepts in optical physics. When light hits a surface or crosses a boundary between media of different concentrations, some of it is absorbed, some of it is reflected and some changes its direction (refracts). This change in direction is known as scattering. When near-infrared light is shone on the head, it crosses tissues of various viscosities (such as, skin, skull, and cerebrospinal fluid). Due to this the proportion of light that scatters is far greater than what is absorbed. In cerebral tissue, the main chromophores (light absorbing compounds) are hemoglobin, water and cytochrome oxidase. NIRS is based on the measurement of differential absorption properties of these chromophores in the near-infrared range, i.e., between 700 and 1,000 nm. Hemoglobin exists in the

blood as O_2Hb and HHb. The deoxygenated state of hemoglobin (HHb) is primarily absorbed at 760 nm, whereas the oxygenated state (O_2Hb) at 850 nm (Wray, Cope, Delpy, Wyatt, & Reynolds, 1988). Hence, by monitoring the difference in absorbency between the two wavelengths, one can evaluate the degree of tissue deoxygenation.

NIRS units comprise of a near-infrared light emitting optode and a detector optode. The light entering the head is presumed to travel between emitter and detector following a crescent (banana-like) path (Gratton, Maier, Fabiani, Mantulin, & Gratton, 1994). The depth that the light penetrates is directly proportional to the distance between the emitting and detector optodes (inter-optode distance) and this depth is usually only a few centimeters into the cerebral cortex. It is for this reason that NIRS is limited to measuring oxygenation changes only in the superficial layers of cerebral cortex. The major intracerebral contribution to NIRS probably comes from the grey matter (Okada et al., 1997). Kohri et al. (2002) reported that in human heads, the estimated contribution of cerebral tissue to optical signals is between 55-69% when the inter-optode distance was 4 cm. Previous studies using PET and NIRS simultaneously have shown best correlation between the parameters of the two technologies in the outer 1 cm of the cerebral cortex (Hock et al., 1997; Villringer & Chance, 1997). Additionally, the geometry of the gyri and sulci has negligible effect on the optical path length in the cerebral tissue (Okada et al., 1997). A continuous wave spectrometer applies near-infrared light at constant amplitude, measures attenuation of light and provides relative changes in the concentrations of the

chromophores (Delpy & Cope, 1997; Hoshi, 2005). During the last decade, researchers have used NIRS to evaluate its applicability for use with cognitive, visual, auditory and motor tasks (Fallgater & Strik, 1998; Obrig et al., 1996; Obrig & Villringer, 1997; Wolf, Ferrari, & Quaresima, 2007), study of brain disorders (Irani, Platek, Bunce, Ruocco, & Chute, 2007) and neurorehabilitation of cognitive disabilities(Arenth, Ricker, & Schultheis, 2007).

Neurovascular Coupling

The observed changes in concentration can be attributed to underlying physiological causes with a high degree of specificity (Villringer & Obrig, 2002) and there is a consensus that focal brain activation is accompanied by an increase in regional cerebral blood flow. This change reflects the balance between the oxygen supply at the level of the small blood vessels (i.e., arterioles, capillaries, and venules) and the amount of oxygen extracted by the tissue. Increased localized activation of cerebral cortex is associated with increased glucose consumption (Fox, Raichle, Mintun, & Dence, 1988). In order to metabolize this increased glucose, oxygen consumption increases as well. This increase in oxygen occurs due to a local arteriolar vasodilation induced by increased cortical activation and consequently an increase in cerebral blood flow. This has been termed neurovascular coupling(Roy & Sherrington, 1890). The increase in cerebral blood flow and oxygen delivery exceeds the increase in oxygen consumption and in turn, leads to an increase in intravascular hemoglobin oxygenation during brain activity (Villringer & Dirnagl, 1995). Therefore, cerebral blood oxygenation rises locally which can be measured by NIRS based

on the difference in the absorption patterns of O_2Hb and HHb (Chance, Zhuang, UnAh, & Lipton, 1993; Hoshi & Tamura, 1993; Kato, Kamei, Takashima, & Ozaki, 1993; Malonek & Grinvald, 1996; Villringer et al., 1993). A localized rise in O_2Hb alone, however, is not a reliable indication of neuronal activation, as this could just be due to the increased blood flow to the area, change in blood pressure or increase in blood flow to the skin. The initial increase in O_2Hb and decrease in HHb (after a few seconds) is commonly accepted as the most valid parameters to indicate neuronal activation (Obrig et al., 2000; Obrig & Villringer, 2003; Villringer & Dirnagl, 1995). In NIRS research, a summation of O_2Hb and HHb concentrations is taken as a measure of tHb (or cerebral blood flow). The tHb concentration has been shown to correlate to regional cerebral blood flow changes as monitored by PET using the labeled-water technique (Villringer & Chance, 1997). The difference between the two chromophores is the so-called tissue oxygenation index (Yoshitani et al., 2007).

Driving studies using NIRS

To date, only a few driving studies have been conducted using NIRS to study cerebral oxygenation. In one of the first studies in this field, Harada, Nashihara, Morozumi, Ota, and Hatakeyama (2007) examined the differences in prefrontal cerebral oxygenation while driving between young and old drivers. Young drivers were further subdivided into: experienced young adults (those who drive everyday) and less experienced young adults (those who do not). Regional cerebral activity from resting level, were measured using NIRS. Data were collected from both sides of the forehead while participants drove a real car

approximately 7 km on an ordinary road in an urban environment. They reported that similar oxygenation patterns were obtained on both sides of the prefrontal region in each respective group. Adhering to the conventional definition of neuronal activation, this group defined increase cerebral activity as an increase in O_2Hb and tHb and a concomitant decrease in HHb. In the young adult drivers, there was no significant difference of cerebral activity at rest between the experienced and the less experienced drivers; however, the less experienced participants showed significantly higher cerebral activity than the more experienced group during driving. The less experienced young adult drivers also showed increased prefrontal cerebral activity while stopping at a traffic light. The experienced young adults and elderly drivers showed little change in cerebral activity during driving and stopping at the traffic signal compared to the less experienced drivers. O_2Hb and tHb responses were significantly different between the two age groups; however HHb was not. This indicates that neuronal activation (and by extension cognitive load) was greater in less experienced than experienced drivers during the performance of the driving task.

Another study by Li et al. (2009) used NIRS to evaluate the effects of driving for extended periods of time on cerebral fatigue. Fatigue is one of the major contributing factors to driving errors (Nilsson, Nelson, & Carlson, 1997). In this study, healthy male participants either drove for three hours in a simulated environment or performed a no driving control task while NIRS data was collected from the left prefrontal cortex. The participants in the control condition were required to watch the driving simulation video in a comfortable chair. Their

results indicated an increase in O_2Hb and tHb in the frontal cortex at the start of driving task and a gradual decrease at the end of the three-hour simulated driving. They concluded that the increase in O_2Hb in the beginning of the driving task was an indication of neuronal activation, whereas, reduction in this parameter near the end indicated a reduction in blood flow to the brain. This decrease in O_2Hb over time may be due to gradual fatigue development which is often seen in prolonged periods of driving.

Comparisons with fMRI and other neuroimaging techniques

fMRI and MEG are other major techniques that use indirect measures to estimate cerebral hemodynamic variables. NIRS has gained external validity by its use in conjunction with fMRI and MEG (Huppert, Hoge, Diamond, Franceschini, & Boas, 2006) in a fine motor task. The similarity between NIRS and fMRI stems from the similar underlying principle. As noted above, functional activation of cortical tissue leads to an increase in cerebral blood flow to the region, which exceeds the increased localized neuronal metabolic demands. This increase in cerebral blood flow results in an increase in O_2Hb and a concomitant decrease in HHb concentration in the local tissue. O_2Hb and water have low paramagnetic properties and differ very little from each other. HHb, on the other hands is highly paramagnetic, has very different magnetic properties and can act as a naturally occurring contrast agent (Pauling, 1977). While fMRI measures the differences in the paramagnetic properties of HHb, NIRS measures its concentration directly by measuring the difference in absorption. Huppert et al. (2006) and Toronov et al. (2001), among many others, reported high temporal

correlations between the BOLD signal of fMRI and the HHb concentration in fNIRS on a motor task. Strangman, Culver, Thompson, and Boas (2002), on the other hand, found strong correlation between fMRI changes and all optical measures, but strongest in O_2Hb.

Though fMRI is considered the gold standard for neuroimaging research, it has poor temporal resolution and MEG has poor spatial resolution. NIRS is a valuable compromise between the two and provides a direct measure of concentrations of O_2Hb and HHb which can serve as direct indicators of neuronal activation in the frontal lobe (which serves as evidence for cognitive interference). Other advantages of NIRS are that the equipment is relatively inexpensive and mobile compared to other neuroimaging techniques. NIRS is not as sensitive to muscle tension as EEG, and eye-blinks produce virtually no artifacts when data is collected from the dorsolateral prefrontal cortex (i.e., forehead;(Izzetoglu, Bunce, Onaral, Pourrezaei, & Chance, 2004)).

Safety considerations with NIRS

Near-infrared light is non-ionizing (unlike ultraviolet and shorter length wavelengths), and therefore there is minimal concern about harmful radiation. The primary concern with near-infrared light has been tissue heating. However, this condition is not problematic as the power required for NIRS measurements is well below the level where tissue damage from heating might occur(Ito, Kennan, Watanabe, & Koizumi, 2000).

Cognitive studies using NIRS

The decrease in cerebral oxygenation reported above has also been observed in studies focusing on cognitive load. Izzetoglu, Yurtsever, Bozkurt, and Bunce (2003) employed the 'n-back' task, a frequently used test in cognitive psychology research and reported that as the task became more difficult and cognitively demanding, the blood oxygenation in the dorsolateral prefrontal cortex would increase. This increase was indicative of an increased cognitive load and sustained mental effort. This study also reported that at the point when the task became too difficult and the participant became disengaged in the task, the blood oxygenation decreased. In a follow-up study by the same group, Izzetoglu et al. (2004) replicated their findings when they used the Warship Commander Task (WST), a highly involved video game that was designed to approximate naval air warfare management. They also suggested that a drop in oxygenation change in the dorsolateral prefrontal cortex under high workload conditions may be used to predict a decline in performance. In order to study the oxygenation effects of increased cognitive demands imposed by a simulation task, Ayaz et al. (2010) presented simulated air traffic control situations to professional air traffic controllers. Using NIRS, they concurred that oxygenation in the dorsolateral prefrontal cortex increased as the cognitive demands of the simulations increased.

Since near-infrared spectroscopy is a relatively modern neuroimaging technique, there is limited literature on the reliability and validity of using near-infrared spectroscopy for cognitive tasks and driving research. The current study is designed to verify the test-retest reliability of the NIRS measurements during

simulate driving with and without hands-free telecommunication. These results will add to the extant literature on this issue.

Heart rate and driving

In one of the first investigations in this area, Taggart and Gibbons (1967) studied electrocardiographic (ECG) changes while driving in a busy London neighborhood and a competitive racing track in healthy volunteers. They reported that driving in a dense fast-moving urban traffic increased heart rate from rest by 15-70 bpm and that this increase in heart rate occurred very rapidly in people with normal cardiovascular health. Even more rapid heart rate changes developed before and during competitive motor racing. Brookhuis et al. (1991) also calculated the ECG responses in addition to looking at the performance measures of driving and mobile telephoning. They reported that heart rate and heart rate variability (calculated from the cardiac inter-beat-interval) increased when participants were driving and attending a phone call simultaneously. This increase in physiological stress decreased with practice and had a habituating effect. Haigney, Taylor, and Westerman (2000) used a similar method, in that they calculated maximal change in heart rate from baseline (delta) and revealed that heart rate exhibited highest values during call periods (i.e., +5.66 beats/min). Using on-the-road testing, Healey and Picard (2005) examined physiological responses during 5-minute segments of driving in city, rural and highway environments. Their goal was to use various measures of physiological stress, establish how well each measure allows for determining physiological stress while driving and correlating two or more of these measures. They monitored the

ECG, electromyogram, skin conductivity (using electrodermal activation and galvanic skin response) and respiration (by measuring chest cavity expansion). Their results indicated that they were accurate in determining physiological stress under the three conditions listed above at least 97.4% of the time. As well, skin conductivity and heart rate metrics were most closely correlated with driver stress levels. A previous study by Jang et al. (2002), demonstrated that physiological measures could be used in simulation-based paradigms as well. Their goal was to assess the suitability of using physiological sensors in virtual environments. They reported that skin resistance and heart rate (ECG) measures were the most effective in showing physiological arousal of participants who were engaged in a simulated driving or flying task. Participants in this study demonstrated that physiological arousal can take place when driving in a simulated environment and the responses generally returned to subjective baseline over time.

One of the first studies focusing solely at the effects of telecommunication on heart rate in a simulated driving situation was Reimer et al. (2008). Participants in this study were instructed to drive in a simulated urban environment sub-divided in three equal lengths. Drivers drove in absence of a distraction during periods 1 and 3; and maintain a goal-oriented conversation during period 2. The goal of this study was to differentiate between younger (19-23 years old) and older (51 – 66 years old) drivers in driving performance and heart rate measures. Their results indicated that though average driving speed was not different between the two conditions, the deviation was much greater in the hands-free driving condition. This indicated a reduced driving consistency while

participating in the phone task. Older drivers tended to drive slower than their younger counterparts. Heart rate was averaged for each period and it was significantly higher when younger drivers were driving and conversing simultaneously. In contrast, older drivers showed little change in heart rate along the duration of the experiment. It should be noted that older drivers began the experiment with marginally higher heart rate than the younger drivers. In a recent study by Collet, Clarion, Morel, Chapon, and Petit (2009), heart rate variability was compared when drivers (driving on-the-road test track) listened to radio, talked to an in-car passenger or talked on a hands-free device. In addition to this they measured reaction time to a light stimulus that was shown at random intervals during the course of driving. The conversations with the in-car passenger and over hands-free lasted for 2 minutes and were naturalistic in nature. Their results indicated that response times in the stimulus detection task and mean heart rate increased significantly in the conversation groups as compared to the no-conversation/listening to radio group. As well, no differences were found between conversing with an in-car passenger or over hands-free device. Heart rate acceleration is considered an indicator of physiological arousal in response to increased metal workload. This increase in heart rate may, in turn, indicate that the driver's capacity to respond to additional or unexpected events in the driving environment is compromised. Theoretically, this would eventually lead to greater number of errors while simultaneously driving and telecommunicating (such as, on a hands-free device).

METHODS

Participant Selection

This study used convenient sampling for recruiting participants. This is a nonprobability sampling method that is often used during preliminary and explorative research, without incurring the cost or time required to select a random sample. One of the possible disadvantages of using convenience sampling is that the resulting sample of participants may not be a potentially representative sample of the driving population. However, to address this concern, at the beginning of the first session each of the participants read the information sheet and completed the consent form along with a questionnaire (Appendices A and B). This was done to assess driving history and behavior in order to avoid a potential assembly bias.

Participants were recruited from the general public who responded to posters advertised in the common areas of the University of Alberta, Alberta Motor Association and Glenrose Rehabilitation Hospital. Inclusion criteria for this study were:

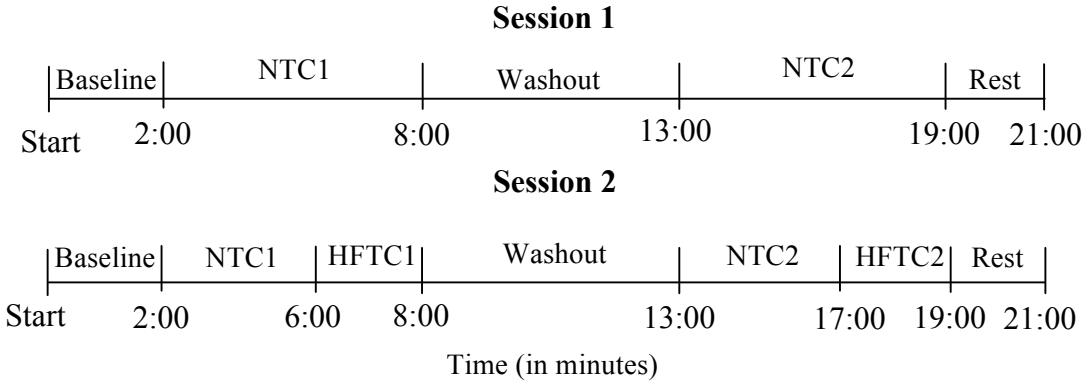
1. biologically male
2. between the ages of 18-50 years
3. possession of currently valid vehicle operator's license (class 5 or higher)
4. normal or corrected vision and/or hearing
5. medically stable
6. no prior history of neurological illness or diagnosis

All the procedures for selecting participants and data collection were approved by the Human Research Ethics Board at the University of Alberta (Appendices C and D). Thirty participants met the above criteria and participated in this study out of which four dropped out due to SAS.

Testing took place in the Building Trades of Alberta Courage Centre at the Glenrose Rehabilitation Hospital. All participants completed two testing sessions lasting one hour each as indicated in the experimental design below. The two sessions were separated by at least one day and were conducted at roughly the same time of day.

Experimental Design

The design of the present study can be classified as a repeated measure design. In session 1, NTC and in session 2, each condition (NTC and HFTC) was repeated once interspersed by a washout period.



NTC : Driving **without** phone call
HFTC : Driving **with** phone call

Figure 1: Timeline of study design. This study was divided in two sessions. Only data from session 2 was analyzed. In session 2, two trials of NTC and HFTC were completed by each participant.

Test Protocol

Participant Preparation

In their first session, the participants were explained the working of the driving simulator and the various components of the vehicle (visual representation in Appendices E and F). They were then asked to sit comfortably in the driver's seat of the driving simulator and fasten their seatbelts. Seat height, distance and steering wheel height were adjusted according to their individual needs to ensure comfort. An NIRS sensor (visual representation in Appendix G) was then mounted on the left forehead, approximately 2 to 3 cm from the midline and just above the supraorbital ridge (Bhambhani, Maikala, Farag, & Rowland, 2006; Ikezawa et al., 2009; Li et al., 2009). The inter-optode distance was 4.5 cm resulting in a penetration depth of approximately 2.7 cm from the surface of the forehead. At this penetration depth, approximately 1 cm of cerebral grey matter would have contributed to the changes in hemodynamic variables. This was confirmed by two studies performing PET and NIRS simultaneously that have shown the best correlation between NIRS and PET parameters in the outer 1 cm of the brain tissue (Hock et al., 1997; Villringer & Chance, 1997). The cerebral anatomical location with this probe placement likely corresponded to parts of left superior and inferior frontal gyri (Ikezawa et al., 2009; Okamoto et al., 2004). The chest strap for the heart rate monitor (Polar Accurex Plus®, Polar Electro) was placed so that it was comfortably snug on the participant. The hands-free earpiece was then placed in their right ear.

Session One

The purpose of this session was to familiarize all the participants (irrespective of their past experience with virtual reality simulations) with the driving simulator and driving in a virtual city environment. The participants were instructed to drive as they normally would and observe traffic regulations. Each participant was allowed to drive in a highway environment for 5 minutes. They were encouraged to accelerate, decelerate, turn and change lanes to familiarize themselves with the sensitivity of the accelerator, brake, steering wheel and vehicle controls. At the end of this period, they were required to take a 5-minute break and their symptoms of SAS were assessed. If the participants did not show signs of severe SAS, they were allowed to continue to the city simulation.

The testing began with the participants closing their eyes for two minutes in order to obtain a stable baseline. At the end of this baseline period, participants were asked to open their eyes and start the vehicle by twisting the ignition key. They were then asked to follow the audio and video cues presented by the simulator to drive on a designated path in the virtual city environment. Driving in the urban environment consisted of two trials lasting six minutes each without cell phone intervention, interspersed with a 5-minute washout period. At the end of both driving trials, participants were asked to close their eyes again and rest for 2 minutes.

Session two

The general procedure in this session was similar to session one. Prior to driving, participants filled out a questionnaire to assess driving history and

behavior (Appendix H). Thereafter, the wireless heart rate monitor was placed appropriately around the chest, just below the sternum, to ensure that the measurements were displayed on the digital watch. The participant then sat comfortably in the driver's seat, adjusted the seat setup (if necessary) and secured the seat belt. The hands-free telecommunication device (Plantronics® Explorer 390) was secured in their right ear. This headset was then paired with the research assistant's personal mobile phone (Apple® iPhone 4). The research assistant made a practice phone call to the headset using the hospital's landline telephone to verify communication. Participants were instructed to press the 'accept' button on the headset when they heard a beeping sound emitted by the headset in their ear. When the phone call was answered, the research assistant confirmed with the participant if the volume was comfortable. Upon successful completion of the practice phone call, the components and working of the simulator were explained once again followed by placement of the NIRS sensor as previously described.

Data collection was initiated with a 2-minute baseline with the eyes closed. At the end of this baseline period, participants opened their eyes and started the vehicle by twisting the ignition key. They were then asked to follow the audio and video cues presented by the simulator to drive on a designated path in the city environment. For the first four minutes of city driving, participants drove normally without responding to a phone call from a hands-free device (No Telecommunication; NTC). Previous studies have established that 4-5 minutes is sufficient time to establish a stable baseline in the concentration of O_2Hb (Bhambhani et al., 2006). After four minutes of simulated driving, the participant

received a phone call and was required to answer it (Hands-free Telecommunication; HFTC). A research assistant conversed with the participant for two minutes while the participant continued to drive (sample conversation in Appendix I). Previous studies (Beede & Kass, 2006; Strayer & Johnston, 2001; Strayer & Drews, 2007) and pilot testing indicated that a two-minute phone conversation was sufficient to induce changes in the cerebral hemodynamic responses. This constituted the first trial (HFTC1 in Figure 1). After the first phone call ended, the participant was instructed to slowly bring the vehicle to a complete stop. At this time the driving simulation was paused and a blank screen appeared on all three monitors. The participant was asked to breathe normally and rest with their eyes closed for five minutes. Previous research demonstrated that five minutes of rest was sufficient time for the neural activity to return to the participant's subjective baseline (Huppert et al., 2006). After this washout, a second trial (HFTC2 in Figure 1) was repeated in exactly the same manner as the first trial (Figure 1). Two trials of each condition (NTC and HFTC) were conducted to verify the test-retest reliability of the physiological and behavioral measurements. At the end of both driving trials, participants were asked to close their eyes again and rest for two minutes.

During HFTC, the research assistant began the conversation with the participant and asked questions that were related to current events (e.g., "What do you think of the mayor's decision on raising property taxes?") or visuo-spatial in nature (e.g., "How do you get to the international airport from your house?"). However, declarative questions (e.g., "What are you planning to do this

weekend?") were also incorporated to enhance conversational flow. The questions in the secondary list were different from the first list but similar in nature. The confederate proceeded with the next question only after the participant had an opportunity to answer the previous one. Such a conversation has been shown to be engaging for the driver and competitive for cognitive resources (Beede & Kass, 2006; Consiglio et al., 2003; Hancock et al., 2003; Strayer & Johnston, 2001). None of the questions were emotional in nature and were asked in a tone that was not emotionally charged.

