VISUOSPATIAL WORKING MEMORY AND DISTRACTED DRIVING: DECIPHERING GAZE BEHAVIOR, COGNITIVE WORKLOAD, AND DRIVING ERRORS

Ph.D. Thesis

By

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DISCIPLINE OF PSYCHOLOGY

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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A THESIS

Submitted in partial fulfillment of the
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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis titled, **VISUOSPATIAL WORKING MEMORY AND DISTRACTED DRIVING: DECIPHERING GAZE BEHAVIOR, COGNITIVE WORKLOAD, AND DRIVING ERRORS** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **DISCIPLINE OF PSYCHOLOGY, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from July 2013 to April 2019 under the supervision of Dr. Sanjram Premjit Khanganba, Associate Professor, Indian Institute of Technology Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

(SAJAD AHMAD NAJAR)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

(Dr. SANJRAM PREMJIT KHANGANBA)

SAJAD AHMAD NAJAR has successfully given his Ph.D. Oral Examination held on **August 19, 2019**.

Chairperson (OEB) Date:	External Examiner Date:	Thesis Supervisor Date:
PSPC Member Date:	PSPC Member Date:	PSPC Member Date:
Convener, DPGC Date:	Head of School Date:	

To

My Parents and Teachers

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LIST OF ABBREVIATIONS

AOI	Area of interest
ARM	Articulatory rehearsal mechanism
CS	Complex suppression
CWL	Cognitive workload
DBQ	Driver behavior questionnaire
DPI	Double-purkinje-image
DSR-OS	Distracting stimuli regulator – object and spatial
DSR-S	Distracting stimuli regulator – spatial
D3	Direction following in distracted driving
D3-OS	Direction following in distracted driving – object and spatial
D3-SARM	Direction following in distracted driving – suppressed articulatory rehearsal mechanism
D3-SSS	Direction following in distracted driving – Spatial – simultaneous and – sequential
ECG	Electrocardiogram
EEG	Electroencephalography
EMG	Electromyography
EOG	Electrooculography
ERPs	Evoked-related-potentials
HEI	Human error identification
HRV	Heart rate variability

IVIS	In-vehicle information systems
LCT	Lane change test
LSD	Least significance difference
MEPs	Magnetic –evoked-potentials
NASA-TLX	National aeronautics and space administration – task load index
NATRAX	National automotive test tracks
NATRiP	National automotive testing and R&D infrastructure project
NHTSA	National highway traffic safety and administration
NS	Non-suppression
RT	Reaction time
SARM	Suppression of articulatory rehearsal mechanism
SHERPA	Systematic human error reduction approach
SS	Simple suppression
SWAT	Subjective workload assessment technique
VSWM	Visuospatial working memory
VV Box	Video velocity box
WM	Working memory

ABSTRACT

This research examines issues concerning visuospatial working memory (VSWM) related to distracted driving. Analyses of gaze behavior, driving errors, and cognitive workload (CWL) are emphasized. This dissertation is comprised of three experiments conducted on a two-lane test-track. The role of VSWM processes are investigated in terms of suppression of Articulatory Rehearsal Mechanism (ARM), in-vehicle object and spatial distractions, and in-vehicle spatial – simultaneous and – sequential distractions. This dissertation reports development of three variants of an experimental paradigm named as *'Direction Following in Distracted Driving (D3)*' that were employed in three separate experiments.

Experiment-1 investigates the effect of suppressed ARM on gaze behavior and driving performance. In this experiment, 45 drivers voluntarily participated and drove an instrumented vehicle on a two-lane track. The results demonstrate that there are significantly lesser fixation durations and fixation counts under Complex Suppression (CS) of ARM as compared to the other two levels of suppression, i.e., Simple Suppression (SS) and Non-Suppression (NS) of ARM. Overall driving error analysis revealed that there are more significant errors under CS as compared to SS and NS. Moreover, drivers committed more slips than lapses irrespective of the levels of suppression.

Experiment-2 investigates how in-vehicle distractions (object and spatial distractions) affect drivers' gaze behavior and driving performance (N = 47). The results demonstrate that compared to spatial distraction, during object distraction fixation durations on AOI are significantly reduced and driving errors (i.e., both slips and lapses) are significantly increased. The frequency of committing slips and lapses is significantly higher in novices than expert drivers. The results of the study also demonstrate that the drivers experienced more CWL during object distraction as compared to spatial distraction. Furthermore, an increased CWL is associated with an increase in the occurrence of slips and lapses.