Equipment

Driving simulator

All participants drove in a VS500M Car Simulator marketed by Virage Simulation based in Montreal, Canada (Appendices E and F). The VS500M is a commercially available driving simulator that was designed for the purposes of driver training. The VS500M Car Simulator consists of an open cabin with the driver seat and center console of a GM compact car (Pontiac Sunfire®), a fully functional instrument and warning light cluster, a wide visual display and a three-axis motion/vibration system. The steering wheel is connected to a dynamic electrical load unit allowing for the simulation of the force felt on the steering wheel during the turning maneuvers and feedback from the road surface such as holes, road shoulder or even rolling over a sidewalk. The VS500M is complete with a seat belt, a fully function real-life steering wheel, dynamic and responsive automatic instrument panel (to indicate speed, revolutions per minute, fuel quantity, etc.), turn signal lever, shifter stick, heating controls, accelerator and

brake pedals. The height of the seat and the distance from the steering wheel was adjusted for each participant separately to ensure physical comfort and driving conditions were simulating real driving experience as closely as possible.

VS500M is built around the most advanced simulation software available in the industry using a sophisticated driver environment. It is built with actual car components and provides a realistic feel of all controls (such as accelerator, brake, steering wheel and temperature controls). The VS500M is a fully immersive car simulator with superior quality graphics. 3D sound and high fidelity motion provide an ideal simulated driving experience.

The visual optical system consists of a five-channel PC-based image generator and three 52" LCD displays that provide 180 degrees front view. Two side screens provide additional visual feedback for the left and right blind zones. The high-resolution system generates 1920 x 1080 pixels per front display, 60 Hz refresh frequency, as well as antialiasing and anisotropic filtering for high quality, stable real time rendering. Rear view and side view mirrors are simulated through a window inset within the main screen. VS500M is an interactive car simulator that creates panoramic viewing conditions for the driver. The program allows for investigator control over development of driving scenario, ensuring that all participants encounter the same events and conditions while driving. External and internal validity of VS500M has not been experimentally established.

Near Infrared Spectroscopy

Cerebral hemodynamic measurements were continuously measured using dual-wavelength NIRS equipment (Model Oxymon MK-III, Artinis Medical Systems, The Netherlands). This instrument consists of three units: (1) an optode holder that contains two optodes. The transmitting optode emits two unique wavelengths of light at 760 and 850 nm using a fibre optics cable, and a receiving optode that collects the light waves reflected from the tissue. The distance between these two optodes was 4.5 cm; (2) a recording device that was interfaced with a laptop computer (Dell XPS L502X) for a real-time data collection; and (3) near infrared spectroscopy dedicated software (OxySoft 2.0) that calculated the cerebral hemodynamic values using standard algorithms. The light source penetration depth was 60% of the interoptode distance and was approximately 2.7 cm. This depth was sufficient to reflect photons from cortical tissue (gray matter). A sampling rate of 10 Hz was used. The probe was placed on the left frontalis muscle approximately 3 cm away from the midline of the forehead, just above the left supraorbital ridge. The probe was secured on the forehead with a dark tensor bandage so that background light would not affect the signal. The validity of this optode position against fMRI and PET areas has been demonstrated (Huppert et al., 2006). The test-retest reliability of cerebral hemodynamics responses during functional tasks has also been reported (Sako, Hamaoka, Higuchi, Kurosawa, & Katsumura, 2001) for this probe placement. Pilot testing with this probe placement was completed during other cognitive tasks to ensure that a good NIRS signal, which was sensitive to subtle changes in functional tasks, was obtained.

Heart rate

A wireless heart rate monitoring device (Polar Electro, Finland) was used to record the heart rate continuously during the entire test protocol. The Polar Electro OY chest strap was moistened with lukewarm water and placed directly below the sternum of the participant. Using a Polar Accurex Plus® watch, heart rate was monitored and recorded by the research assistant.

Telecommunication device

A Plantronics Explorer® 390 Bluetooth headset was used for hands-free telecommunication. Prior to the start of the second session, this headset was sanitized with an alcohol swab and placed in the right ear of the participant. The placement and volume were adjusted individually for each participant to ensure comfort and an audible hearing volume.

Data Collection

Behavioral measurements (driving performance):

A research assistant recorded the driving related errors in a pre-set data collection sheet (Appendix J). Driving related errors were operationally defined as:

(1) centreline crossing

(2) road edge excursion

(3) speed exceedance

(4) lane change without signaling

(5) failing to stop at a STOP sign

(6) failing to stop at the red light at a traffic signal

(7) stopping without the presence of a STOP sign or a traffic light

(8) ignoring a STOP sign or traffic light

(9) vehicle collision and collision with other objects.

Cerebral hemodynamics and heart rate measurements

Four NIRS variables were recorded continuously during the two testing sessions: oxy-hemoglobin (O_2Hb), deoxy-hemoglobin (HHb), total hemoglobin (tHb, which is O_2Hb + HHb) and difference in hemoglobin (HbDiff, which is O_2Hb – HHb). NIRS data were collected at 10 Hz sampling rate from the start of the session to the end of the last resting phase. Prior to any statistical analysis, a 5 sample moving average filter (previously used by(Wolf et al., 2002)) was applied to the raw data set on the four NIRS variables using the OxySoft 2.0 software (Artinis Medical systems, Version 2.1.6). This was done to enhance visibility of the cerebral O_2Hb trends and avoid mistaking artifacts caused by the movement in the left frontalis muscle as oxygenation peaks. Each variable was then biased to a zero baseline (Wolf et al., 2002) so that the cerebral O_2Hb and HHb trends could be observed and analyzed. The mean concentration of each NIRS variable was calculated for each condition and trial separately and was reported as *Average Activity*. In addition to calculating the average activity, a delta value was also computed to assess the maximum change from baseline that was observed in the NIRS variables as a result of the HFTC. The difference between the mean activity in the 5-second window before the end of each condition (“end”) and 5-second window before the onset of the condition (“baseline”) was calculated and this difference value was termed, *Delta Activity*. It has been observed in previous

studies (Ikezawa et al., 2009) that the maximal change from baseline occurs towards the end of the experimental condition. Delta was computed in this way to ensure that maximum change from baseline was recorded if it occurred during this period of time. Although NIRS data were collected during both sessions the data from session one were not used for analysis. Only data from session two were analyzed as the HFTC was incorporated only in this session. Heart rate was continuously monitored only during session two and recorded at 1-minute intervals. An average heart rate value was computed for each condition (NTC and HFTC) and trial and was called *Mean Heart Rate*.

Statistical analysis

The following statistical procedures were used to analyze the participant demographics, behavioral, NIRS, and heart rate responses during the two trials for each condition (NTC and HFTC):

1. Descriptive statistics: mean, standard deviation, and coefficient of variation (ratio between standard deviation and mean).
2. Test-retest reliability was determined using intra-class correlation coefficients (ICCs) and Bland-Altman analysis (Bland & Altman, 1986). A Bland-Altman plot was constructed by plotting the difference score of the measurements taken in two trials on the Y-axis against the mean of the two measurements on the X-axis for each subject. The 95% confidence intervals (±1.96 SD) of the difference scores were identified and used to visualize how well the two measurements agreed for the two trials in each session. The smaller the range between these two limits the better the

agreement was judged to be. Individual values that existed outside the limits of agreement were considered as outliers.

3. A two-way repeated-measures ANOVA was conducted to examine differences between the mean values of the measurements. The two factors (and levels) of the ANOVA were Trial (1 and 2) and Condition (NTC and HFTC). The Bonferroni adjustment to correct for Type 1 errors for a p value of 0.05 was applied to determine statistical significance of Trial and Condition.

Statistical analyses were conducted using SPSS 17.0 and MATLAB 2007b (only for Bland-Altman plots). An alpha of 0.05 was used for all statistical tests.

RESULTS

Participant Attrition and Demographics

In all, 30 male participants were tested. Data from four participants were excluded, as they could not participate in session two due to severe symptoms of SAS. Participants' responses on driving history and behavior questionnaire are available in Table 1 and graphical representations of these are depicted in Figures 2 (a-r). The mean ± SD of age of participants was M=27.6 ± 6.00 years and driving experience was M=10.8 ± 7.27 years.

Behavioral Data/Driving Errors

Descriptive Statistics

Mean, standard deviation and coefficient of variation for driving related errors are summarized in Table 2. The different types of driving errors committed during the two trials and conditions are depicted in Figure 3. The coefficient of variation for NTC was 0.60 and 0.47 in trials 1 and 2, respectively. However, the coefficient of variation for HFTC was 0.50 and 0.38 in trials 1 and 2, respectively.

Reliability

The ICCs of driving errors between trials is summarized in Table 3. ICC for driving-related errors in the two trials of NTC was 0.32, which was not statistically significant. However, ICC for driving errors in the two trials of HFTC was 0.59, which was statistically significant at $p<.05$.

Bland-Altman plots between the two trials of NTC and HFTC for mean number of driving errors are depicted in Figure 4 (a) and (b), respectively. All of the data points were within the 95% confidence intervals for the HFTC and there

was only one outlier during the NTC. Overall, these results indicated a moderate to high degree of test-retest reliability of these measurements.

Mean differences

An overview of the results of the two-way ANOVA with repeated measures is provided in Table 4. For the driving related errors, there was no significant interaction between Trial x Condition. There was, however, a significant main effect of Condition ($F(1,25)=91.89$, $p<0.001$) but not Trial. Pairwise comparisons revealed that participants committed significantly more errors ($p<.001$) in HFTC than NTC condition. A visual representation of these mean differences is available in Figure 5.

Near Infrared Spectroscopy data

Typical trends of hemodynamic variables

Examination of acute hemodynamic responses revealed two distinct trends reflecting neuronal activation and neuronal deactivation as illustrated in figures 6(a) and 6(b), respectively. During the two-minute baseline period (figure 1), the combined NIRS variables were stable. During NTC1, a gradual increase was observed in O_2Hb, tHb, and HbDiff accompanied by a stable HHb that did not change significantly from the baseline. In HFTC1, a sudden and steady increase in O_2Hb, tHb, and HbDiff was observed along with a steady decline in HHb. During the 5 minute washout period all the NIRS variables acquired a stable plateau; however, nearing the end of the 5 minutes a slight decline was observed in O_2Hb, tHb, and HbDiff accompanied by a slight incline in HHb, perhaps due to anticipation of the start of the second trial. At the onset of NTC2, the four NIRS

variables once again changed in a manner similar to that observed during NTC1. Similarly, the qualitative changes in the four NIRS variables during HFTC2 were comparable to those observed in HFTC1. For some participants the level of increase in O_2Hb, tHb, and HbDiff during HFTC2 was not as high as in HFTC1; however closer evaluation revealed a general incline. At the end of HFTC2, O_2Hb, tHb, and HbDiff showed an initial decline followed by a systematic increase, whereas HHb demonstrated a gradual decrease. In a few participants, at least once during session 2, a simultaneous increase in both O_2Hb and HHb was observed. This has previously been argued to reflect an artifact or a change in systemic or extracerebral hemodynamics (Obrig & Villringer, 2003).

For twelve participants, a different trend was observed at least once during session 2. This trend was characterized by a decline in O_2Hb and a gradual increase in HHb, opposite to that observed in previous participants. Some previous studies have termed this "neuronal deactivation" (Ekkekakis, 2009; Obrig et al., 2000; Obrig & Villringer, 2003; Villringer & Chance, 1997) and the implications of this will be subsequently discussed.

Descriptive Statistics

Mean, standard deviation and coefficient of variation for mean concentrations and delta values of NIRS variables are summarized in Table 2.

Reliability

The ICCs between the two trials of mean concentrations and delta values of NIRS variables are summarized in Table 3. The ICCs for mean concentration during NTC ranged from 0.43 to 0.76 and for HFTC they ranged from 0.55 to

0.80. The ICCs for delta during NTC ranged from 0.48 to 0.62 and for HFTC they ranged from 0.51 to 0.64. All the ICCs mentioned above were statistically significant at $p<.05$.

Bland-Altman plots between the two trials of NTC and HFTC for mean concentration of the four NIRS variables are depicted in Figure 7 (a-h) and delta values in Figure 8 (a-h). Most of the Bland-Altman plots showed good agreement between trials with one or two outliers in each of the plots with the exception of HHb delta of the two trials of NTC. Some of the data points are on the limit of confidence interval limit; however, using a conservative approach, they have been indicated as outliers. Overall, these NIRS variables show good agreement between the two trials for both methods of evaluation.

Comparisons between HFTC and NTC

The significant interactions and main effects of Trial and Condition for mean concentration and delta values of NIRS variables are summarized in Table 4.

For mean concentration of O_2Hb, results of this two-factor repeated-measures ANOVA indicated that the interaction between Condition x Trial was significant, $F(1,25)=18.64$, $p<.001$. Post-hoc paired sample t-test revealed that mean concentration of O_2Hb in HFTC was significantly greater than NTC in trial 1 ($p<.01$). For mean concentration of HHb, the interaction between Condition x Trial was significant, $F(1,25)=6.57$, $p<.05$. A significant main effect of Condition was also observed, $F(1,25)=13.82$, $p<.01$. Post-hoc paired sample t-test revealed that, mean concentration of HHb in NTC was greater than HFTC in both trials

($p<.01$ and $p<.05$ in trials 1 and 2, respectively). For mean concentration of tHb, the interaction between Condition x Trial was significant, $F(1,25)=12.79$, $p<.01$. Post-hoc paired sample t-test resulted in no significant differences between trials and conditions. For mean concentration of HbDiff, the interaction between Condition x Trial was significant, $F(1,25)=19.19$, $p<.001$. A significant main effect of Condition was also observed, $F(1,25)=9.98$, $p<.01$. Post-hoc paired sample t-test revealed that mean concentration of HbDiff in HFTC was greater than NTC in trial 1 ($p<.001$) and greater in HFTC1 than HFTC2 ($p<.05$).

For delta values of O_2Hb, results of the two-factor repeated-measures ANOVA indicated that the interaction between Condition x Trial was significant, $F(1,25)=4.75$, $p<.05$. Significant main effects of Condition [$F(1,25)=18.21$, $p<.001$] and Trial [$F(1,25)=10.37$, $p<.01$] were also observed. Post-hoc paired sample t-tests revealed that delta O_2Hb in HFTC was greater than NTC in trial 1 ($p<.01$) and trial 2 ($p<.001$). For delta values of HHb, the interaction between Condition x Trial was not significant. However, significant main effect of Condition [$F(1,25)=4.45$, $p<.05$] and Trial [$F(1,25)=12.08$, $p<.001$] was observed. Pairwise comparisons revealed that delta HHb in NTC was greater than HFTC ($p<.05$). For delta values of tHb, the interaction between Condition x Trial was not significant. However, the main effect of Condition was significant, $F(1,25)=11.09$, $p<.01$. Pairwise comparisons revealed that delta tHb in HFTC was greater than NTC ($p<.01$). For delta values of HbDiff, the interaction between Condition x Trial was not significant. However, significant main effect of Condition [$F(1,25)=21.59$, $p<.001$] and Trial [$F(1,25)=16.29$, $p<.001$] was

observed. Pairwise comparisons revealed that delta HbDiff in HFTC was greater than NFTC ($p<.001$) and trial 1 was greater than trial 2 ($p<.001$). A visual representation of these mean differences is available in Figure 9 for mean concentration and Figure 10 for delta concentration.

Correlation between number of errors and NIRS variables

Pearson Product-Moment Correlation Coefficients between number of driving errors and NIRS variables during NTC and HFTC are summarized in Table 5. Most of these correlations were weakly positive; however, none were significant. The Pearson correlation between number of errors and mean concentration of NIRS variables was between -0.24 and 0.33; and number of errors and delta between -0.20 and 0.24.

Heart rate data

Descriptive Statistics

Mean, standard deviation and coefficient of variation for average heart rate activity are summarized in Table 2.

Reliability

The ICCs of mean heart rate between the two trials are summarized in Table 3. The ICCs for mean heart rate during NTC was 0.94 and for HFTC was 0.96. Both of these ICCs were highly significant.

Bland-Altman plots between the two trials of NTC and HFTC for mean heart rate are depicted in Figure 11 (a-b). These Bland-Altman plots showed good agreement between trials with one outlier between the two trials of NTC and two outliers between the two trials of HFTC. This was true for mean heart rate during

two trials of both NTC and HFTC. Overall, heart rate data showed good agreement between the two trials.

Mean differences

The significant interaction and main effects of Trial and Condition are summarized in Table 4. Results of this two-factor repeated-measures ANOVA indicated that the interaction between Condition x Trial was not significant. There was, however, a significant main effect of Condition [($F(1,25)=63.45$, $p<0.001$)] and Trial [$F(1,25)=9.05$,$p<.01$]. Pairwise comparisons revealed that heart rate was significantly higher in HFTC than NTC ($p<.001$) and in trial 1 than trial 2 ($p<.01$). A visual representation of these mean differences is available in Figure 12.

DISCUSSION

Demographic Data and Questionnaire Results

The results of the present study are based on a sample of 26 healthy male adults within the age range of 18 to 50 years. Therefore, the generalizability of the findings is restricted to this age range and the relatively small sample size. The coefficient of variation (ratio between standard deviation and mean) of NIRS variables is very high, but most studies typically have a sample size of 10-20 participants. The current sample size of 26 participants was deemed adequate considering the scope, time, and resources available. Typically a participant had around 11 years of driving experience, in which they had received up to 1-3 traffic tickets in the last two years and 1-3 tickets during their driving careers. They were involved in no accidents in the past two years but half of the participants had been in an accident (fault undetermined) in their driving career. Many were familiar with virtual reality application (such as simulators or video games) and did not experience dizziness or disorientation while engaging in such applications. As was the requirement of proceeding to the experimental session, all participants reported that they did not frequently experience motion sickness. Four participants dropped out due to SAS, which is around 13.33% of the total sample. The proportion of participants that dropped out due to SAS is comparable to other studies (Allen, Park, Fiorentino, Rosenthal, & Cook, 2006, October; Freund & Green, 2006; Lee et al., 2003). All but one reported listening to music (via radio or personal devices) while driving. A majority admitted to using phones while driving on the road and not using hands-free devices. Many had no prior

experience with hands-free headset technology and typically did not own cars that were pre-equipped with hands-free capability. Amongst those who admitted using phones while driving, all but one said that subjectively they felt distracted by phone use and a majority reported that they were only somewhat distracted. These characteristics are fairly common in the male driving population of North America and draw parallels from other studies (Beede & Kass, 2006; Strayer et al., 2006).

Comparing the responses of driving behavior to driving errors and cerebral activity, qualitatively it seems that drivers in this study over-estimated their ability and did experience significant distraction while driving. In our study, participants attended two sessions. The goal of the first session was only to familiarize them with the driving simulation of the urban environment and to abate the signs of SAS. In the practice session, participants first drove for five minutes in a highway simulation and then for about 20 minutes in urban simulation. Urban simulations have previously been reported to induce more ocular discomfort than rural and highway simulations (Mourant & Thattacherry, 2000). Our simulations corroborated this finding, as participants complained of symptoms of SAS more often in the urban environment. Only participants who had overcome the more severe symptoms continued on to the experimental session. During the experimental session, almost all participants complained of minor ocular discomfort, which resolved itself in the first minute of driving. Since more women than men exhibit signs of SAS (Classen, Bewernitz, & Shechtman, 2011), this study was limited to male drivers only.

Behavioral Data/Driving Errors

The speeding infraction was not quantified, i.e., frequency of a participant exceeding speed limit was accounted for, but not quantified by how much. On average, in trial 1, drivers committed 1.96 errors when driving without telecommunication. This increased to 3.42 errors when driving and conversing via hands-free device. This trend was repeated in trial 2, where drivers committed 2.30 errors without but 3.96 errors with hands-free use while driving. Overall, these findings suggested that HFTC significantly increased the number of driving errors in a simulated environment, supporting the concept of "distracted driving." The most common errors were centerline crossings and speed exceedances. These two errors were roughly half the total errors committed in each condition and trial. The increased frequency of these two types of errors can be explained. Since the experimental session was only the second time that participants were driving in the simulation, it is understandably difficult to maintain the proper position of the car without crossing the centerline a few times. Drivers crossed the centerline more frequently when they were talking on the hands-free device than when they were not. This was observed in both trials. Additionally, the posted speed limit in the simulated urban environment was 50 KPH. Since most participants in this study were urban drivers they may be accustomed to the more common 60 KPH on city roads. This difference in expectation may have resulted in the higher number of speed exceedance errors. Interestingly, the number of errors in trial 2 was higher than in trial 1 which could be an indication of fatigue. However, it should be noted that the variety of errors was significantly reduced in trial 2,

which could be indicative of better control on the vehicle. For instance, in trial 1, drivers made more navigational and vehicular control errors leading to missed directions, road edge excursion, illegally crossing on a red traffic light and collisions. Errors in lane control, crossing the centerline, and missing directions have been reported previously by Drews et al. (2008). The urban simulation used in this study did not include pedestrian traffic; however, it can be expected that if pedestrian traffic were present, the number and severity of driving errors would be higher. Also, only speed exceedance was considered an error but not driving at extremely low speeds. This, however, was not an issue in the present study as most of the participants drove around or over the posted speed limit.

Reliability

Intraclass correlation demonstrated that drivers made consistently more errors during HFTC than NTC. This can be indicative of the variability in maneuvering and vehicle control when driving only but consistently making errors when distracted by hands-free communication. The results of the Bland-Altman analysis also demonstrated this variability, as there were two participants who were outliers in NTC, but no outlier during HFTC.

Cerebral hemodynamics

In this study, only the effect of hands-free telecommunication devices was studied. One of the primary reasons for this was a previous NIRS study (Curcio et al., 2009) which reported that electromagnetic radiation emitted from hand-held mobile devices artificially induced an increase in HHb concentration in the frontal cortex. This increase in HHb was then linked with increased oxygen consumption

in the frontal cortex. Hands-free devices have not been reported to have this effect and therefore were deemed more suitable for this study.

In all four NIRS variables, a low frequency oscillation was observed. This slow wave likely corresponds to Mayer wave oscillations, which are waves in arterial blood pressure brought about by oscillations in baroreceptors and chemoreceptor reflex control systems (Elghozi, Laude, & Girard, 1991; Julien, 2006). NIRS is able to reliably detect these slow waves that exist between 0.01-0.04 per second frequency (Obrig et al., 2000). These slow-wave oscillations are particularly evident in O_2Hb tracing(Wolf et al., 2007). The high frequency oscillations that form a part of the slow waves likely correspond to the cardiac cycle (Strangman et al., 2002). The high frequency oscillations are due to the arterial pulsations caused by heartbeats (Wolf et al., 2007). The 5-sample moving average was applied to this dataset in order to minimize the noise introduced by these high frequency oscillations and to eliminate sudden changes caused by forehead muscle movement artifact.

The coefficient of variation of mean concentration of all four NIRS variables (O_2Hb, HHb, tHb, HbDiff) and delta were very high (Table 2), indicating a heterogeneous dataset. This suggests a high degree of variation in the NIRS variables, which is expected due to a low signal-to-noise ratio. The high variability in NIRS variables has been observed in many previous studies (Li et al., 2009). The heterogeneity of response pattern could mean that oxygenation changes in the prefrontal cortex reflect a highly individualized pattern of neuronal activity (Ekkekakis, 2009).

The current consensus amongst fNIRS researchers is that an increase in O_2Hb concentration with a concomitant decrease in HHb is a valid index of neuronal activation of the cerebral cortex (Boas et al., 2003; Obrig et al., 2000; Obrig & Villringer, 2003; Villringer & Dirnagl, 1995; Wolf et al., 2002). The decrease in HHb occurs because the blood rich in O_2Hb (i.e., arterial blood) washes the HHb out of the capillary bed. According to the hypothesis of this study, cortical activation would increase during simulated driving when compared to rest and it would increase further when the participants were answering a mobile phone call simultaneously. This increase in neuronal activation in the prefrontal cortex is not surprising, as this brain region has been implicated in planning, complex cognitive behavior, and decision-making(Miller & Cohen, 2001). This trend was observed in most of our participants as indicated in Figure 6 (a). In a minority of participants, however, this trend reversed, i.e., HHb increased as O_2Hb decreased. This trend has been argued to be an index of either functional deactivation (Ekkekakis, 2009) or an increase in oxygen consumption (Wolf et al., 2002).

A previous study by Matsuda and Hiraki (2004) reported a sustained decrease of O_2Hb in the dorsolateral prefrontal cortex during four kinds of video games including one game, which involved driving in an urban environment. This group only reported O_2Hb trends arguing that it is the best indicator of regional cerebral blood flow and therefore neuronal activity. They did not report an increase in HHb. Li et al. (2009) aimed to study the development of mental fatigue during three hours of consecutive simulated driving using NIRS. They

reported an increase in O_2Hb near the start of the driving trial (the first 40 minutes), a plateau between 40 minutes to two hours, and a gradual decline near the end (after two hours) of driving. A similar trend for tHb was observed. They elaborated that perhaps the decrease in O_2Hb indicated reduced oxygen delivery to the brain. Interestingly, however, they also reported an inverse trend for HHb, i.e., a decline in the first forty minutes, a plateau between forty minutes to three hours and a gradual increase after three hours of driving. They reasoned that this could have implications for fatigue development in the brain, that after prolonged periods of driving, the direction of O_2Hb and HHb reverse. A possible explanation for the reversed trend in the present study could be development of fatigue. It is likely a contributing factor but not the sole explanation. This is because fatigue development in Li et al. (2009) paradigm took hours before manifesting itself, whereas the present study consisted of two driving trials lasting only six minutes each. Another study utilized a motor imagery paradigm elaborated on this NIRS trend (Holper, Shalóm, Wolf, & Sigman, 2011). Participants in this study either drew or imagined drawing a simple or complex figure while NIRS data were collected from the motor cortex. The trend in the NIRS variables clearly indicated a decline in O_2Hb and a concomitant increase in HHb during imagination of complex drawing. In addition to this, they computed delta values similar to the present study and reported a negative ΔO_2Hb and a positive ΔHHb. They proposed three competing hypotheses to try and explain the "neuronal deactivation" trend (1) NIRS is very noisy, which makes the signal weak and this could mean that the sign of some measurements may be reversed, (2) this trend

may reflect anatomical variability, (3) or it may indicate subject-to-subject variability. Of these three hypotheses, they reasoned that inter-subject variability was the most feasible. In the present study, the inversed trend of O_2Hb decline and HHb incline, could be due to the heterogeneity of the NIRS dataset owing to highly individualized responses.

Reliability

Even with large coefficients of variation, the mean concentration and delta values for all four NIRS variables demonstrated a high degree of reliability between the two driving trials of NTC and HFTC. This was evident by high Intraclass Correlation Coefficients and high degree of agreement in the Bland-Altman Plots between the two trials of each condition. This implies that evaluation of these NIRS responses could be confidently used to evaluate the effects of such intervention on cerebral activation.

Mean Differences

Results from the 2 x 2 repeated-measures ANOVA suggest that there was a significant difference between NTC and HFTC, but not between the two trials of the same condition. O_2Hb, which is considered an indication of neuronal requirement for oxygenation, showed a marked increase when drivers were conversing on the hands-free device as compared to when they were not. This trend was observed for mean concentration only in trial 1. For maximum change from baseline (delta), a different and interesting trend emerged. During NTC, the maximum change from baseline was negative, indicating that less O_2Hb was necessary as compared to baseline. This could perhaps indicate a habituation

effect or that the frontal cortices in the brain were not very heavily taxed during this time. The maximum change from baseline (significantly higher delta) occurred when drivers were required to telecommunicate via hands-free device. This could indicate that the need for O_2Hb increased in the frontal cortices when the driver faced additional attentional load. This trend occurred in both trials for average activity and maximal change from baseline. The difference in O_2Hb activity between NTC and HFTC was significant for both trials.

An opposite trend was noticeable for HHb. The mean concentration of HHb was lower than the baseline in NTC (both trials). This mean concentration decreased further as compared to the baseline when the driver was conversing on hands-free device simultaneously (both trials). This trend was seen for the delta values as well.

Trends of tHb and HbDiff were the same as those for O_2Hb. This is intuitive as O_2Hb is the major component of hemoglobin and tHb is derived from the addition of O_2Hb and HHb. An increase in tHb is indicative of an increase in total blood flow to the cerebral cortex when driving and using hands-free device (Villringer & Chance, 1997). This was indirectly supported by the significant increase in heart rate during HFTC.

Correlation between number of errors and NIRS variables

A recent NIRS study Liu, Saito, and Oi (2012) used a driving video game and counted errors, but did not examine the relationships between these variables. In the present study, Pearson Product-Moment Correlation coefficients between number of driving errors and average concentration of NIRS variables were

within -0.24 and 0.33; and number of errors and delta between -0.20 and 0.24. None of these coefficients were significant as shown in Table 5. This suggested that the increase in the mean number of driving errors during HFTC was not associated with the increased level of neuronal activation measured non-invasively by NIRS. This lack of correlation could be due to the difference in variability in the two datasets (refer to Table 2 for coefficient of variation values). The NIRS variables were highly variable when compared to driving related errors, which were more homogenous in nature.

Comparison with previous driving studies using NIRS

Harada et al. (2007) were interested in noting changes in NIRS trends between young and experienced drivers during 7 km of on-the-road driving. Using the conventional definition of neuronal activation, this group reported that there were no significant differences in neuronal activation between young and experienced drivers at rest. However, during the driving trials, the younger drivers had significantly higher activation than their older counterparts. This result was not replicated in the present study. It was qualitatively observed that age and number of years of driving experience had no overt relationship with proportion of participants that showed neuronal activation versus deactivation.

Liu et al. (2012), studied the difference in NIRS trends based on differences in cognitive load during simulated driving. They manipulated route-stability (fixed or changing) and memory-load (driving with or without a route map) in a simulated video game which involved driving a taxicab in an urban environment. They defined fixed-route with a map as intrinsically driven

cognitive load and changing routes without a map as extrinsically driven cognitive load. This group, like Matsuda and Hiraki (2004), reported changes in O_2Hb only, arguing that O_2Hb was most sensitive to regional cerebral blood flow and most indicative of neuronal activation. They reported that intrinsically- and extrinsically-driven cognitive loads led to different neuronal activation patterns in the bilateral prefrontal cortex, with extrinsically driven cognitive load eliciting a greater change in O_2Hb. The present study only used a fixed route with an audio-visual route guidance system and most participants showed similar increase in O_2Hb as that reported by Liu et al. (2012).

Heart rate

Descriptive Statistics and Mean Differences

An increase in heart rate is indicative of increased physiological stress that may accompany a strenuous task. In our study, average heart rate in trial 1 of NTC was 70.8 bpm, which increased to 74.9 bpm during HFTC. This trend was repeated in trial 2, where mean heart rate for NTC was 69.5 bpm and 73.3 bpm during HFTC. Coefficient of variation of average heart rate was quite low (between 12% and 14%). Heart rate increased significantly during HFTC (in both trials) and was higher in trial 1 than trial 2. This increase in heart rate during HFTC and trial 1 could be indicative of increased cardiovascular stress, resulting from the muscular component involved in simulated driving (Healey & Picard, 2005) and/or a response to the novelty of driving simulation. However, the subsequent decrease in trial 2 could be indicative of habituation. The increase in

heart rate while driving and simultaneously engaging in a phone call has been reported previously (Brookhuis et al., 1991; Collet et al., 2009).

Limitations of the present study

The present study only compared the behavioral and physiological effects of driving during a hands-free cell phone conversation. Though hands-free phone are slowly becoming the standard legal way of telecommunication while driving, a comparison between hand-held and hands-free phone would have made this dataset richer and more generalizable. It can, however, be reasonably assumed that if the goal is to study only cognitive interference and increased mental load caused due to conversation, use of a hands-free phone is far more suitable. Additionally, as mentioned before, use of hand-held phones induces an artificial increase in the HHb concentration, which makes the use of hands-free phones the only viable option in an NIRS study (Curcio et al., 2009).

Another limitation of this study was the participation of only male drivers. Previous studies have shown that females are more susceptible to the SAS and its more severe symptoms (Classen et al., 2011). Therefore, the choice to include only male participants was made from the health viewpoint of the potential female participants. The selection of male participants limits the generalizability of the results; however, considering that driving skills of women are comparable to that of men, similar results can be anticipated if this study was repeated in the female population.

The use of a driving simulator, as opposed to on-the-road testing, can also be considered as a minor limitation. However, keeping the cost of research in

mind along with the safety of the participants and the general public, driving simulation was the most suitable alternative to on-the-road testing. Also, the nature of the simulator used in the present study was such that it simulated real driving very closely as it provided the appropriate physical and proprioceptive feedback to the driver. Moreover, driving simulation is routinely used as a screening method by various organizations for evaluating driving capability. The brief duration of driving periods (two trials of six minutes each) is also a limitation of the study design. The duration of NTC (four minutes) was chosen to acquire a stable baseline in the NIRS variables and to ensure that the participant did not experience fatigue. The duration of HFTC was considered suitable as previous studies (Beede & Kass, 2006; Strayer & Johnston, 2001; Strayer & Drews, 2007), have demonstrated that two minutes is adequate to simulate a realistic conversation while driving.

A final limitation of the present study was that the assessor that counted driving-related errors was not blinded to the conditions (NTC or HFTC). This could potentially bias the results; however, the assessor was objective and systematic in his decision of assessing errors and only counted a driving infraction where the error was conspicuous, such as, hitting a curbside or a speedometer rating of over 50 KPH (for speed exceedance). When deciding whether an event really was an error, the participant was granted the benefit of doubt. This concern can be eliminated in future studies by using a driving simulator that has the inherent capacity to monitor and record driving-related errors.

CONCLUSIONS

The goal of the present study was to evaluate the behavioral and cerebral hemodynamic effects of hands-free telecommunication during simulated driving. The behavioral effects were monitored by the number of driving-related errors committed and the cerebral hemodynamic effects were measured non-invasively using NIRS at the prefrontal lobe. Though the NIRS variables and driving errors were not correlated, possibly due to the heterogeneity of NIRS data, the results indicated that telecommunication while driving caused an increase in neuronal activation (based on the proportion of participants with an increase in O_2Hb and decrease in HHb), most likely due to increased cognitive load. This increased load on the driver's attentional resources causes distraction, which leads to an increased number of errors while driving, many of which have serious consequences. This enhanced cognitive load can be reliably measured by near infrared spectroscopy and the overall physiological stress by examining the heart rate data.

Current laws concerning distracted driving limit the use of hand-held devices whereas hands-free phones are considered more user friendly. Given that the physical limitation imposed by a hand-held phones are absent in the hands-free alternative, it allows the driver to keep both hands on the steering wheel and obtain a better physical control over the vehicle. From this viewpoint, hands-free phones are the safer alternative. However, they too cause cognitive distraction and compete for valuable attentional resources of the driver. In the present study it should be noted that although number of driving-related errors did not correlate

with cerebral hemodynamic variables; there was a significant increase in the number of errors, neuronal activation, and heart rate.

Table 1: Participant questionnaire data

Question	Subject number	Age	Year in which driving license (Class 5) was obtained	Number of years of driving experience	Number of traffic violation tickets in the past 24 months	Number of traffic violation tickets so far	Number of traffic accidents in the past 24 months	Number of traffic accidents so far	Are you familiar with driving simulators?	Are you familiar with computer/ video games?
Possible Responses		(Years)	(Year)	(Number)	0, 1-3, 4-6, 7-9, 10+	0, 1-3, 4-6, 7-9, 10+	0, 1-3, 4-6, 7+	0, 1-3, 4-6, 7+	Yes / No	Yes / No
Response	**1**	19	2009	3	0	0	0	0	Yes	Yes
	2	24	2003	8	0	0	0	0	Yes	Yes
	3	35	1992	19	0	1-3	0	1-3	Yes	No
	4	26	2001	10	0	0	0	1-3	Yes	Yes
	5	27	2003	8	1-3	7-9	0	1-3	Yes	Yes
	6	30	1997	14	1-3	1-3	0	0	No	No
	7	44	1983	28	0	1-3	0	0	Yes	Yes
	8	31	1995	16	0	1-3	0	1-3	Yes	Yes
	9	25	2002	9	1-3	1-3	0	0	Yes	Yes
	10	19	2008	5	0	0	0	0	Yes	Yes
	11	29	2002	9	1-3	1-3	0	0	Yes	Yes
	12	24	2005	6	0	0	0	0	Yes	Yes
	13	25	2002	10	1-3	1-3	0	1-3	Yes	Yes
	14	23	2007	4	0	0	0	0	Yes	Yes
	15	25	2003	9	1-3	1-3	1-3	1-3	Yes	Yes
	16	27	2005	6	1-3	1-3	0	1-3	Yes	Yes
	17	26	2003	9	0	1-3	1-3	1-3	Yes	Yes
	18	29	1996	15	0	1-3	0	0	Yes	Yes
	19	29	2000	11	1-3	10+	0	1-3	Yes	Yes
	20	33	2004	14	0	1-3	0	0	Yes	Yes
	21	39	1988	23	0	1-3	0	1-3	Yes	Yes
	22	36	1998	13	0	0	0	0	No	Yes
	23	22	2005	6	1-3	1-3	1-3	1-3	Yes	Yes
	24	24	2009	2	1-3	1-3	1-3	1-3	Yes	Yes
	25	20	2009	2	1-3	1-3	1-3	1-3	Yes	Yes
	26	26	2002	10	1-3	4-6	0	0	No	Yes

Table 1 contd.

Question	Subject number	Answer phone calls while driving	Use hands-free while driving	Bluetooth ® headset?	Car audio system Bluetooth ® enabled	Hand-held use while driving	Listen to music while driving?	Answering phone calls distracts you?	If yes, how much?	Dizziness during simulation?	Often motion sick?
Possible Responses	(number)	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	Yes / No	(Options below)	Yes / No	Yes / No
Response	**1**	Yes	No	No	No	Yes	Yes	Yes	Not that much	No	No
	2	Yes	Yes	Yes	No	Yes	Yes	Yes	Somewhat	No	No
	3	No	No	No	No	No	Yes	Yes	A lot	No	No
	4	No	No	No	No	No	Yes	Yes	A lot	No	No
	5	Yes	Yes	No	Yes	No	Yes	Yes	Not that much	No	No
	6	Yes	No	No	No	Yes	Yes	Yes	Somewhat	Yes	No
	7	No	No	No	No	No	Yes	Yes	A lot	No	No
	8	No	No	No	No	No	Yes	Yes	Somewhat	No	No
	9	Yes	No	No	No	Yes	Yes	No	Often	No	No
	10	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No
	11	Yes	Yes	Yes	No	Yes	Yes	Yes	Somewhat	No	No
	12	Yes	Yes	No	Yes	No	Yes	No	Often	No	No
	13	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No
	14	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No
	15	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No
	16	Yes	No	No	No	No	Yes	Yes	Somewhat	No	No
	17	Yes	No	No	Yes	Yes	Yes	Yes	Somewhat	Yes	No
	18	Yes	Yes	No	Yes	No	Yes	Yes	Not that much	No	No
	19	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No
	20	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Always	No	No
	21	No	No	No	No	No	Yes	Yes	Often	No	No
	22	No	No	No	No	No	No	Yes	Often	No	No
	23	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No
	24	Yes	Yes	Yes	No	Yes	Yes	Yes	Not that much	No	No
	25	Yes	Yes	No	Yes	Yes	Yes	Yes	Somewhat	No	No
	26	Yes	No	No	No	Yes	Yes	Yes	Somewhat	No	No

Table 2: Summary of Descriptive Statistics (N=26)

	Results Mean (Std. Dev.) Coefficient of Variation			
Measures	**NTC1**	**HFTC1**	**NTC2**	**HFTC2**
Driving Related Errors (in numbers)	1.96* (1.18) 0.60	3.42* (1.72) 0.50	2.31+ (1.09) 0.47	3.96+ (1.51) 0.38
NIRS-Mean Concentration (in µmol)				
O_2Hb	0.43* (0.85) 1.99	1.14* (1.04) 0.92	0.71 (1.64) 2.32	0.64 (1.67) 2.63
HHb	-0.10* (0.61) -5.82	-0.48* (0.70) -1.45	-0.15+ (0.60) -4.00	-0.35+ (0.72) -2.09
tHb	0.32 (1.12) 3.46	0.66 (1.09) 1.67	0.56 (1.84) 3.29	0.29 (1.85) 6.37
HbDiff	0.53* (0.97) 1.81	1.62* (1.40) 0.86	0.86 (1.64) 1.91	0.98 (1.80) 1.83
NIRS-Delta (in µmol)				
O_2Hb	-0.74* (1.58) -2.16	0.83* (1.54) 1.85	-1.74+ (1.57) -0.90	0.58+ (1.27) 2.19
HHb	-0.10 (0.65) -6.07	-0.48 (0.87) -1.81	0.17 (0.48) 2.87	-0.18 (0.60) -3.32
tHb	-0.84* (1.78) -2.12	0.35* (1.51) 4.28	-1.58+ (1.68) -1.06	0.41+ (1.38) 3.38
HbDiff	-0.63* (1.64) -2.61	1.31* (1.99) 1.52	-1.91+ (1.60) -0.84	0.75+ (1.42) 1.88
Mean Heart Rate	70.76* (10.05) 0.14	74.91* (9.27) 0.12	69.45+ (9.81) 0.14	73.29+ (10.35) 0.14

* Statistically significant difference between NTC 1 and HFTC 1 at $p<.05$

\+ Statistically significant difference between NTC 2 and HFTC 2 at $p<.05$

Table 3: Summary of Intraclass correlation

	Intraclass Correlation Coefficients	
	between NTC1 and NTC2	between HFTC1 and HFTC2
Driving Related Errors	.32	.59*
NIRS-Mean Concentration		
O_2Hb	.54*	.55*
HHb	.76*	.80*
tHb	.69*	.65*
HbDiff	.43*	.56*
NIRS-Delta		
O_2Hb	.60*	.60*
HHb	.48*	.44*
tHb	.56*	.64*
HbDiff	.62*	.51*
Mean Heart Rate	.94*	.96*

* Statistically significant at $p<.05$

Table 4: Summary of 2 x 2 Repeated Measures ANOVA

	Significant			Post-hoc t-test			
				Trial 1 NTC / HFTC	Trial 2 NTC / HFTC	NTC Trials 1 / 2	HFTC Trials 1 / 2
Driving Related Errors	Main Effect Trial	Main Effect Condition	Interaction Trial X Condition				
		✓		p<.001	p<.001	n.s.	n.s.
NIRS Mean concentration	Main Effect Trial	Main Effect Condition	Interaction Trial X Condition				
O_2Hb			✓	p<.01	n.s.	n.s.	n.s.
HHb		✓	✓	p<.001	p<.05	n.s.	n.s.
tHb			✓	n.s.	n.s.	n.s.	n.s.
HbDiff		✓	✓	p<.001	n.s.	n.s.	p<.05
NIRS Delta (End-Baseline)	Main Effect Trial	Main Effect Condition	Interaction Trial X Condition				
O_2Hb	✓	✓	✓	p<.01	p<.001	p<.001	n.s.
HHb	✓	✓		n.s.	n.s.	n.s.	n.s.
tHb		✓		p<.05	p<.001	n.s.	n.s.
HbDiff	✓	✓		p<.01	p<.001	n.s.	n.s.
Mean Heart Rate	Main Effect Trial	Main Effect Condition	Interaction Trial X Condition				
Average HR	✓	✓	✓	p<.001	p<.001	n.s.	n.s.

Table 5: Summary of correlation between driving errors and NIRS variables

Pearson Product-Moment Correlation Coefficients

	Driving related errors during…			
	NTC1	HFTC1	NTC2	HFTC2
NIRS-Mean Concentration				
O_2Hb	-0.18	-0.21	0.08	-0.04
HHb	-0.18	-0.02	0.33	0.31
tHb	-0.24	-0.21	0.18	0.08
HbDiff	-0.05	-0.14	-0.04	-0.16
NIRS-Delta				
O_2Hb	-0.11	-0.11	0.03	0.03
HHb	0.15	0.24	0.24	0.19
tHb	-0.05	0.02	0.09	0.12
HbDiff	-0.16	-0.20	-0.05	-0.05

None of the correlations were significant at the .05 level.