Experiment-3 focuses on investigating the role of in-vehicle spatial distractions (spatial-simultaneous and spatial-sequential) in driving errors and gaze behavior by engaging 27 participants. The results demonstrate that in comparison to spatial-sequential in-vehicle distractions, fixation durations and fixation counts on AOI (i.e., direction signboards) are significantly reduced and overall driving errors (i.e., both slips and lapses) are significantly increased during in-vehicle spatial-simultaneous distractions. Moreover, the results of the study also reveal that the drivers have committed more number of slips than lapses. The results of the study indicate that spatial-simultaneous distraction has more detrimental effect on driving performance as compared to spatial-sequential distraction.

Keywords: Working memory; articulatory rehearsal mechanism (ARM); distracted driving; driving errors; gaze behavior; fixation durations; slips; lapses; in-vehicle distractions

Chapter 1

Introduction

1.1. Background of the study

Driving is a common everyday activity that people perform. It involves handling of multiple tasks (e.g., lateral and longitudinal control, hazard perception, traffic rule compliance, etc.) in a dynamic environment. Often drivers are engaged in tasks that have potential to take their attention off the road. Driver distraction is one of the serious issues in automotive human factors (Papantoniou, Papadimitriou, & Yannis, 2016) which refers to diverting attention of the driver from the critical activity of maneuvering the vehicle. One of the factors responsible for on-road crashes and near crashes is distracted driving (Gordon, 2009) and the matter is more concerning as more interactive devices find their way inside the vehicles. World Health Organization (2011) acknowledged that distracted driving is a large and growing threat to road safety. Driver distractions, such as talking to passengers, eating, drinking, lighting a cigarette, tuning radio etc. existed since the inception of automotives, but since last decade distractions like use of interactive devices, e.g., sending and receiving emails, communicating via cellular devices, watching movies, using internet and GPRS has made an immense increase in the number of on-road crashes (Bureau, Govt. of India, 2017). The reason behind the increased number of crashes could be attributed to the concern that these distractions are more cognitively engaging and are performed over a sustained period of time.

The concept of distracted driving has received much research attention from contemporary researchers (Regan, Lee, & Young, 2009), but there is still larger scope to explore issues concerning visuospatial processing of working memory (WM) and their causal relationship with gaze behavior, cognitive workload (CWL), and driving errors. There is meager knowledge about these issues. This could be so, partly due to lack of experimental paradigms pertaining to distracted driving. This dissertation reports a series of experiments emphasizing scientific investigation of issues related to object and spatial distractions, gaze behavior and driving errors.

1.2. Context of the problem

Road-traffic accidents are identified as a major public health issue, which are among leading causes of deaths and disabilities resulting in a huge socio-economic loss (WHO, 2013). With reference to India, road-traffic accidents represent one of the top four leading causal factors for deaths within the age-range of 15-49 years (Bureau, Government of India, 2017). From the last decade, number of deaths on Indian roads show an upward trend. In the year 2016, the number of deaths on Indian roads was 150,785 whereas in 2015 the total number of deaths resulting from traffic accidents was 146,133 (an increase of 3.2 per cent over the previous year). Actual scenario is expected to be worst since reported figures do not account for various instances that remain officially non-recorded. Despite of the fact that more safety measures and smart features to avoid collisions are embedded in many vehicles, the severity of accidents, i.e., the number of persons killed per 100 accidents has seen a constant yearly increment from 21.6 in 2005 to 31.4 in 2016 (Bureau, Government of India, 2017). According to the 'Road Accidents in India – 2016 Report' drivers' fault is the single most important factor responsible for 84% of the road accidents. The risk of an on-road fatal accident is influenced by many intrinsic factors of drivers, e.g., age (Massie, Campbell, & Williams 1995; Eustace, & Wei, 2010); gender (Massie, Campbell, & Williams 1995); experience (McCartt, Mayhew, Braitman, Ferguson, & Simpson, 2009); driver's state, i.e., fatigue, drowsiness, intoxication, drugs and alcohol, emotional state, etc. (Zhao, Zhang, Zhang, & Rong, 2015; Zhao, Zhang, & Rong, 2014; Mortazavi, Eskandarian, & Sayed, 2009; Roidl, Frehse, & Hoger, 2014). Apart from these intrinsic factors, distracted driving makes it worst and significantly contributes to on-road fatal crashes, near crashes or injuries (Gordon, 2009). During 2016 alone, 4,976 accidents occurred on Indian roads due to distracted driving in which 2,138 persons died and 4,746 persons were injured (Bureau, Government of India, 2017).