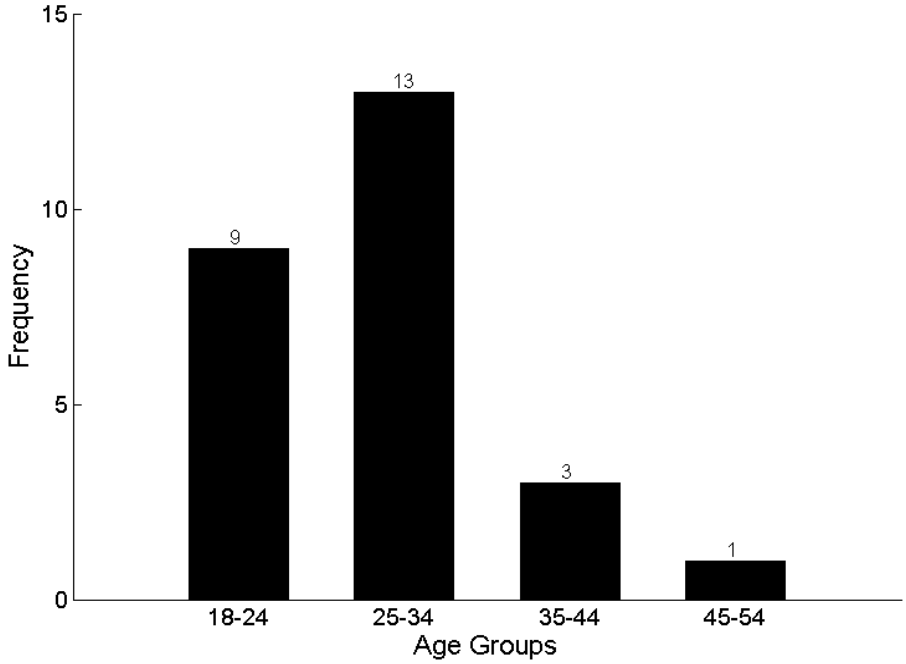


Figure 2 (a): Distribution of age participants

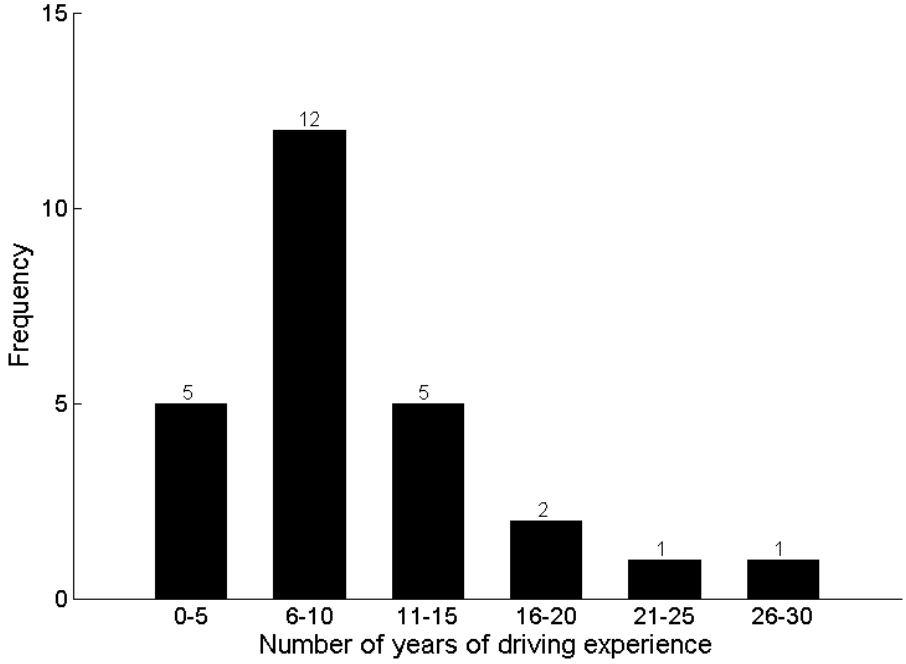


Figure 2 (b): Distribution of number of years of driving experience

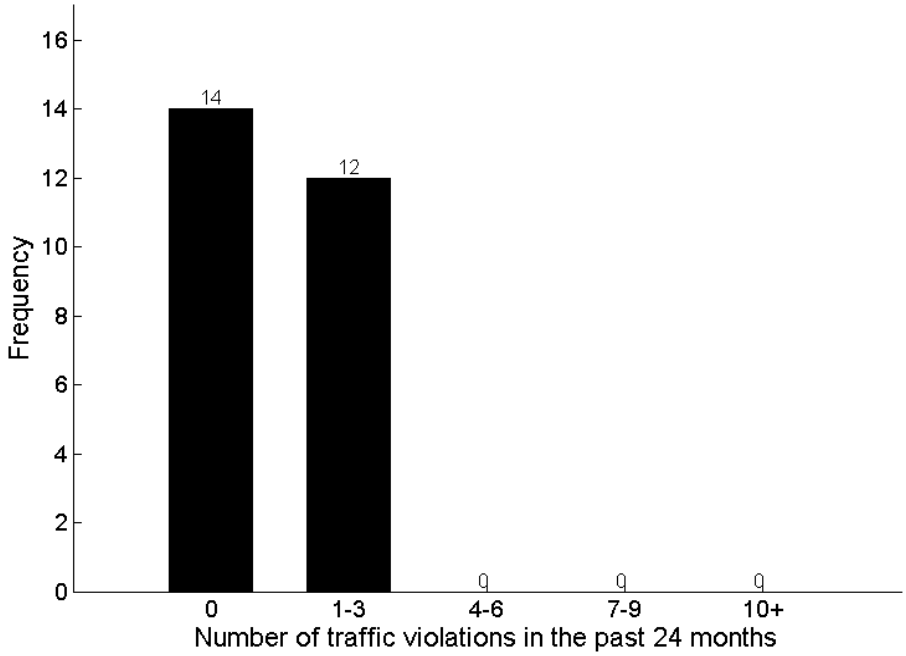


Figure 2 (c): Distribution of number of traffic violation tickets in the past 24 months

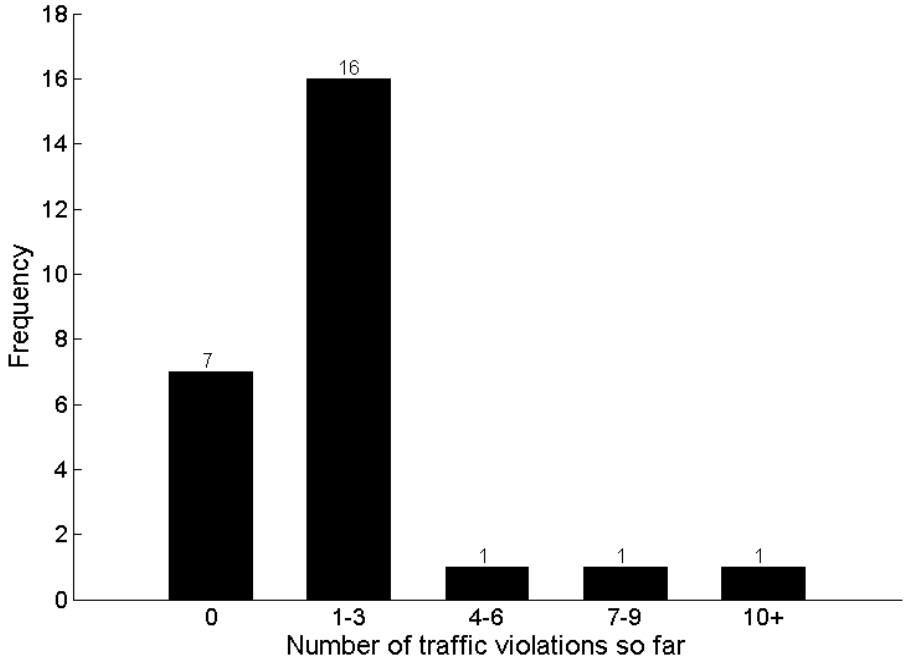


Figure 2 (d): Distribution of number of traffic violation tickets so far

Figure 2 (e): Number of traffic accidents in the past 24 months

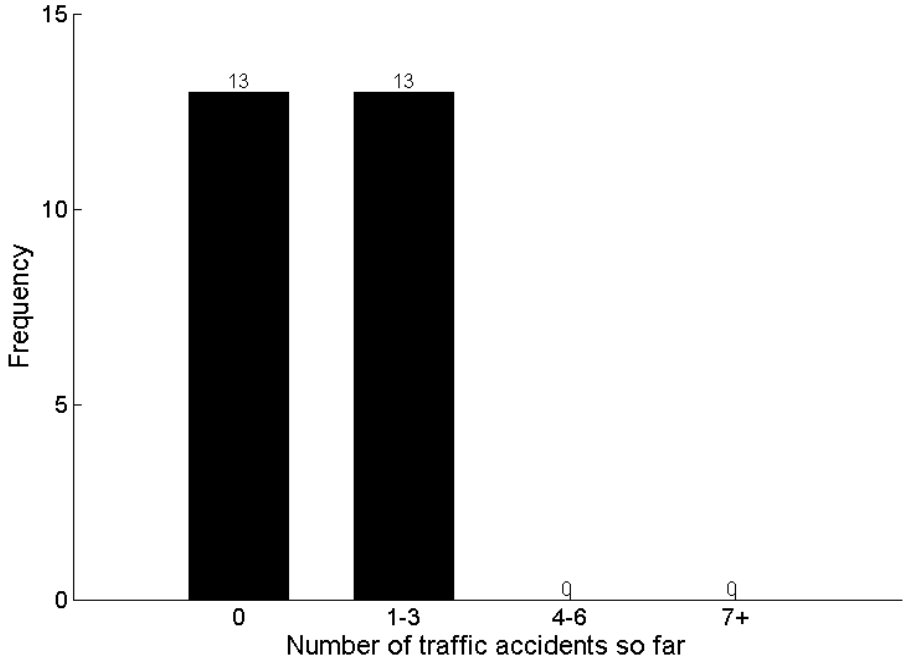


Figure 2 (f): Distribution of number of traffic accidents so far

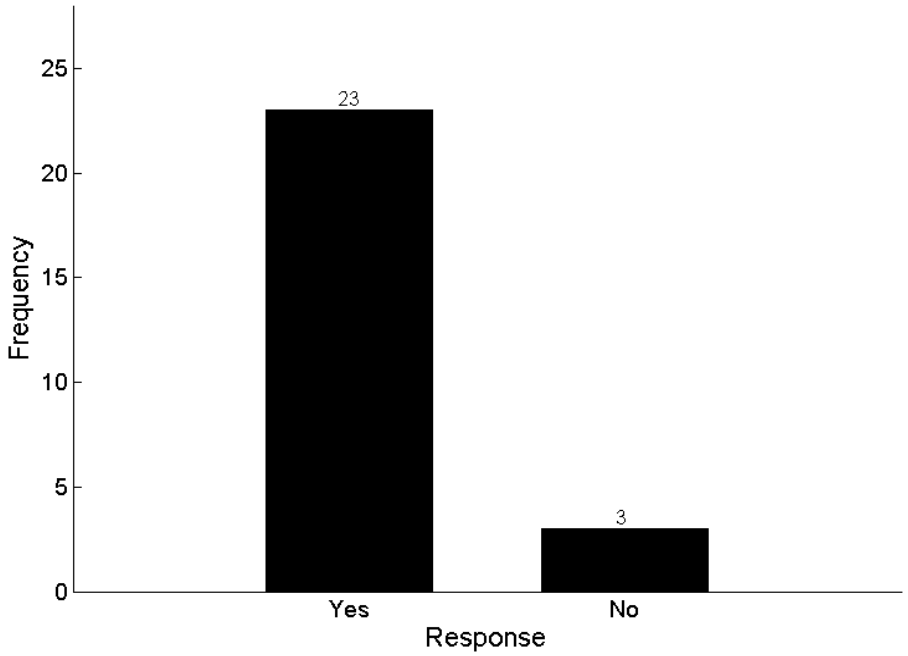


Figure 2 (g): Participant responses to "Are you familiar with driving simulators?"

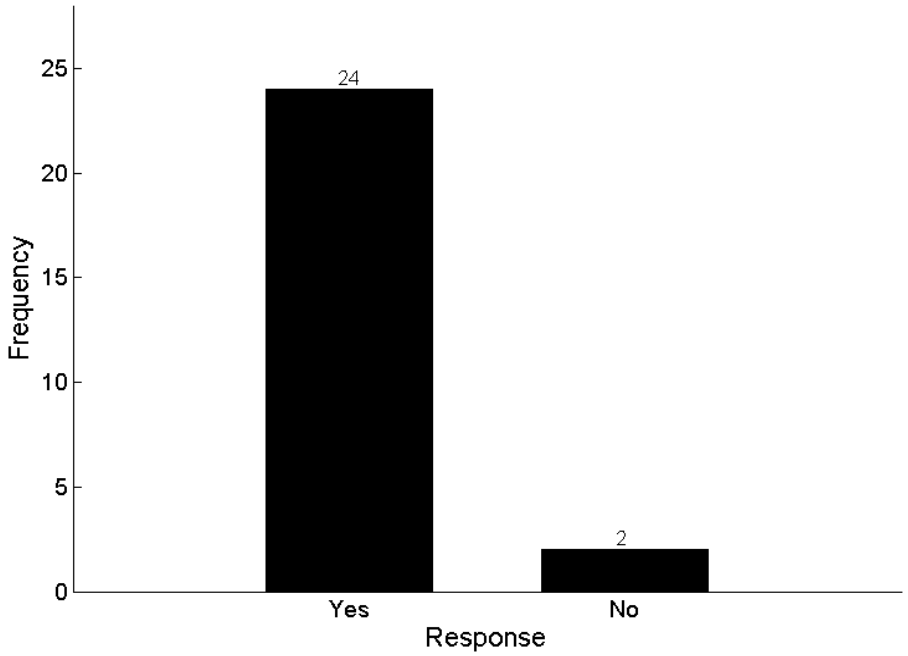


Figure 2 (h): Participant responses to "Are you familiar with video games?"

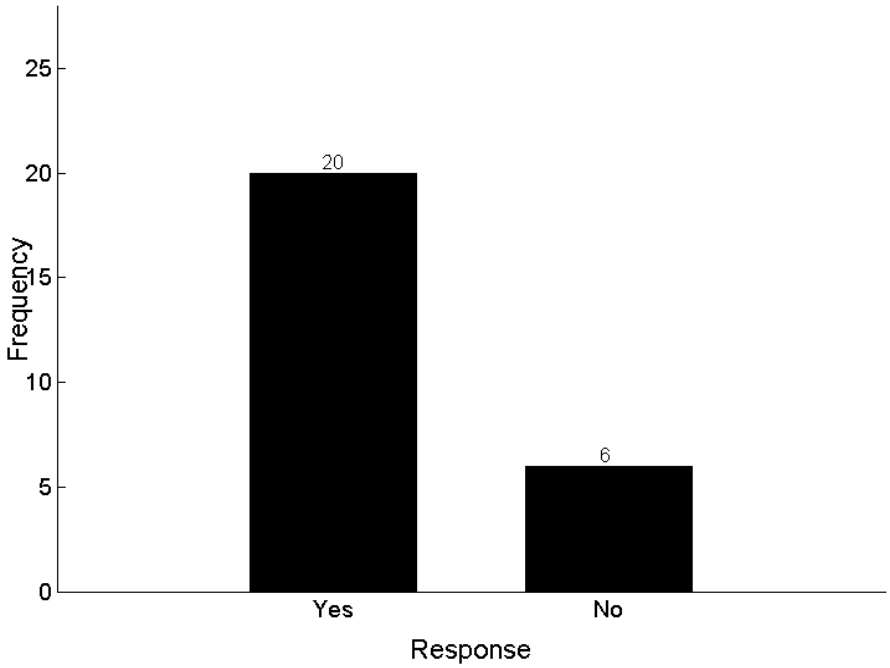


Figure 2 (i): Participant responses to "Do you answer phone calls while driving on the road?"

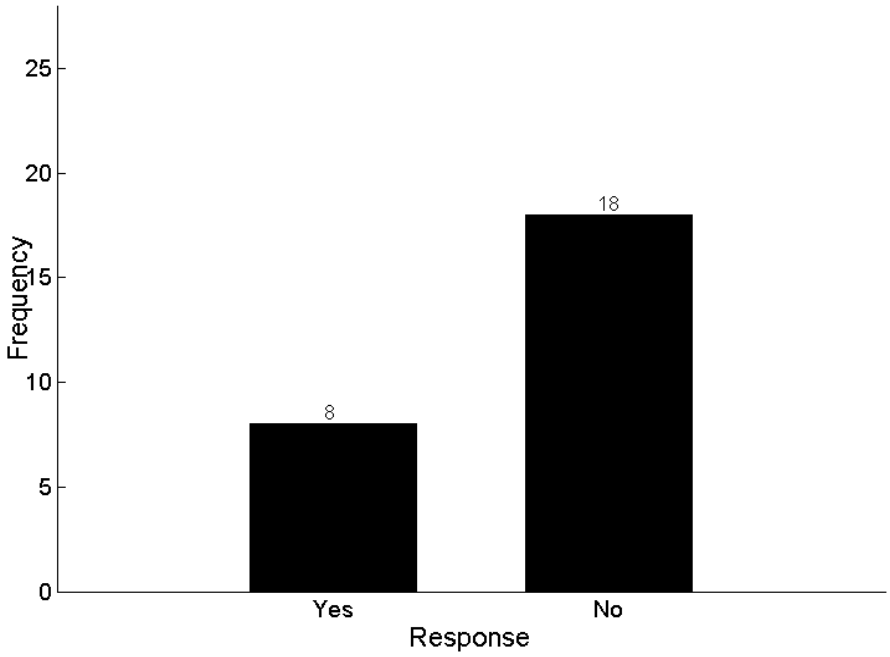


Figure 2 (j): Participant responses to "Do you use a hands-free while driving on the road?"

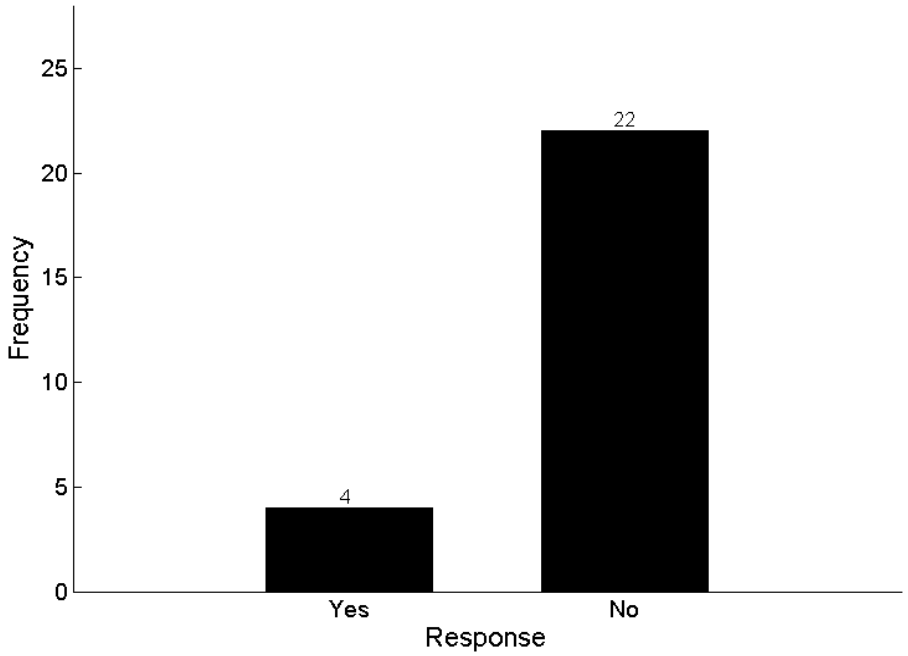


Figure 2 (k): Participant responses to "Do you use a Bluetooth® headset while driving on the road?"

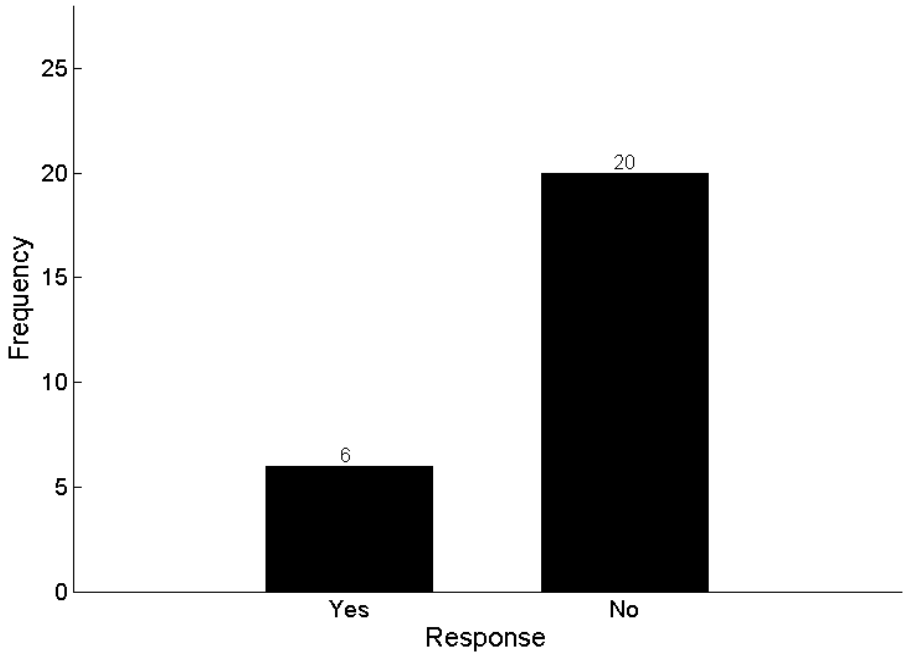


Figure 2 (l): Participant responses to "Is your car audio system Bluetooth® enabled?"

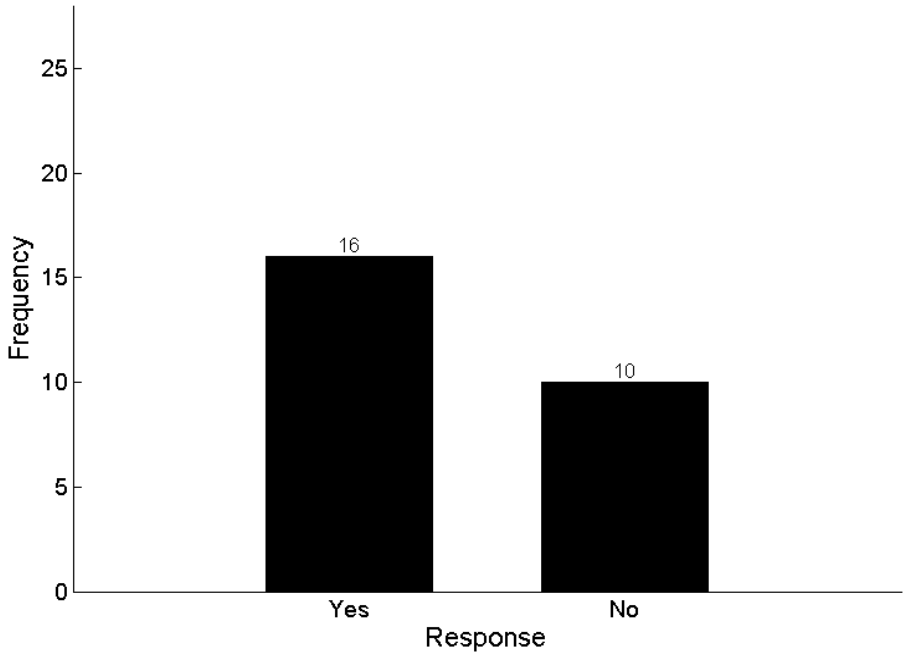


Figure 2 (m): Participant responses to "Do you use a hand-held device while on the road?"

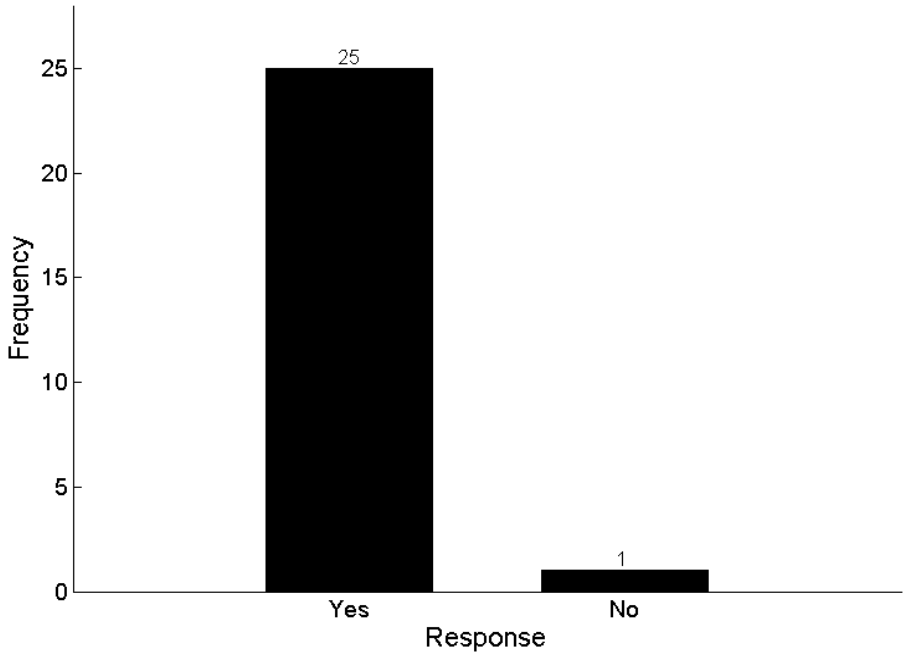


Figure 2 (n): Participant responses to "Do you listen to music (radio/CD/iPod) while driving on the road?"

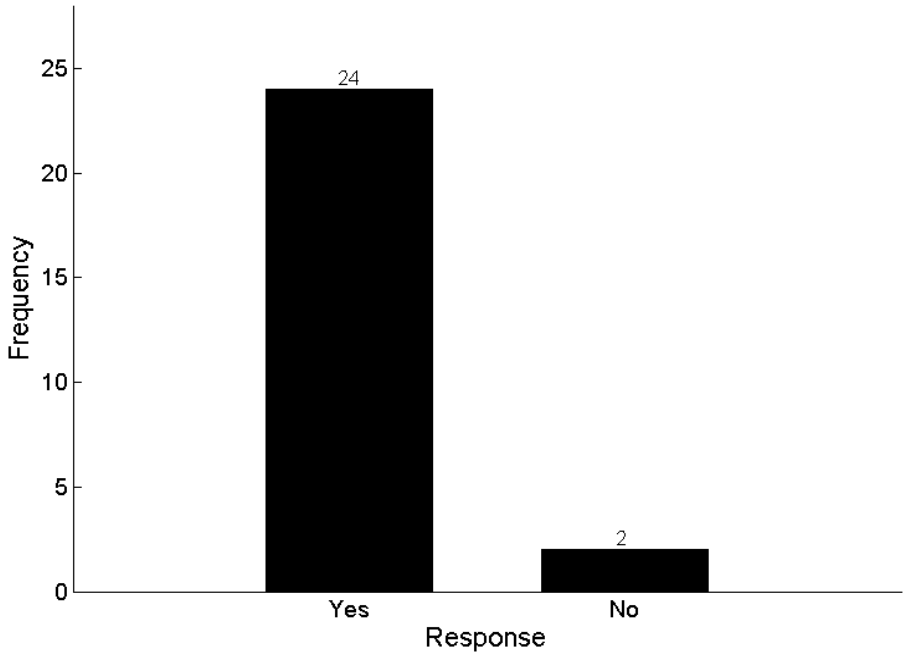


Figure 2 (o): Participant responses to "Do you believe that answering a phone call while driving distracts you?"

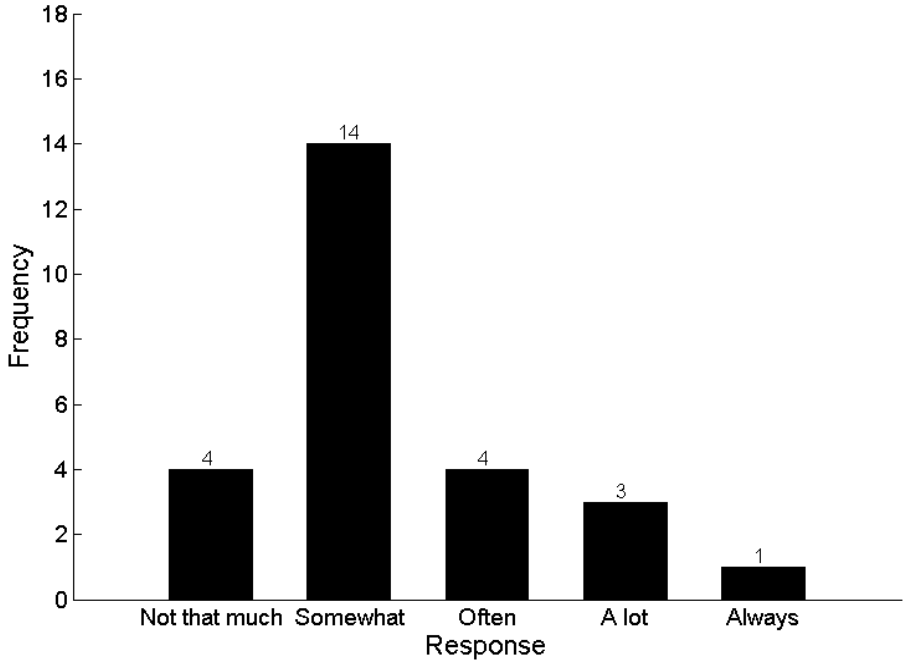


Figure 2 (p): Participant responses to "How much do you think answering phone calls while driving distracts you?"

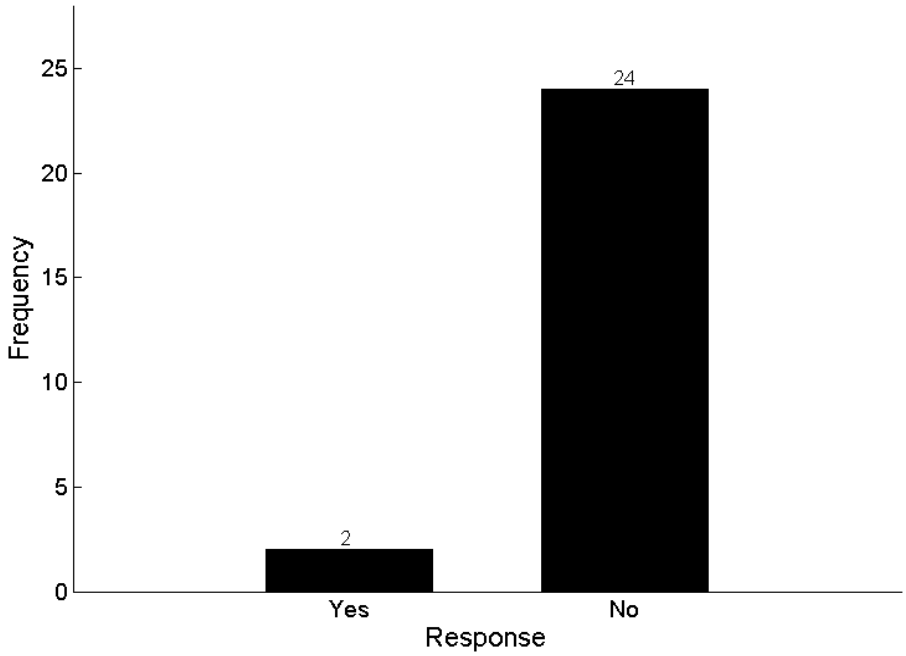


Figure 2 (q): Participant responses to "Do you experience dizziness while engaging in a simulation or video game?"

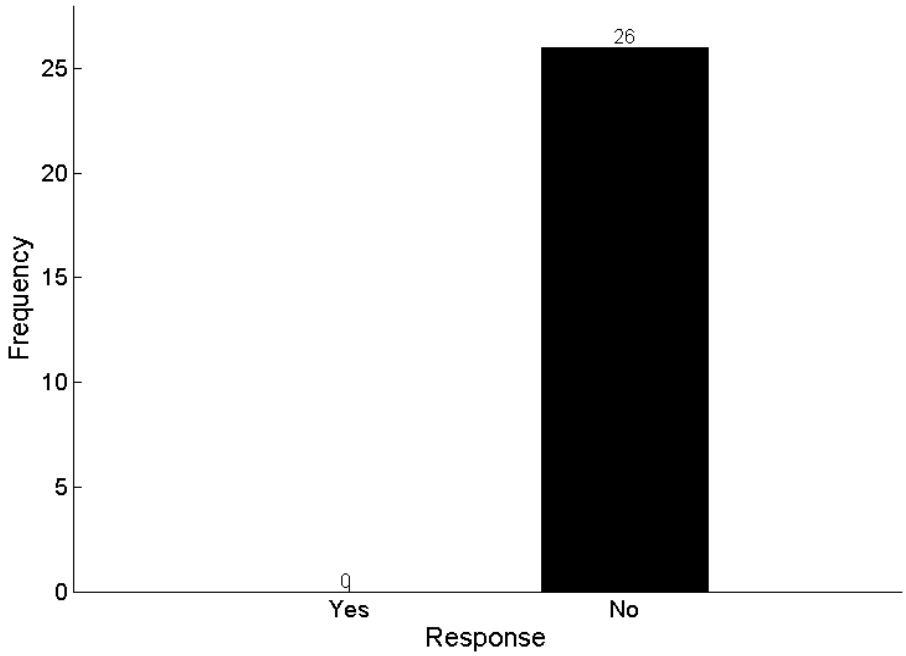


Figure 2 (r): Participant responses to "Do you frequently experience motion sickness?"

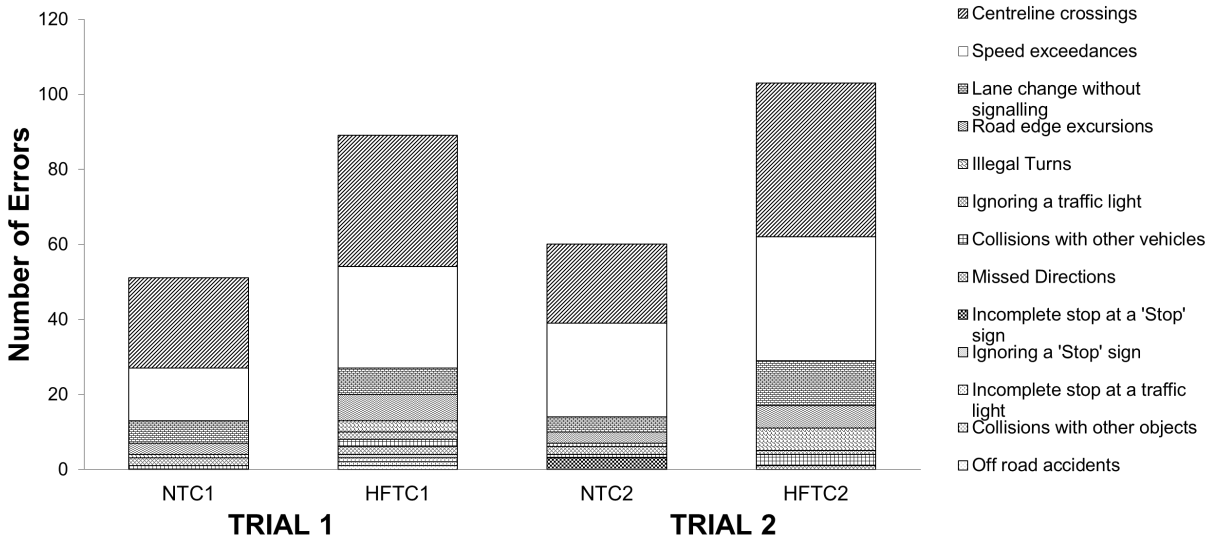


Figure 3: Number and types of driving-related errors

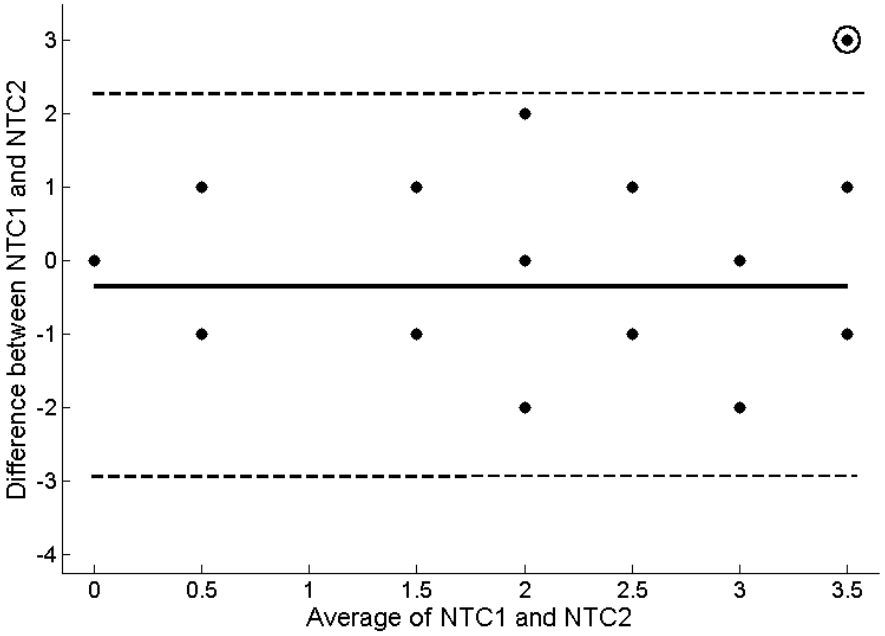


Figure 4 (a): Bland-Altman plot for number of driving-related errors in the two trials of NTC. Outlier in circled. Number of driving-related errors between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

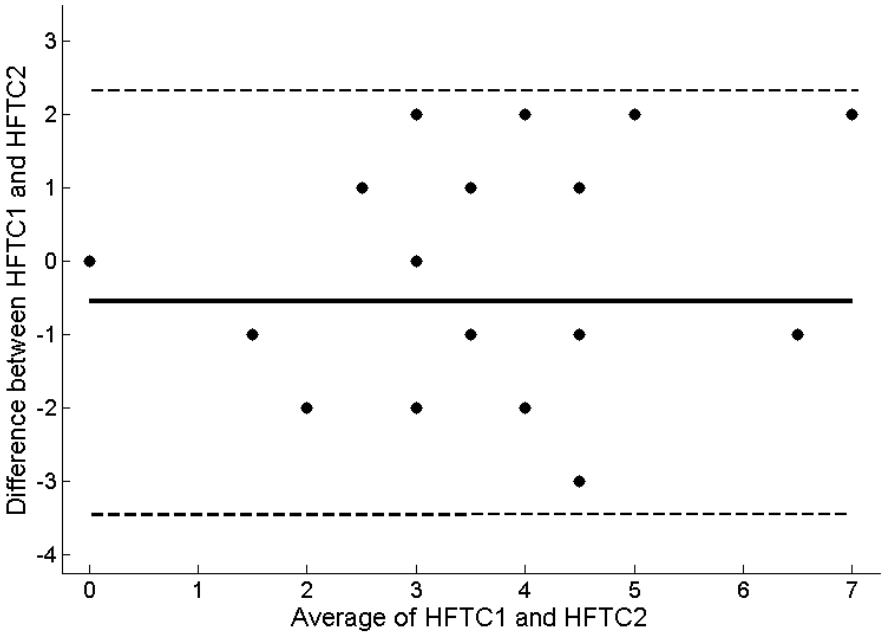


Figure 4 (b): Bland-Altman plot for number of driving-related errors in the two trials of HFTC. Number of driving-related errors between the two trials of HFTC shows high repeatability as all data points are within ±2 SD.

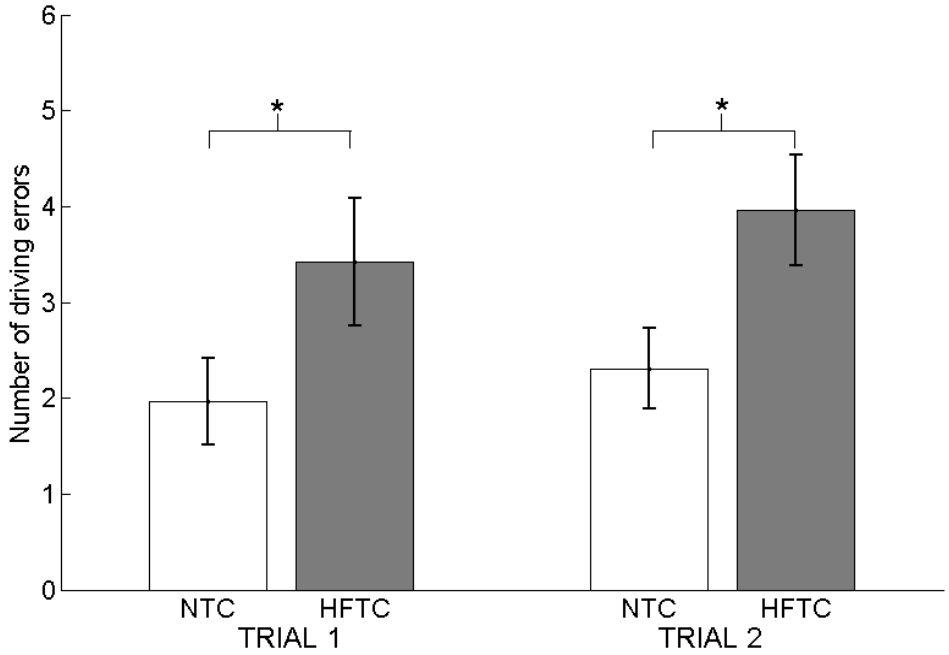


Figure 5: Mean number of driving-related errors during simulated driving NTC and HFTC.
* indicates significant difference at $p<0.001$

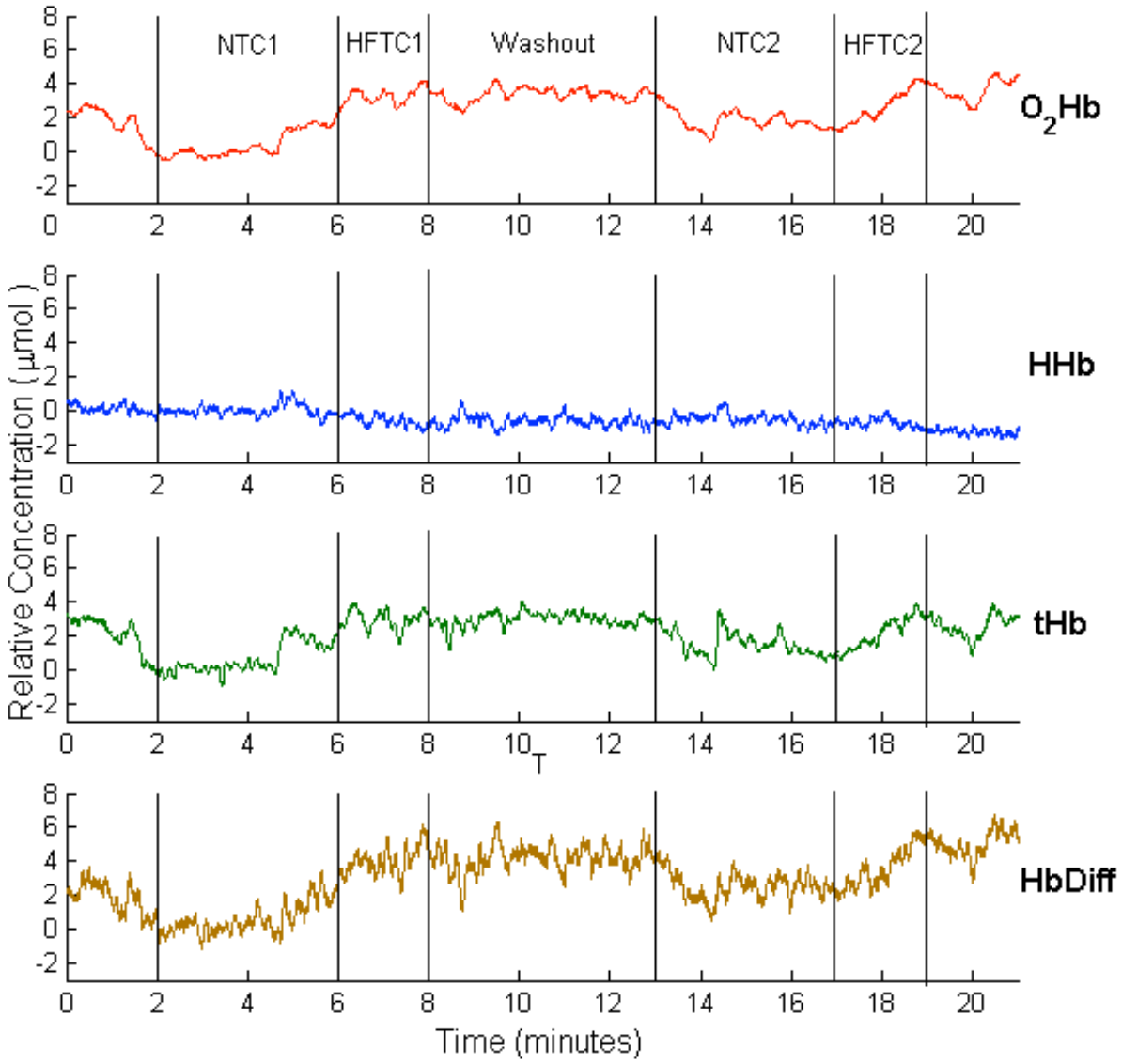


Figure 6 (a): Representative NIRS trace for demonstrating neuronal activation. The gradual increase in O2Hb and concomitant decline in HHb has been conventionally defined as neuronal activation.

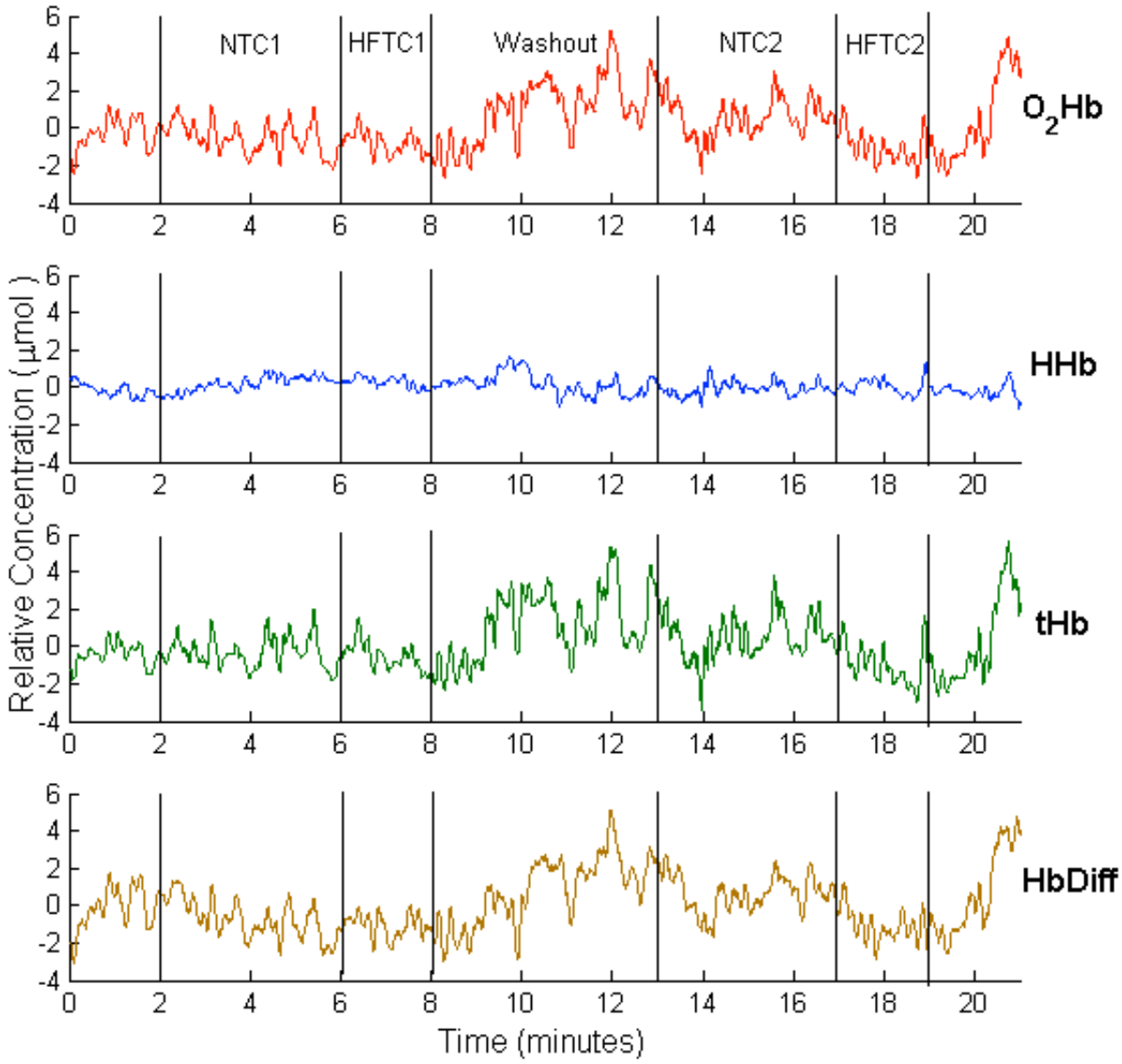


Figure 6 (b): Representative NIRS trace for demonstrating neuronal deactivation. The gradual decrease in O2Hb and concomitant increase in HHb has been conventionally defined as neuronal deactivation.