Drivers get driving related information mainly through visual, auditory, and haptic receptors but it is predominantly visuospatial in nature (Sivak, 1996). The process of dealing with any raw information for further processing pertaining to the task at hand involves WM which is a limited capacity system (Baddeley & Hitch, 1974; Baddeley, 2000, 2007). WM temporarily stores and actively manipulates information in order to guide goal-directed behavior (Baddeley, 2007). In the context of driving, since the environment is dynamic and the drivers need to process visuospatial information from the driving environment (e.g. traffic lights, road signs, pedestrians, and other road users) to allow judgements of vehicle speed, lane positioning, and detection of potential hazards, the WM of drivers is constantly engaged. In such scenarios even if the driver gets distracted for a very brief period, there are high possibilities of crashes or near crashes. Despite the fact that many cognitive tasks (Cohen et al., 1994; Gronwall, 1977) have been developed in the context of WM, researchers have not studied the issue of WM related distractions and the underlying dynamics of gaze behavior and performance compromise.

1.3. Purpose of the study

Almost every driver, at one point of time or the other engages in distracted driving, unlucky are those who meet crashes, near crashes, or injuries. Those who do not meet such incidents does not mean they do not commit driving errors, it is just that they are lucky to escape from any negative consequences. Unfortunately, there has been very little research that has explicitly examined the role of WM processes in terms of Articulatory Rehearsal Mechanism (ARM), and processing of object and spatial information in a distracted driving scenario. Stanton and Salmon (2009) compared the research investigations of aviation sector and road transport sector and highlighted that in transport sector there is limited investigation of the types of errors that drivers make. There is meager knowledge about driving errors and their actual causal factors. Considering that establishing suitable procedure for experimentation is essential, this dissertation emphasizes on development and reporting of experimental paradigms in a series of test-track driving studies. The current research intends to gain scientific understanding of the underlying causal relationships between WM, driving performance and gaze behavior in the context of distracted driving.

This dissertation focusses on VSWM processes and reports execution of three experiments performed in a test-track driving environment. For any visual information to stay longer in WM till it is acted upon, it needs to be recoded into phonological information and rehearsed by ARM, but in a distracted driving scenario, the function of ARM would be suppressed due to which some of the driving related information would not be acted upon by the driver. In this context, experiment-1 investigates driving errors and gaze behavior of drivers when the ARM is suppressed. Available literature indicates that object appearance information and information about its location in space are processed by different cognitive systems (Hecker & Mapperson, 1997; Logie & Marchetti, 1991; Tresch, Sinnamon, & Seamon, 1993), and by different areas of the brain particularly parietal and dorsolateral frontal cortex play a significant role in processing the spatial location of objects, and that the ventral areas of the temporal and frontal lobes are mainly involved in processing the visual properties of objects (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991;

Courtney, Ungerleider, Keil, & Haxby, 1996; Munk et al., 2002; Nelson et al., 2000). In the light of this understanding, experiment-2 compares object and spatial distractions in terms of their effect on gaze behavior, CWL, and driving performance of drivers. Experiment-3 further investigates the issues related to spatial processing of information during distracted driving. Pazzaglia and Cornoldi (1999) distinguished between simultaneous and sequential spatial components of VSWM. The purpose of this study is to examine spatial-simultaneous and spatial-sequential distractions with respect to their effect on gaze behavior and driving performance.

1.4. Significance and objectives of the study

Driving is a task which is undertaken in a highly dynamic environment and it relies heavily on visuospatial information. Drivers need to process driving related information from various sources and integrate relevant information into a unified representation of the situation. Moment by moment this representation of the driving environment needs to be updated, thus challenging a driver's WM (De Waard, 1996). However, in a distracted driving scenario, drivers often fail to devote sufficient attentional resources to driving because of their engagement in some other competing activity (e.g., interaction with an in-vehicle interface). On the whole, in a series of experiments, the current research investigates how suppression of ARM, and in-vehicle object and spatial distractions affect drivers' gaze behavior, CWL, and driving performance. The dissertation reports development and implementation of three variants of *'Direction Following in Distracted Driving (D3)'* in three separate experiments. D3 could be used by automotive human factors researchers for investigating distracted driving not only in test-track driving studies but also in driving simulation studies. The three variants are '*Direction Following in Distracted Driving – Suppression of Articulatory Rehearsal Mechanism (D3-SARM*)' (mentioned in chapter-3), *'Direction Following in Distracted Driving –*

Object and Spatial (D3-OS)' (mentioned in chapter-4), and '*Direction Following in Distracted Driving: Spatial – Simultaneous and – Sequential (D3–SSS)*' (mentioned in chapter 5). The results of this research signify the importance of strict enforcement of legislation and policies related to distracted driving. For compliance with laws to be achieved, high levels of enforcement must be maintained overtime, thereby increasing the perceived risk of being caught, while penalties for transgression should be stipulated and publicized so that they act as a deterrent. In such a way, legislation can also become an important tool for shaping behavior and fostering a culture of road safety that results in sustained reductions in road traffic injuries–or at least prevent the level of safety from degrading in the future.

Particularly the present research explores the role of distractions which engage specific WM processes, (i.e., ARM, object and spatial information processing), and expertise in gaze behavior and driving performance. In this scientific endeavor, a series of experiments were conducted in a test-track driving environment with the following specific objectives:

A. Experiment-1

1. To investigate the effect of suppression of ARM on drivers' gaze behavior.
2. To investigate the effect of suppression of ARM on driving errors.

B. Experiment-2

1. To investigate the effect of in-vehicle object and spatial distractions on drivers' gaze behavior.
2. To investigate the effect of in-vehicle object and spatial distractions on driving errors.

3. To investigate the effect of expertise on drivers' gaze behavior.
4. To investigate the effect of expertise on driving errors.
5. To investigate the respective CWL imposed by in- vehicle object and spatial distractions.

C. Experiment-3

1. To investigate the effect of in-vehicle spatial-simultaneous and spatial-sequential distractions on drivers' gaze behavior.
2. To investigate the effect of in-vehicle spatial-simultaneous and spatial-sequential distractions on driving errors.

1.5. Direction following in distracted driving (D3)

An experimental paradigm named as *'Direction Following in Distracted Driving (D3)'* is developed for this research. D3 paradigm (as a generic nomenclature) is used in all the three experiments reported in this dissertation. This paradigm incorporates the parameters of vehicular platform, lane setting, direction input, speed range, distance, and distraction inducement. Description of each parameter is given in the next paragraph.

In this research, an instrumented vehicle (*vehicular platform*) was driven by drivers on a two-lane track with a total length of 1 km. The two lanes were separated from each other by lane markers (*lane setting*). The drivers were instructed to follow certain directions displayed on the direction signboards (*direction input*). There were 4 identical pairs of direction signboards (hereafter referred to as twin signboards) in total (where direction signboards installed on one side of the track were the copy of the direction signboards installed on the other side of the track). On a two-lane track, according to the rule of product, there are six sets of unique possible directions. In case of this dissertation, as shown in table 1 each set consists of three directions. All the six sets of directions were randomized and the distance between any two direction signboards was 250 meters. Depending on the distance of the track, the number of direction signboards could be utilized and in the current study, the *distance* was 1 km so only first four direction signboards could be used. In addition to the actual experimental two-lane track, a grace length of around 250 meters were utilized so that the driver could attain the required speed limit (i.e., within the *speed range* of 20-45 km/h for experiment-1, and 25-35 km/h for experiment-2 and experiment-3). The speed limits are set by taking into consideration the maximum speed limits suggested by Tingvall and Haworth (1999) guidelines. Drivers were required to drive according to their comfortable speed without deviating from the stipulated range. Each pair of direction signboards were marked by two signs "↑" and "X". "↑" sign indicates that the driver has to take the corresponding lane, while the other lane was marked by a "X" sign, which indicates that the driver has to avoid driving in the corresponding lane. The starting lane of the drive was decided on random basis which came out to be the left lane. The height of the direction signboards, color of the figure and background, and the size of the "↑" and "X" were decided by strictly following the Code of Practice for Road Signs (Third Revision) published by Indian Road Congress (2012). In order to achieve experimental control, it was ensured that any 'unwanted' movement on the experimental track was not allowed. For this purpose two crew members were deployed at the strategic points of the track. Drivers were distracted by three different mechanisms (*distraction inducement*) in three corresponding variants of D3 paradigm. Each variant of D3 is used in three separate experiments.