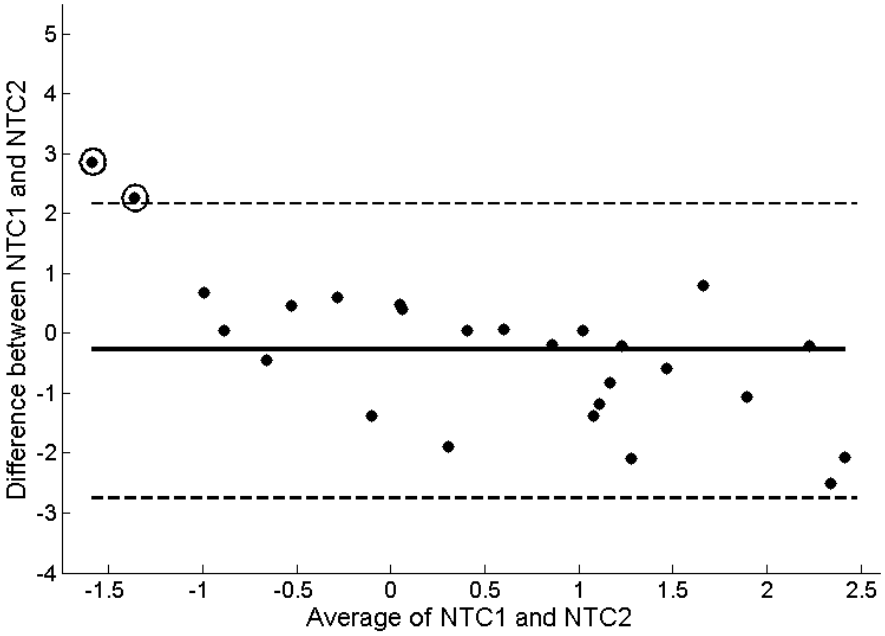


Figure 7 (a): Bland-Altman plot for mean concentration of O_2Hb in the two trials of NTC. Outliers are circled. Mean concentration of O_2Hb between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

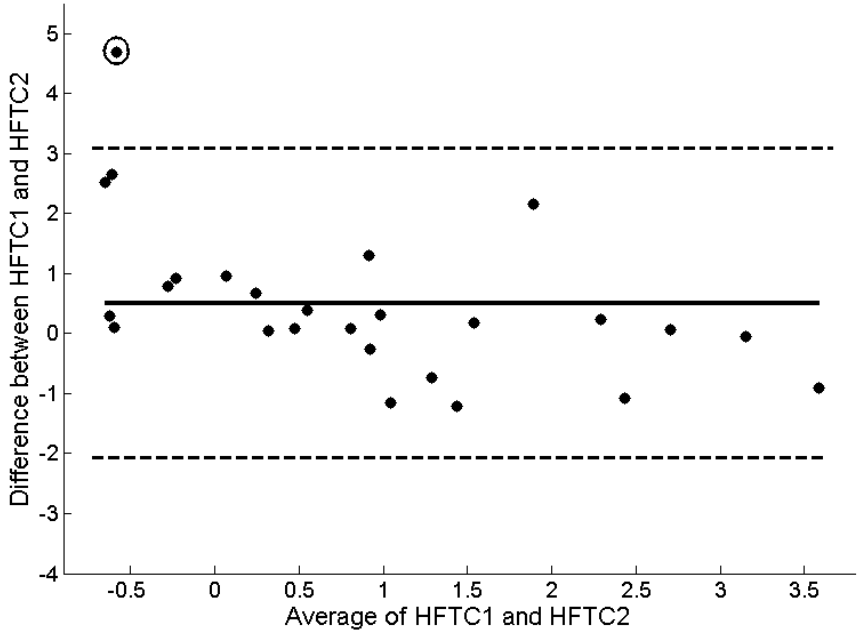


Figure 7 (b): Bland-Altman plot for mean concentration of O_2Hb in the two trials of HFTC. Outlier is circled. Mean concentration of O_2Hb between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

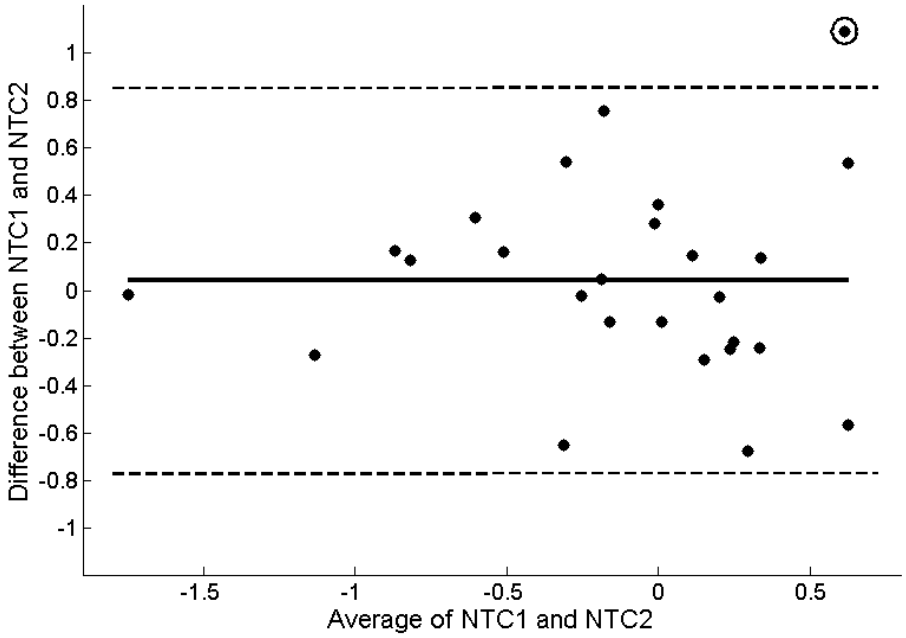


Figure 7 (c): Bland-Altman plot for mean concentration of HHb in the two trials of NTC. Outlier is circled. Mean concentration of HHb between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

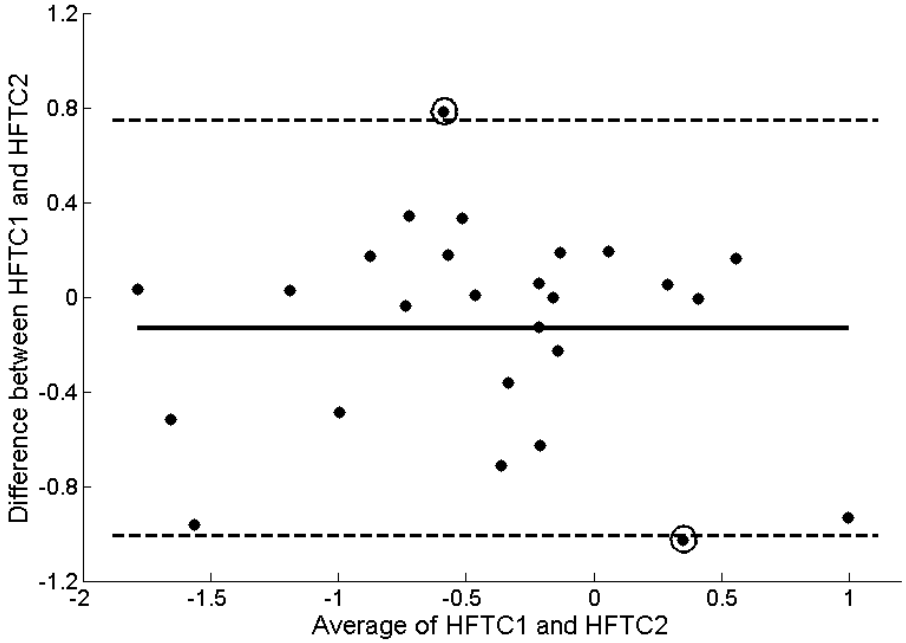


Figure 7 (d): Bland-Altman plot for mean concentration of HHb in the two trials of HFTC. Outliers are circled. Mean concentration of HHb between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

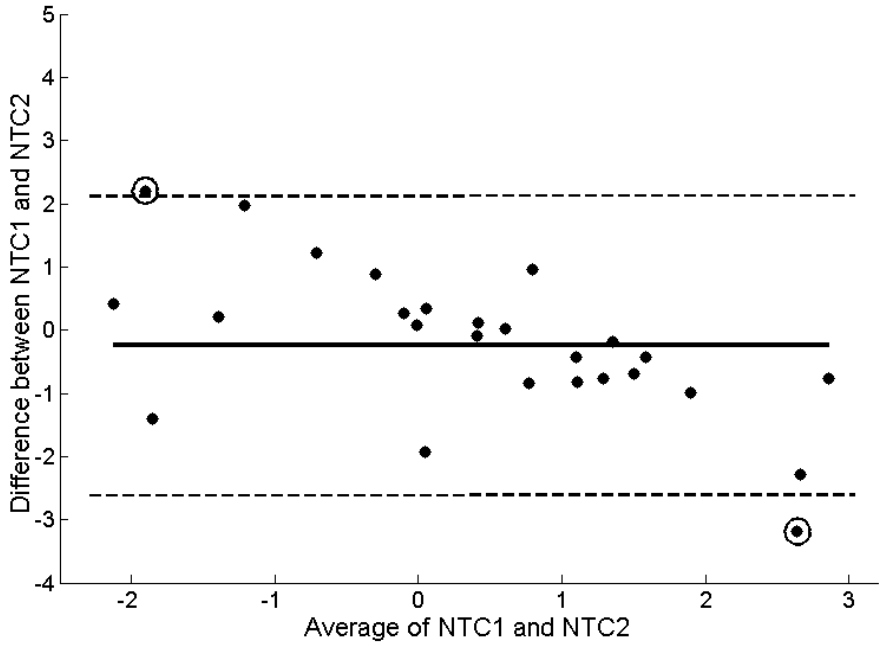


Figure 7 (e): Bland-Altman plot for mean concentration of tHb in the two trials of NTC. Outliers are circled. Mean concentration of tHb between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

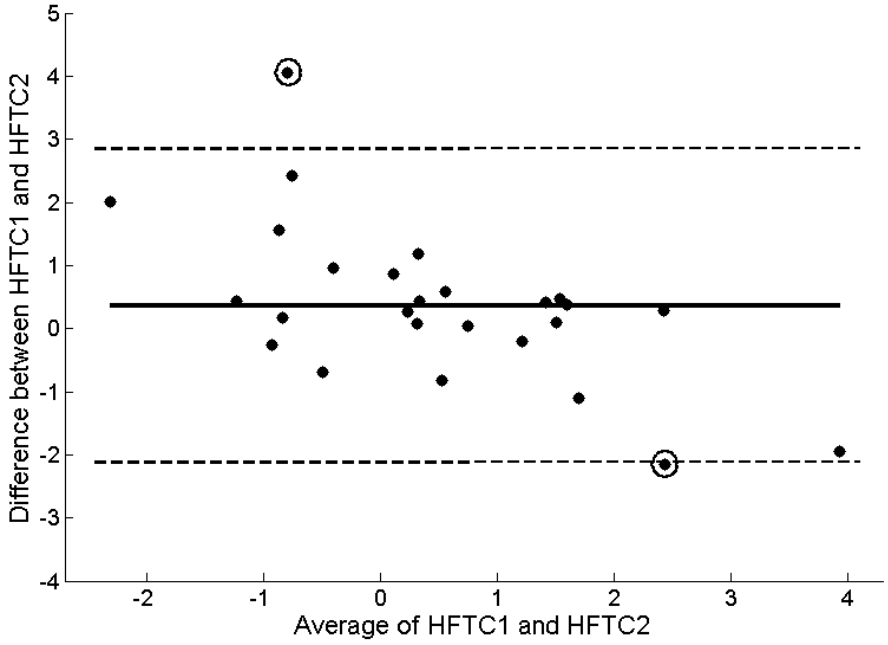


Figure 7 (f): Bland-Altman plot for mean concentration of tHb in the two trials of HFTC. Outliers are circled. Mean concentration of tHb between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

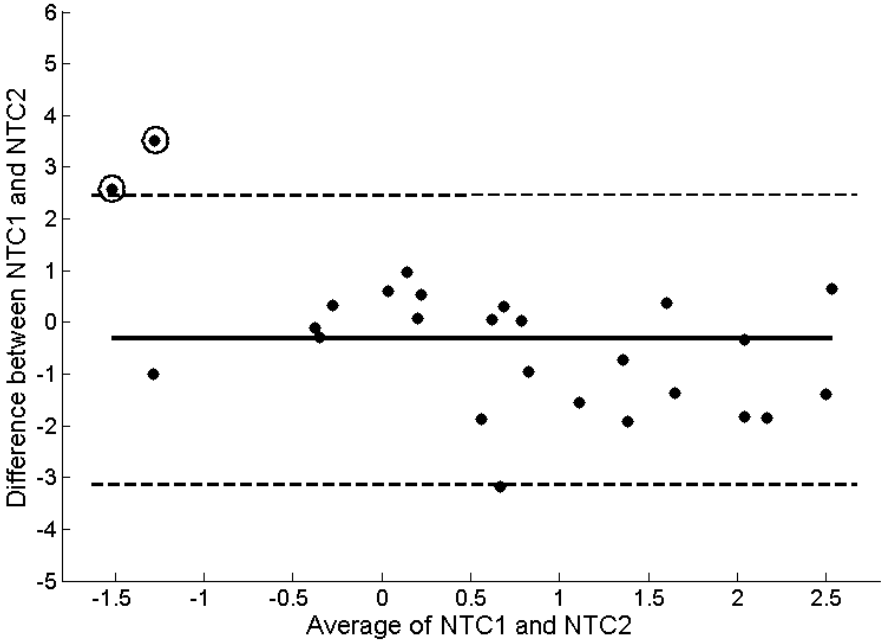


Figure 7 (g): Bland-Altman plot for mean concentration of HbDiff in the two trials of NTC. Outliers are circled. Mean concentration of HbDiff between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

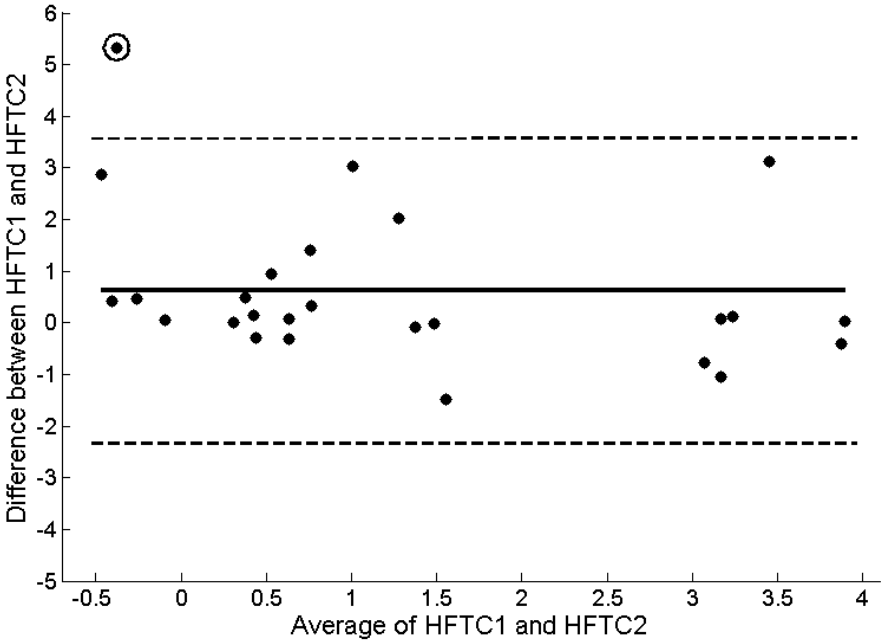


Figure 7 (h): Bland-Altman plot for mean concentration of HbDiff in the two trials of HFTC. Outlier is circled. Mean concentration of HbDiff between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

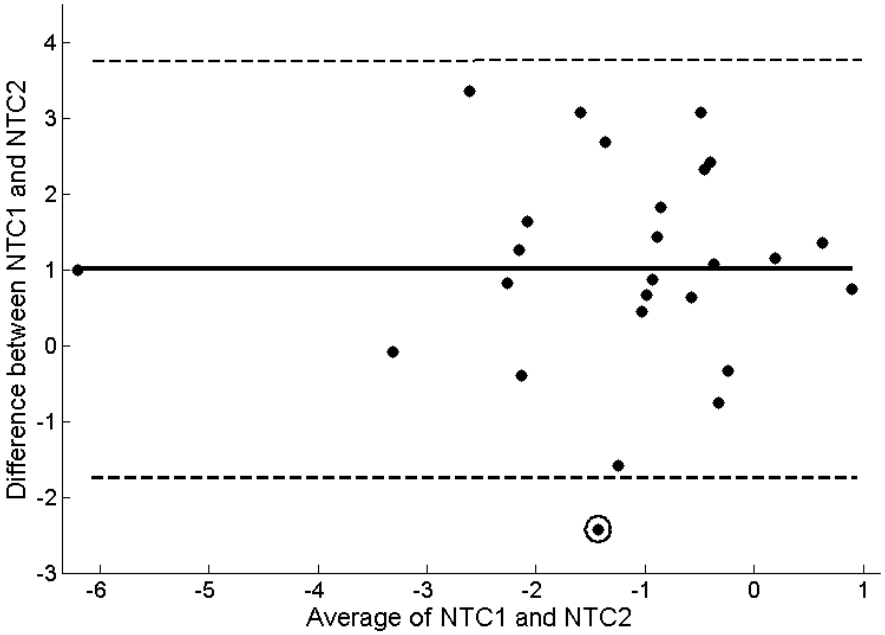


Figure 8 (a): Bland-Altman plot for delta of O_2Hb in the two trials of NTC. Outlier is circled. Delta of O_2Hb between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

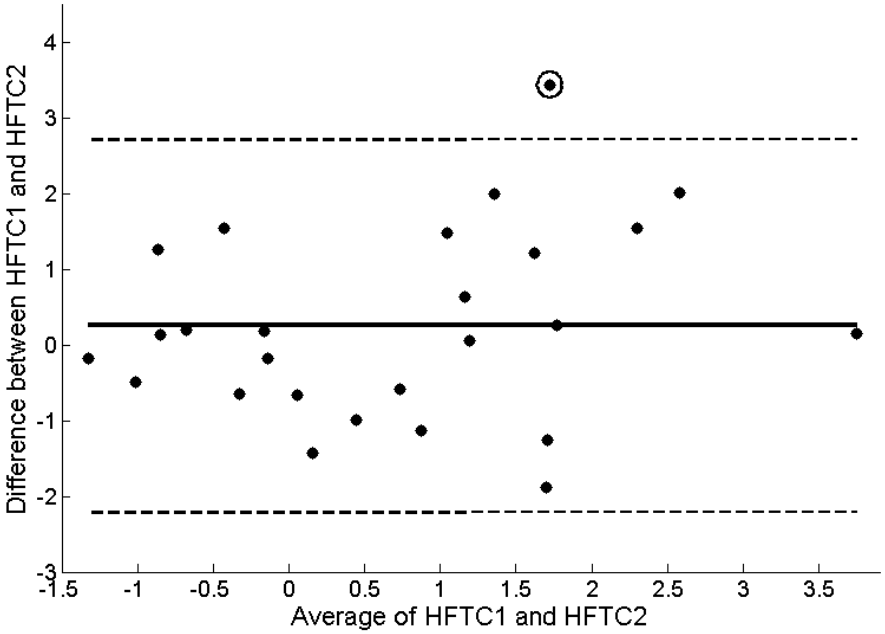


Figure 8 (b): Bland-Altman plot for delta of O_2Hb in the two trials of HFTC. Outlier is circled. Delta of O_2Hb between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

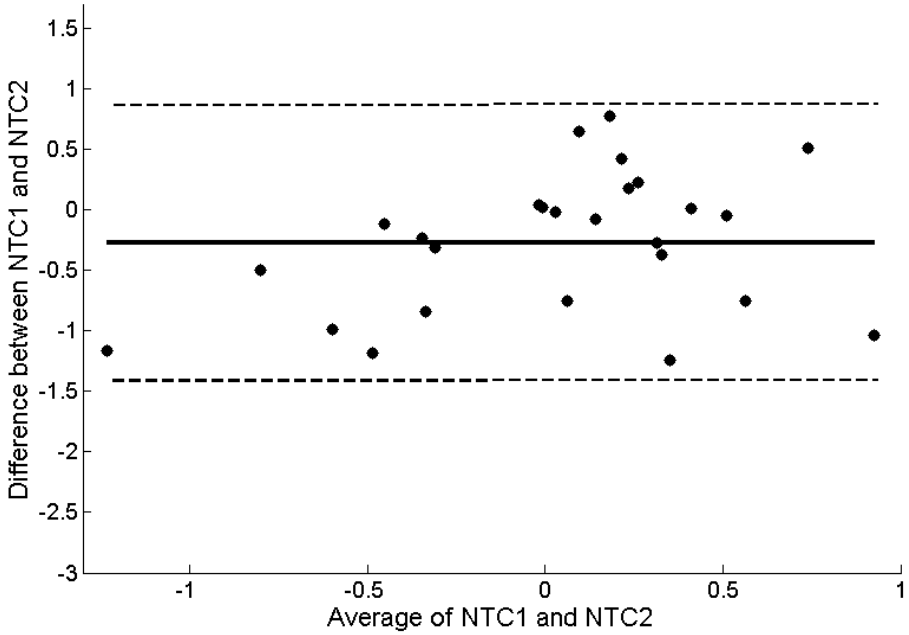


Figure 8 (c): Bland-Altman plot for delta of HHb in the two trials of NTC. Delta of HHb between the two trials of NTC shows high repeatability as all data points are within ±2 SD.