The three variants of D3 paradigm are specified below. Detailed descriptions of D3-SARM, D3-OS, and D3-SSS are reported in chapter 3, chapter 4, and chapter 5, respectively.

a) *Direction Following in Distracted Driving – Suppression of Articulatory Rehearsal Mechanism (D3-SARM) paradigm:* Experiment-1 uses this variant of D3 paradigm in order to investigate the effect of suppression of articulatory rehearsal mechanism on driving performance and gaze behavior.

b) *Direction Following in Distracted Driving – Object and Spatial (D3-OS) paradigm:* Experiment-2 uses this variant of D3 in order to examine the effect of in-vehicle distractions while processing object appearance information and information related to the location of the object in space (i.e., spatial information) on driving performance and gaze behavior.

c) *Direction following in distracted driving: spatial – simultaneous and – sequential (D3–SSS) paradigm:* Experiment-3 uses this variant of D3 paradigm in order to study the effect of in-vehicle spatial distractions (in terms of spatial–simultaneous and spatial–sequential distractions) on driving performance and gaze behavior of drivers.

In the context of the current research, D3 paradigm is executed on a two-lane test-track. In any study, in order to use D3 paradigm the track has to have at least two lanes. In the future, researchers may modify &/or adapt the existing variants of D3 with respect to the current parameters and cognitive processes involved. For instance, based on the requirement of the specific research problem(s), investigator(s) may employ research strategies within the framework of D3 paradigm by using more number of direction signboards or increased length of the test track or even focusing on any other relevant aspect of cognitive processing. In case D3 is executed on a track involving more than two lanes, then the direction signboards should be designed in such a manner that it displays the exact number of lanes involved in the experiment. Furthermore, researchers are free to come up with new ideas (including additional parameters) to suit the requirement of scientific endeavor.

1.6. Thesis outline

This chapter has highlighted the background and the context of the study. It has also specified the purpose and objectives of the current study. Chapter 2 discusses the available literature specifying the role of WM in distracted driving, issues related to driving errors, and the changes in gaze behavior due to distracted driving. This includes a review of previous research on the role of CWL and expertise in affecting driving performance and gaze behavior. Chapter 3 reports Experiment-1, which investigated how the eye movement patterns and driving performance is affected by the suppression of ARM (a mechanism in WM for rehearsing phonological information) in a test-track driving environment. Chapter 4 reports Experiment-2, which investigated how the in-vehicle object and spatial distractions affect eye-movement patterns and driving performance. This chapter also examines the respective CWL while processing object and spatial information. Experiment-3 is reported in Chapter 5, in which processing of spatial information is further investigated (in terms of spatial-simultaneous and spatial-sequential) in the context of driving. Finally, Chapter 6 provides a comprehensive discussion on the basis of the findings of the three experiments, and chapter 7 presents a consolidated account of the findings, discusses the limitations and the implications of this research, and describes the scope for future research.

Table 1.

Sets of directions

	Direction 1	**Direction 2**	**Direction 3**	**Representation of the Physical Configuration (in terms of the Sets of Directions) Used in D3-SARM**
Set 1	Lane 2	Lane 1	Lane 1	
Set 2	Lane 2	Lane 2	Lane 1	
Set 3	Lane 1	Lane 2	Lane 1	
Set 4	Lane 2	Lane 1	Lane 2	
Set 5	Lane 1	Lane 1	Lane 2	
Set 6	Lane 1	Lane 2	Lane 2	