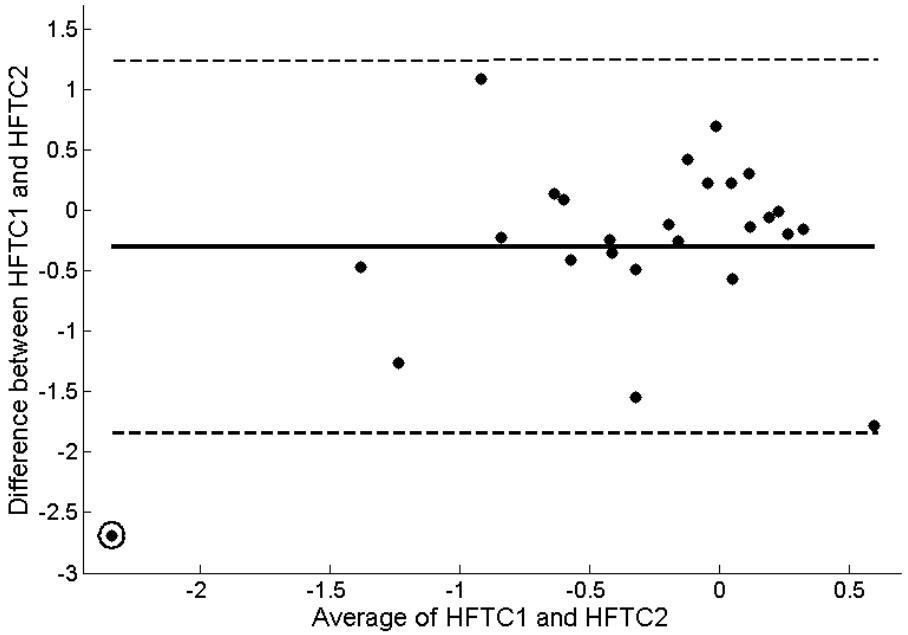


Figure 8 (d): Bland-Altman plot for delta of HHb in the two trials of HFTC. Outlier is circled. Delta of HHb between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

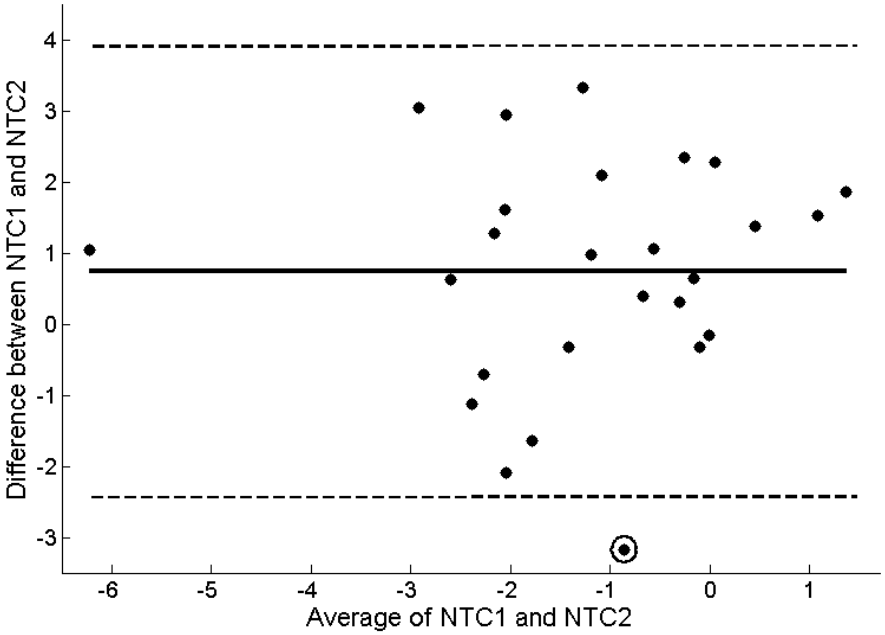


Figure 8 (e): Bland-Altman plot for delta of tHb in the two trials of NTC. Outlier is circled. Delta of tHb between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

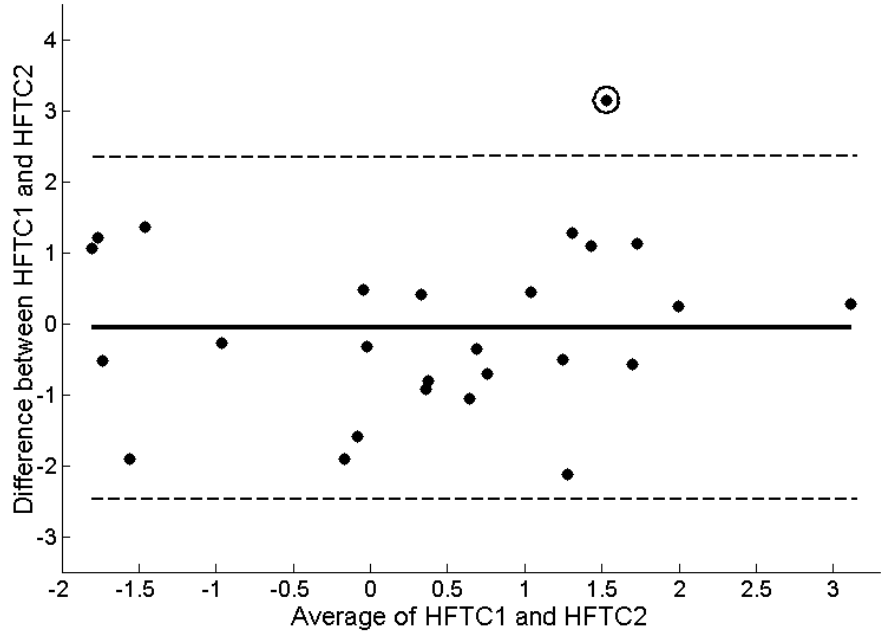


Figure 8 (f): Bland-Altman plot for delta of tHb in the two trials of HFTC. Outlier is circled. Delta of tHb between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

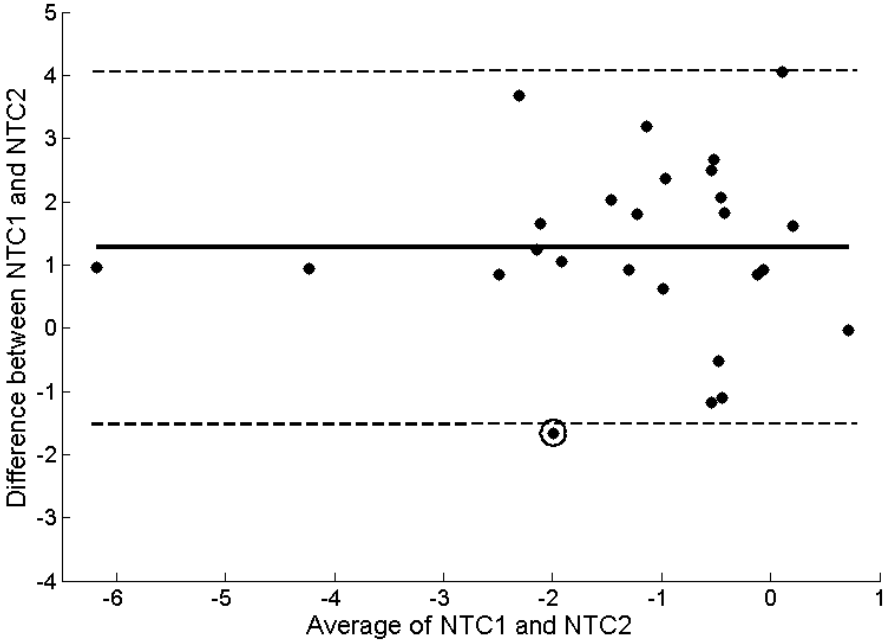


Figure 8 (g): Bland-Altman plot for delta of HbDiff in the two trials of NTC. Outlier is circled. Delta of HbDiff between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

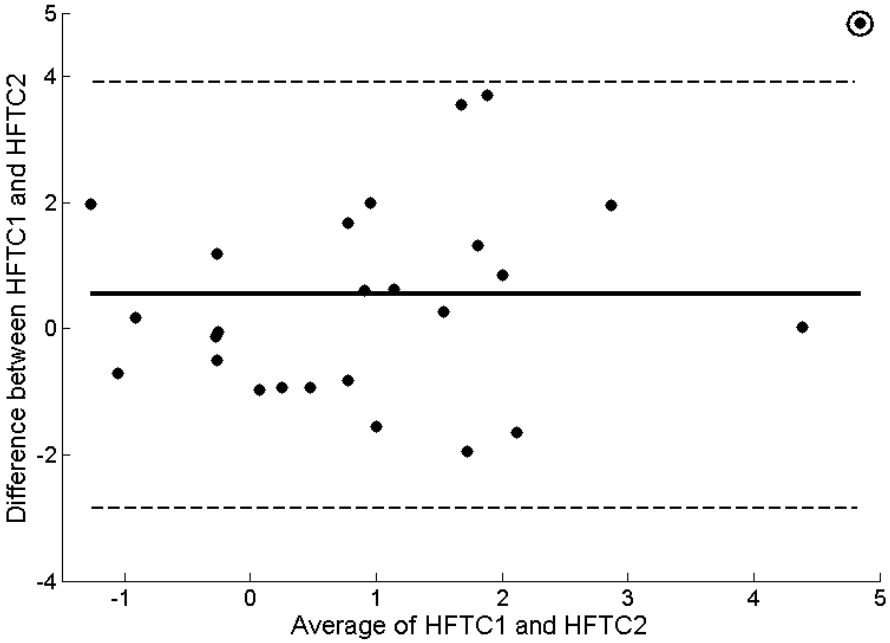


Figure 8 (h): Bland-Altman plot for delta of HbDiff in the two trials of HFTC. Outlier is circled. Delta of HbDiff between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

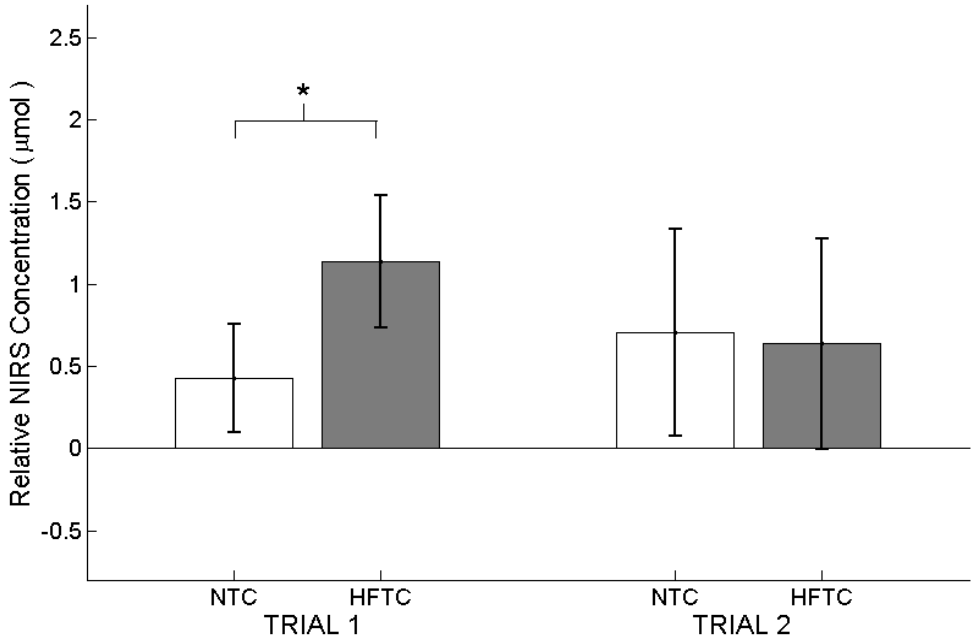


Figure 9 (a): Mean concentration of O_2Hb during simulated driving with NTC or HFTC.
* indicates significant difference at $p<0.01$

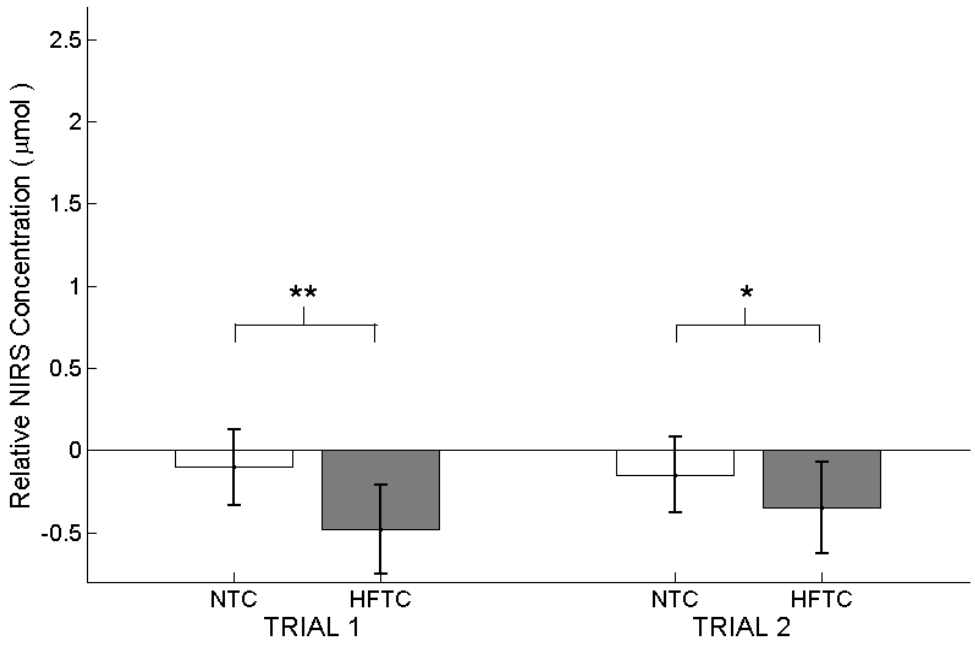


Figure 9 (b): Mean concentration of HHb during simulated driving with NTC or HFTC
* indicates significant difference at $p<0.05$
** indicates significant difference at $p<0.001$

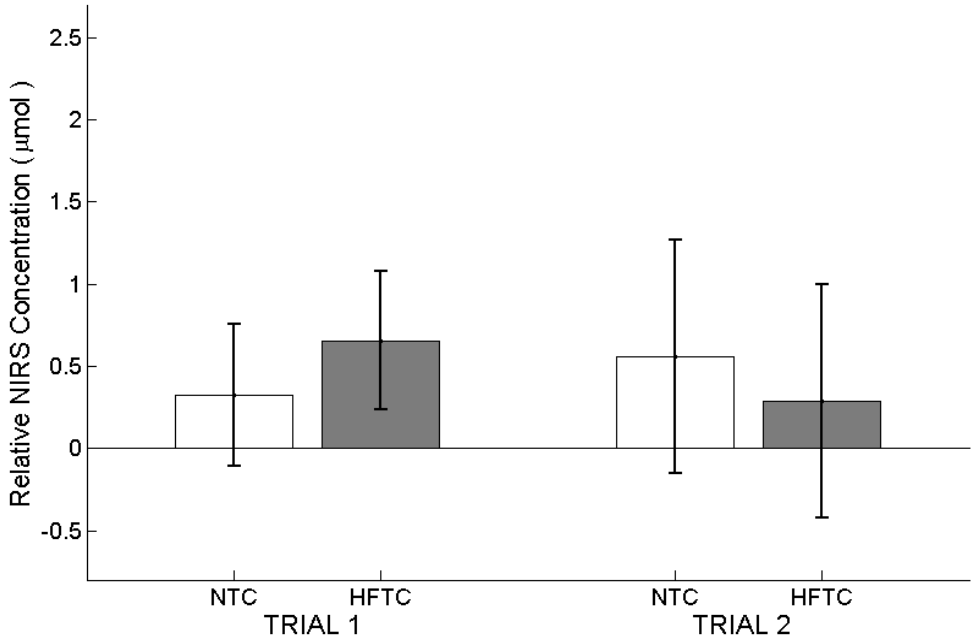


Figure 9 (c): Mean concentration of tHb during simulated driving with NTC or HFTC

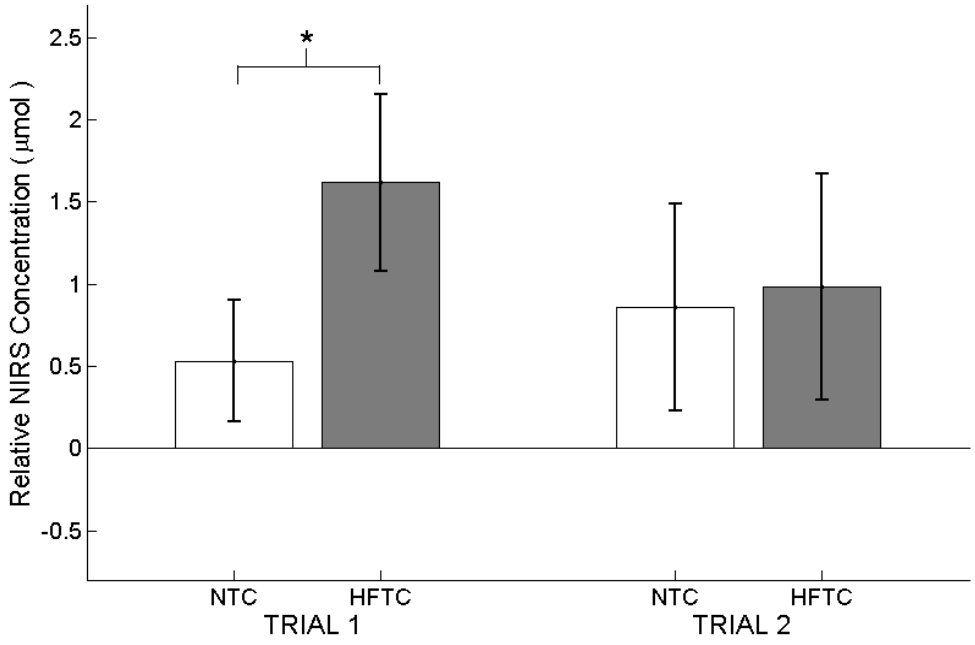


Figure 9 (d): Mean concentration of HbDiff during simulated driving with NTC or HFTC
* indicates significant difference at $p<0.001$

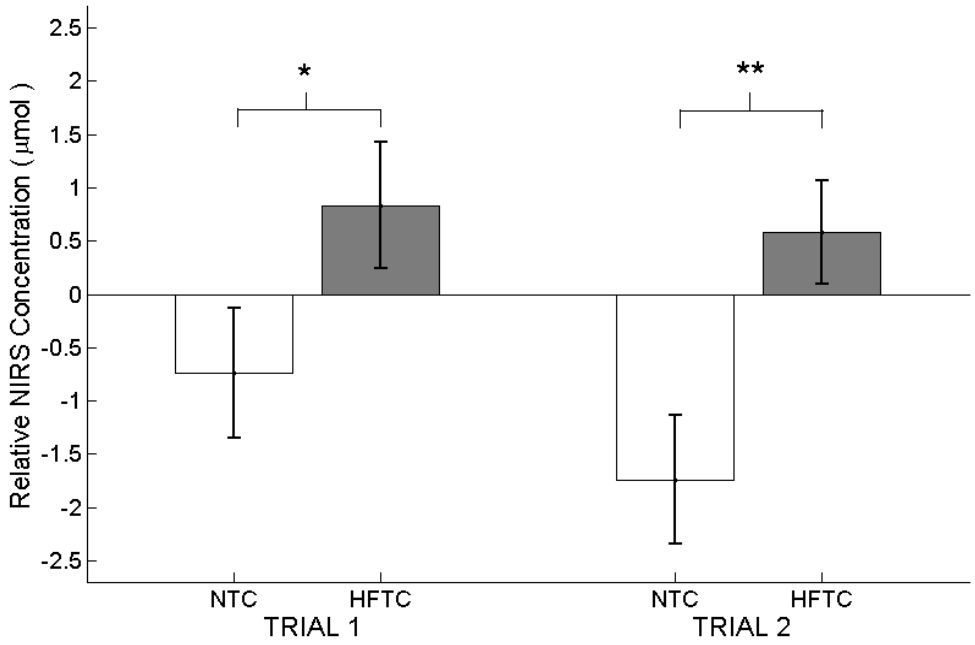


Figure 10 (a): Delta O_2Hb during simulated driving with NTC or HFTC.
* indicates significant difference at $p<0.01$
** indicates significant difference at $p<0.001$

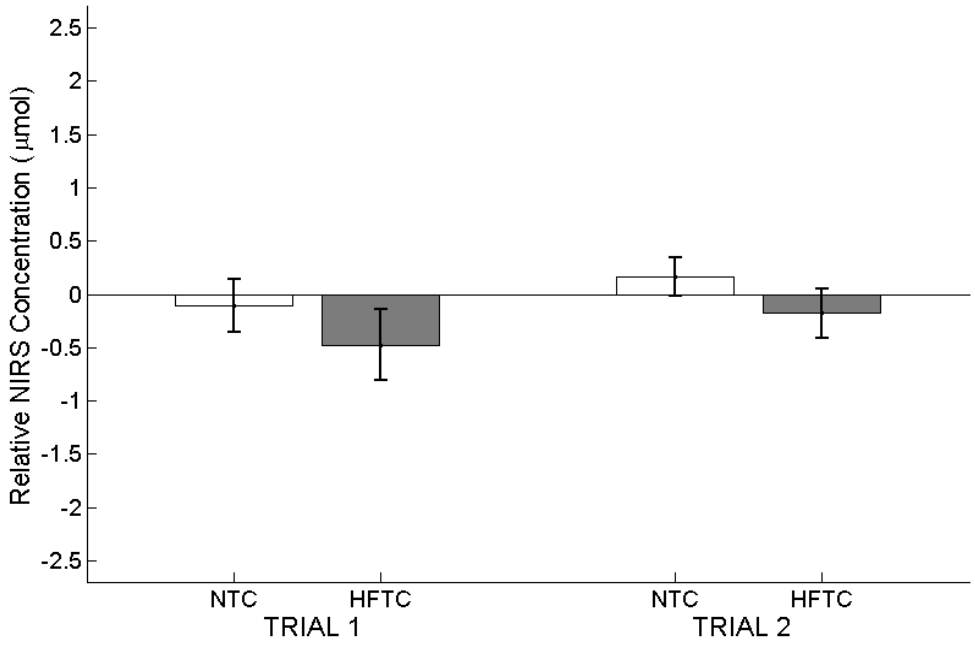


Figure 10 (b): Delta HHb during simulated driving with NTC or HFTC.

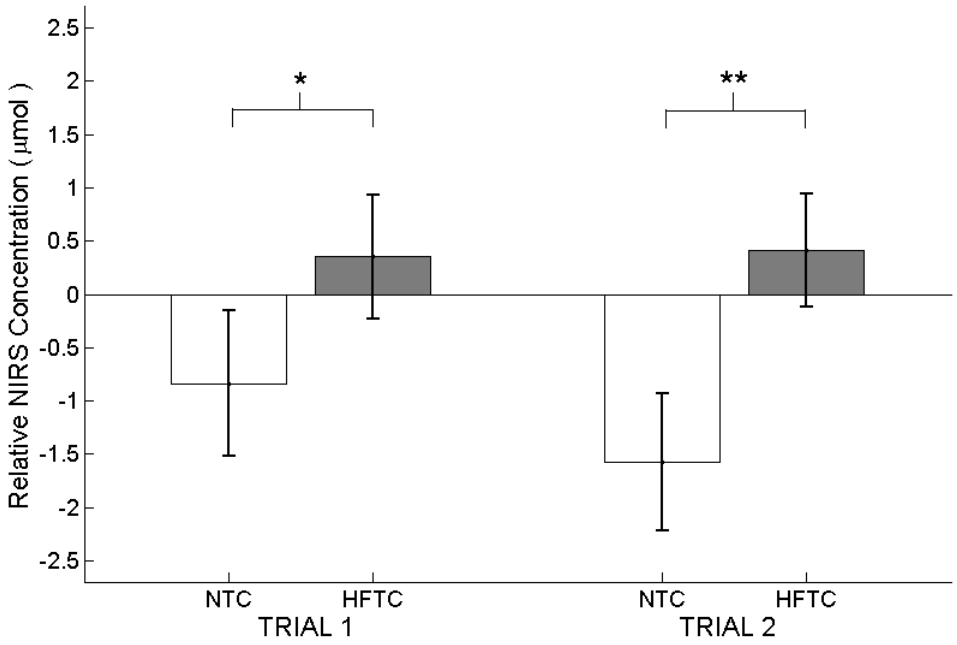


Figure 10 (c): Delta tHb during simulated driving with NTC or HFTC.
* indicates significant difference at p<0.05
** indicates significant difference at p<0.001

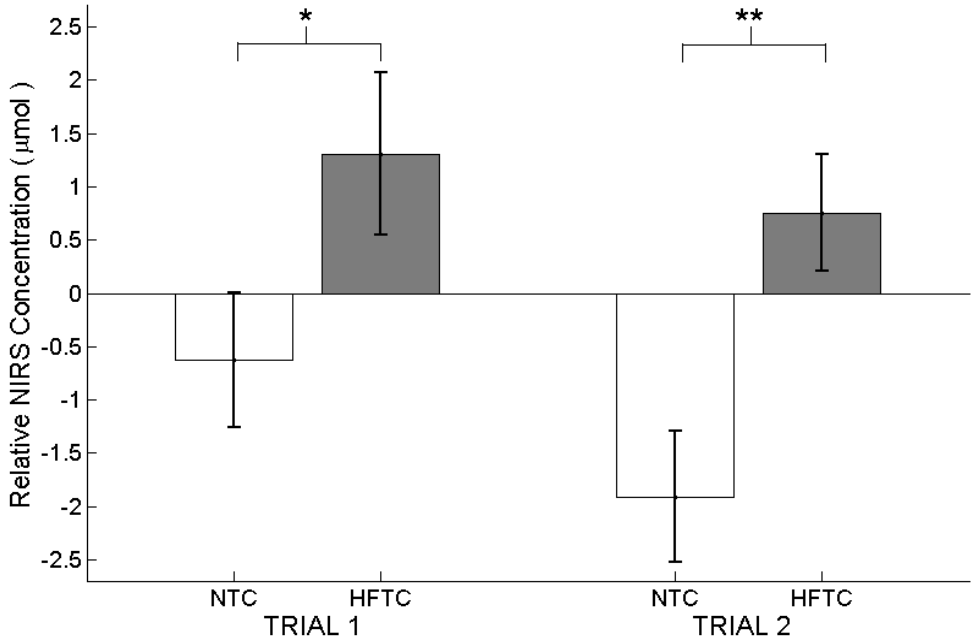


Figure 10 (d): Delta HbDiff during simulated driving with NTC or HFTC.
* indicates significant difference at p<0.01
** indicates significant difference at p<0.001

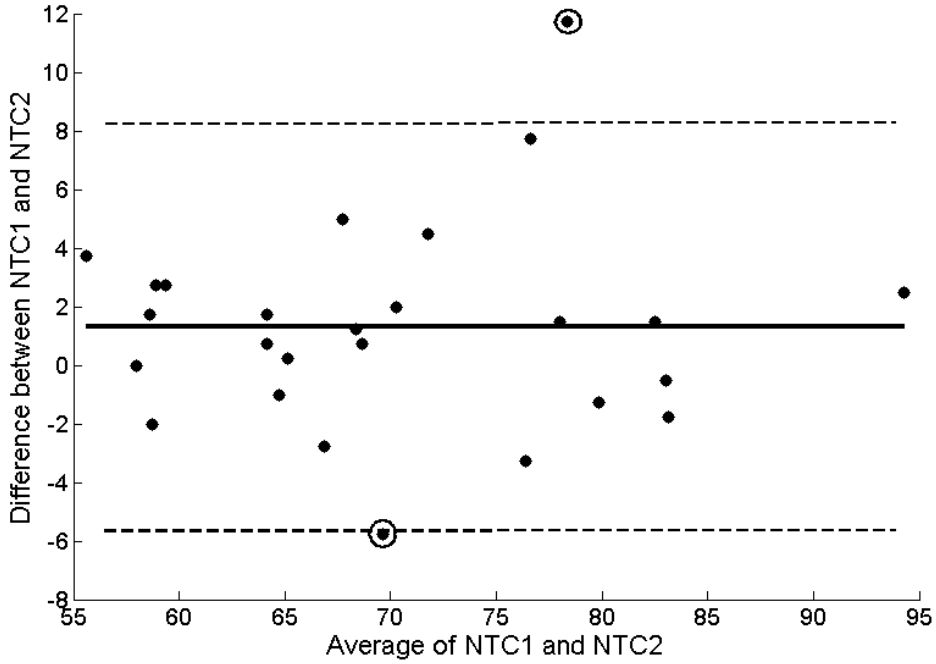


Figure 11 (a): Bland-Altman plot for mean heart rate in the two trials of NTC. Outliers are circled. Heart rate between the two trials of NTC shows high repeatability as most data points are within ±2 SD.

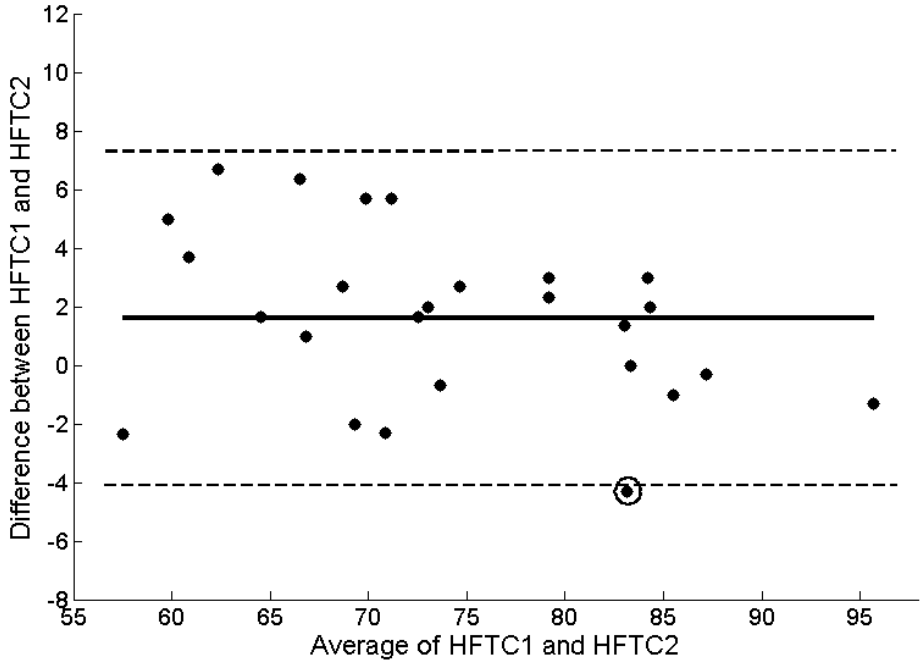


Figure 11 (b): Bland-Altman plot for mean heart rate in the two trials of HFTC. Outlier is circled. Heart rate between the two trials of HFTC shows high repeatability as most data points are within ±2 SD.

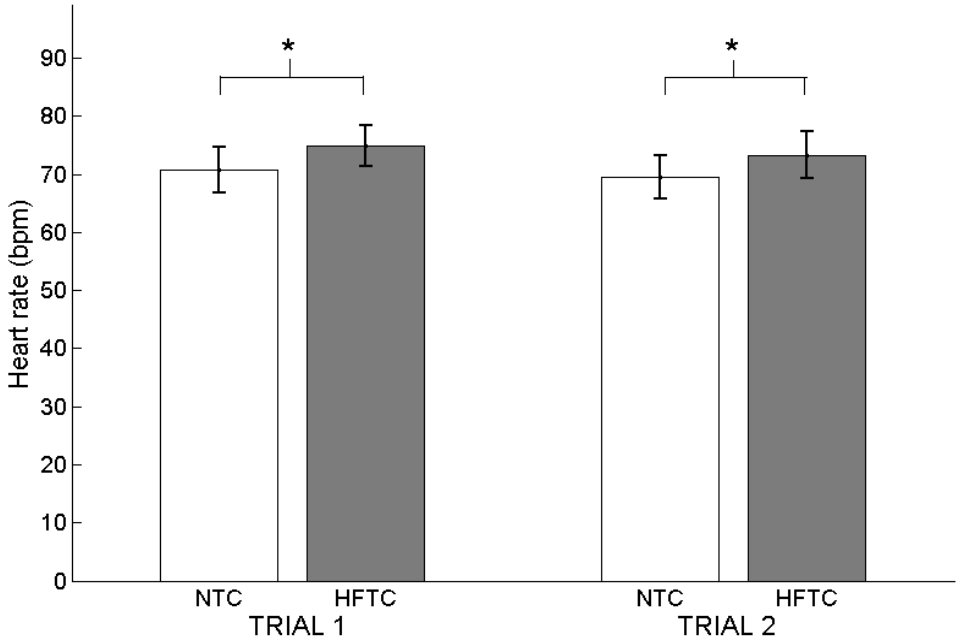


Figure 12: Mean heart rate during simulated driving with NTC or HFTC
* indicates significant difference at $p<0.001$

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APPENDICES

Appendix A:
Information Sheet

INFORMATION SHEET

Project Title: Cerebral Oxygenation and Behavioural Responses during simulated driving with and without hands-free telecommunication: a near infrared spectroscopy study

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Background Information

Talking on a hand-held cell phone while driving negatively effects driving performance. The use of hand held cell phones is illegal in many cities in North America. However, the use of hands-free cell phones is still legal in many cities. We do not know whether this method of talking while driving is safe. Near infrared spectroscopy is a non-invasive method of measuring oxygen levels to the brain. Increases in brain oxygen levels during a task indicate that the brain is more active. We are interested in finding out what happens to brain oxygen levels while you are driving and talking on a hands-free cell phone at the same time.

Purpose of the Study

In this study we will compare the changes in brain oxygenation during simulated driving while you are talking using a hand-held and hands-free a cell phone. The brain oxygenation levels will be measured from your forehead while you drive for half hour on a driving simulator. We will record the number of mistakes that you make while driving under the two conditions. We will then check whether the number of mistakes you make are related to the changes in brain oxygenation.

Study Requirements

You will be required to come to Building Trades of Alberta Courage Centre, 3rd floor, West
Wing, Glenrose Rehabilitation Hospital, 10230 - 111 Avenue NW, Edmonton, Alberta T5G 0B7 on
two occasions. These testing sessions will be arranged at a time that is convenient to you.

Session One – approximately 35 minutes

In this session we will: (i) ask you to complete this informed consent form, (ii) explain the experiment to you, (iii) set-up a hands-free device in your right ear and a physiological sensor on your left forehead (iv) ask you to drive in a virtual reality driving simulator for approximately 6 minutes without a break (iv) provide an opportunity for rest and (v) repeat steps (ii) and (iii) once. (vi) and set up an appointment for the next testing session.

Sessions Two – approximately 45 minutes

In this session we will: (i) set-up a hands-free device in your right ear and a physiological sensor on your left forehead (ii) ask you to drive in a virtual reality driving simulator for some time,

(iii) ask you to attend the phone call that you will receive through the hands-free device, (iv) provide an opportunity for rest and (v) repeat steps (ii) and (iii) once.

Brain Oxygenation Measurements

At the start of the experiment, the research assistant will place a light source on your left forehead just above your eyebrow. He will use a sticky optode adhesive and Velcro strap to keep it in place. This probe will remain on your forehead for the entire test period. This instrument has been checked and it is working properly. Only a trained research assistant will use it.

Heart Rate Measurements

At the start of the second session, the research assistant will request you to place a heart rate sensor on your chest. You will be asked to use the nearest restroom to rinse the sensor and place it directly on the skin. A slightly wet sensor increases contact with the skin to provide accurate and continuous heart rate monitoring. This sensor will remain on your chest for the entire test period. This instrument will be checked and sanitised before providing it to you.

Behavioural Responses

During the second session, the research assistant will be continuously monitoring your driving and scoring common errors made by drivers. You can request to see the list of these common errors before the start of the second session.

Risks

There are no known risks or long term effects of our experiment. You may feel tired after the simulated driving session because it may be unfamiliar to you.

Benefits

If you volunteer for this study, we will give you information on your driving performance while you are talking using a hand-held and hands-free cell

phone. This research may be useful in setting policies regarding the use of cell phones while driving in North America.

Confidentiality

All the personal information and test results will be held confidential except when professional codes of ethics and/or legislation require reporting. Only the investigators listed on this information sheet and their research assistants will have access to your data. Any report published as a result of this study will not identify you by name. The data will be kept for at least five years after the study is completed. During testing, you will be assigned a code, which will be known only to the investigators and the research assistants. Your electronic files will be stored on a password secured computer. Printed copies of the data will be locked in a filing cabinet in the principal investigator's office.

Freedom to Withdraw

You are free to withdraw from the research study at any time. If any knowledge gained from this or any other study becomes available which could influence your decision to continue in this study, you will be promptly informed.

Additional Contact

If you have any questions or concerns about this study, please contact Dr. Joanne Volden, Associate Dean of Graduate Studies, Faculty of Rehabilitation Medicine; Tel: 492-0651, email: joanne.volden@ualberta.ca.

Appendix B:
Informed Consent Form

CONSENT FORM

Part 1 (to be completed by the Principal Investigator):

Title: Cerebral oxygenation and behavioural responses during simulated driving with and without hands-free telecommunication: a near infrared spectroscopy study
Principal Investigator(s): Dr. Yagesh Bhambhani & Mayank Rehani

Part 2 (to be completed by the research subject):

Do you understand that you have been asked to be in a research study?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate or withdraw from the study at any time? You do not have to give a reason and it will not affect your care.	Yes	No
Has the issue of confidentiality been explained to you? Do you understand who will have access to your records?	Yes	No
Do you want the investigator(s) to inform your family doctor that you are participating in this research study? If so, please provide your doctor's name:	Yes	No

_____

This study was explained to me by: _____

I agree to take part in this study.

_____ _____ _____
Signature of Research Participant Date Witness

_____ _____
Printed Name Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

_____ _____
Signature of Investigator or Designee Date

Appendix C:
Original Ethics Approval

Approval Form

Date:	December 7, 2010
Principal Investigator:	Yagesh Bhambhani
Study ID:	Pro00017694
Study Title:	Cerebral oxygenation and behavioural responses during simulated driving with and without hands-free telecommunication: a near infrared spectroscopy study
Approval Expiry Date:	December 6, 2011

Thank you for submitting the above study to the Health Research Ethics Board - Health Panel . Your application, including revisions received December 2, 2010, has been reviewed and approved on behalf of the committee.

A renewal report must be submitted next year prior to the expiry of this approval if your study still requires ethics approval. If you do not renew on or before the renewal expiry date, you will have to re-submit an ethics application.

Approval by the Health Research Ethics Board does not encompass authorization to access the patients, staff or resources of Alberta Health Services or other local health care institutions for the purposes of the research. Enquiries regarding Alberta Health Services administrative approval, and operational approval for areas impacted by the research, should be directed to the Alberta Health Services Regional Research Administration office, #1800 College Plaza, phone (780) 407-6041.

Sincerely,

Doug Gross, Ph.D.
Associate Chair, Health Research Ethics Board - Health Panel

Note: This correspondence includes an electronic signature (validation and approval via an online system).

Appendix D:
Ethics re-approval with change in location indicated

Amendment Approval Form

Date:	February 22, 2011
Amendment/Renewal ID:	Pro00017694_AME1
Study ID:	MS1_Pro00017694
Study Title:	Cerebral oxygenation and behavioural responses during simulated driving with and without hands-free telecommunication: a near infrared spectroscopy study
Principal Investigator:	Yagesh Bhambhani
Approval Expiry Date:	December 6, 2011

Thank you for submitting an amendment request to the Health Research Ethics Board - Health Panel. This amendment has been reviewed and approved on behalf of the committee. The following has been approved:

- Change in the testing location for this study from Corbett Hall Room 1-94 and Biological Sciences P326 at the University of Alberta to the Building Trades Center of Alberta, Glenrose Rehabilitation Hospital, Edmonton.
- Revised Recruitment Ad (2/14/2011)
- Revised Information Letter (2/14/2011)

Note: Approval for an amendment does not change the original approval date of a study.

Sincerely,

Dr. Jana Rieger
Chair, Health Research Ethics Board - Health Panel

Note: This correspondence includes an electronic signature (validation and approval via an online system).

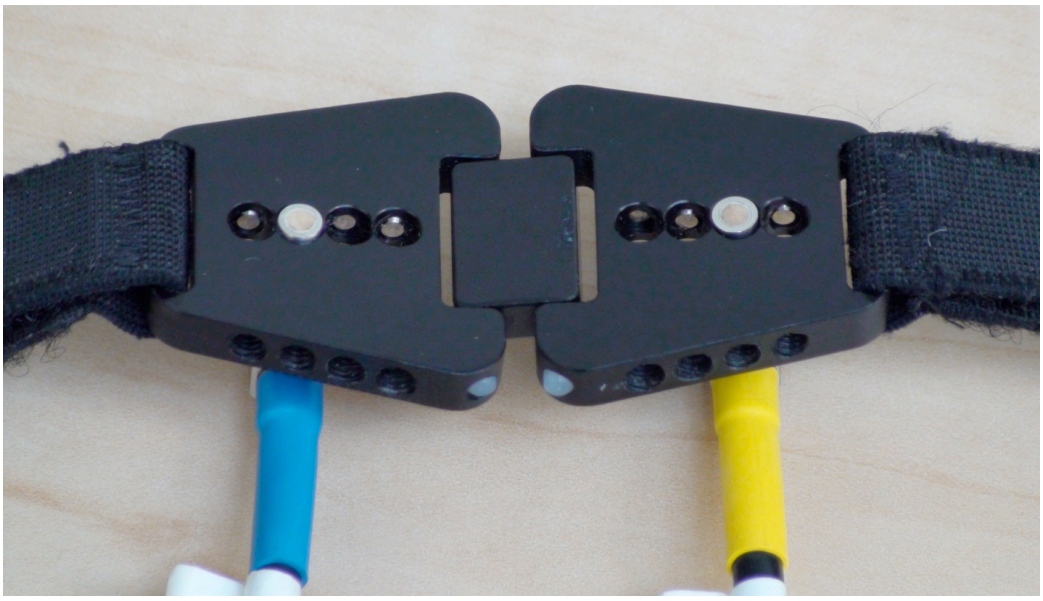
Appendix E:

Equipment setup with VS500M (driving simulator) and Oxymon Mk III (NIRS collection device)

Appendix F:

Close-up of VS500M driving console

Appendix G:



Close-up of NIRS optodes and optode holder. Transmitting optode is on the right and receiving optode is on the left. The inter-optode distance in 35 mm.

Appendix H:
Participant Questionnaire

Cerebral oxygenation and behavioural responses during simulated driving with and without hands-free telecommunication: a near infrared spectroscopy study

Participant ID:	
Age:	
Currently valid driver's license	Yes No
Year in which driving license was obtained	
Number of years of driving experience	
Number of traffic violation tickets in the past 24 months	0 1-3 4-6 7-9 10+
Number of traffic violation tickets so far	0 1-3 4-6 7-9 10+
Number of traffic accidents in the past 24 months	0 1-3 4-6 7+
Number of traffic accidents so far	0 1-3 4-6 7+
Are you familiar with driving simulators?	Yes No
Are you familiar with computer games/video games?	Yes No
Do you answer phone calls while driving on the road?	Yes No
Do you use a hands-free device while driving on the road?	Yes No
Do you use a Bluetooth® headset while driving on the road?	Yes No
Is your car audio system Bluetooth® enabled?	Yes No
Do you use a hand-held device while driving on the road?	Yes No
Do you listen to music (radio/CD/iPod) while driving on the road?	Yes No
Do you believe that answering a phone call while driving distracts you?	Yes No
If yes, how much do you think it distracts you?	Not that much Somewhat Often A lot Always
Do you experience dizziness while engaging in a simulation or video game?	Yes No
Do you frequently experience motion sickness?	Yes No

Appendix I:
Conversation flow and questions asked during hands-free telecommunication

HFTC 1:

"Hi <participant first name>, this is Mayank. How are you doing?...I am well too. Where are you right now?
So, have you ever driven to the international airport?
- If yes: Great! Will you be okay giving me directions?
    - If yes: If I am starting around the university campus, how would I get there?
    - If no: Can you please direct me where to get this information from?
- If no: Oh okay! I am around the university campus right now, can you please tell me where I can get this information?

Great thanks! So what are you doing these days?
- Where are you working? (if participant says they work)
- What are you studying? (if participant says they are in school)

How are you finding that?...Are you enjoying it, then?

So, I need to check something in my car, I will call you back in a bit. Okay, take care."

HFTC 2:

"Hi <participant first name>, this is Mayank again. So, I was talking to another friend and we were looking for a good restaurant for Chinese/Indian/Lebanese cuisine? Do you have one in mind?...And how do I get there?

So how is your family?
- Natural conversation flow, based on participant's responses.

Great! It was so good to talk to you! You take care and drive safely."

Appendix J:
Driving-related errors and heart rate data collection sheet

Trial 1 – Driving **without** a phone call (02:00 – 6:00)

Off road accidents	
Collisions with other vehicles	
Collisions with other objects	
Illegal turns	
Lane change without signalling	
Speed exceedance	
Ignoring a traffic lights	
Incomplete stop at a traffic light	
Ignoring a 'Stop' sign	
Incomplete stop at a 'Stop' sign	
Centreline crossings	
Road edge excursions	

Trial 1 – Driving **with** a phone call (06:00 – 08:00)

Off road accidents	
Collisions with other vehicles	
Collisions with other objects	
Illegal turns	
Lane change without signalling	
Speed exceedance	
Ignoring a traffic lights	
Incomplete stop at a traffic light	
Ignoring a 'Stop' sign	
Incomplete stop at a 'Stop' sign	
Centreline crossings	
Road edge excursions	

Heart Rate

at 00:00

_____

at 02:00

_____

at 03:00

_____

at 04:00

_____

at 05:00

_____

at 06:00

_____

at 07:00

_____

at 08:00

_____

at 10:30

_____

Trial 2 – Driving **without** a phone call (13:00 – 17:00)

Off road accidents	
Collisions with other vehicles	
Collisions with other objects	
Illegal turns	
Lane change without signalling	
Speed exceedance	
Ignoring a traffic lights	
Incomplete stop at a traffic light	
Ignoring a ‘Stop’ sign	
Incomplete stop at a ‘Stop’ sign	
Centreline crossings	
Road edge excursions	

at 13:00

_____

at 14:00

_____

at 15:00

_____

at 16:00

_____

Trial 2 – Driving **with** a phone call (17:00 – 19:00)

Off road accidents	
Collisions with other vehicles	
Collisions with other objects	
Illegal turns	
Lane change without signalling	
Speed exceedance	
Ignoring a traffic lights	
Incomplete stop at a traffic light	
Ignoring a ‘Stop’ sign	
Incomplete stop at a ‘Stop’ sign	
Centreline crossings	
Road edge excursions	

at 17:00

_____

at 18:00

_____

at 19:00

_____

at 21:00
(end)

_____