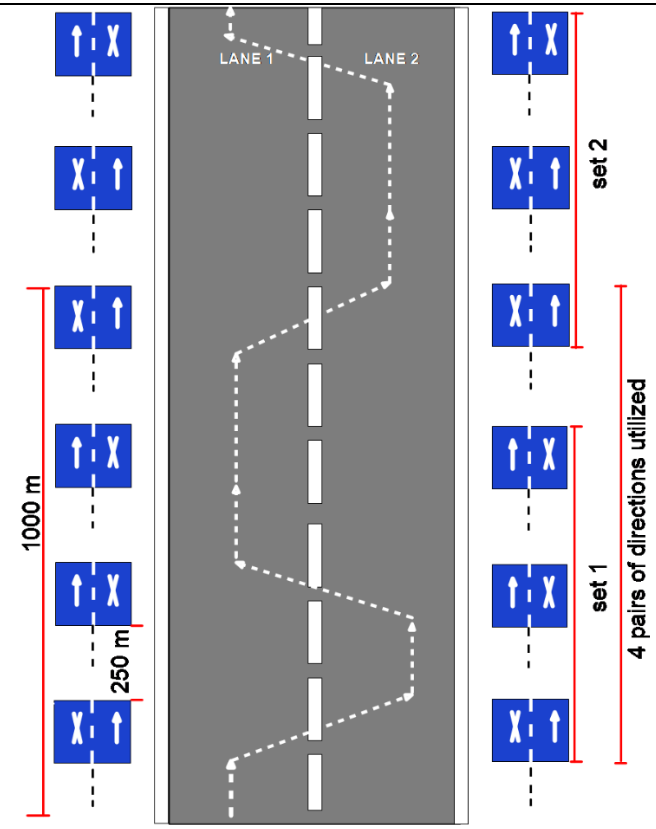
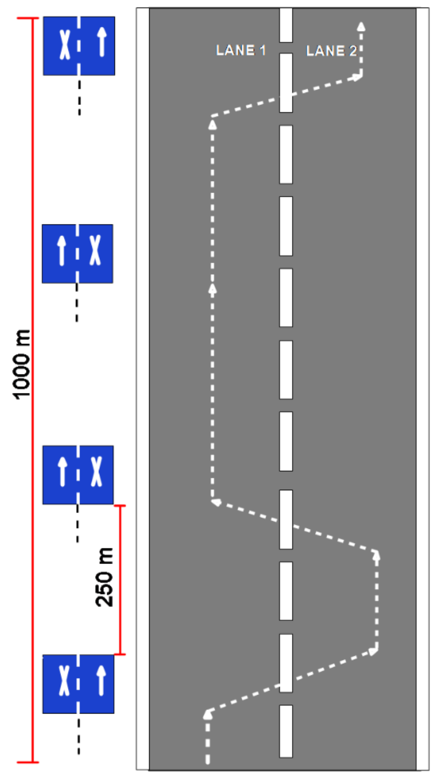


Table 1. *(Continued)*

	Direction 1	Direction 2	Direction 3	Representation of the Physical Configuration (in terms of the Sets of Directions) Used in D3-OS and D3-SSS
Set 1	Lane 2	Lane 1	Lane 1	
Set 2	Lane 2	Lane 2	Lane 1	
Set 3	Lane 1	Lane 2	Lane 1	
Set 4	Lane 2	Lane 1	Lane 2	
Set 5	Lane 1	Lane 1	Lane 2	
Set 6	Lane 1	Lane 2	Lane 2	

Chapter 2

Review of Literature

2.1. Driver cognition: working memory and distracted driving

Driving is a complex and dynamic information-processing task which requires coordination of visuo-motor and other cognitive abilities (Haring, Ragni, & Konieczny, 2012). For a safe driving, a driver has to constantly update the information of the situations he/she is driving in, cognitively process, and accordingly act on that information without any delay. The cognitive processes that are required for driving includes attention, WM, visuospatial abilities, visual search and the knowledge associated with the details of vehicle operation.

Baddeley and Hitch's (1974) model of what they term as 'working memory' has dominated the literature over the past four decades. Although the model has changed a little in fundamental conceptualization over the years, the regular frequent updates that Baddeley has made (1986, 1998, 2000, 2007), have ensured that it provides a coherent account of a far broader range of findings than any competing model (Nairne, 1990; Lovett, Reder, & Lebiere, 1999; Cowan, 1999). Certainly, there are difficulties with some elements of the framework, which are readily conceded by those who work within and those outside the WM framework (e.g., Logie, 1995; Gathercole, 1996; Merat & Groeger, 2003), but its breadth and coherence make it very useful as a way of exploring the dependence of a task such as driving on transitory memory (Groeger, 1997).

In essence, the central concern of WM model is to account for how people acquire and maintain sufficient information to guide their performance in the tasks they perform. The model assumes that there are two systems, the phonological loop (Baddeley, Lewis, & Vallar, 1984) and the visuospatial scratchpad or sketchpad (Baddeley, 1986) which are specialized for dealing with (1) phonological information, and (2) visuo-spatial information (which includes both imagery and movement control) respectively (Logie, 1995). Phonological loop is composed of two elements: a passive store, dedicated to storage of phonological information, and an active rehearsal or translation process, which serves to maintain the level of activity of items in the passive store, and to translate or recode the information from one format to another. Thus, for example, the "articulatory rehearsal process", which is the active maintenance element of the phonological loop, is involved in the transformation of any visual information which has a verbal label, into phonological information (Baddeley, 2007). A third and overarching system, the central executive, is essentially a collection of processes that come into operation when the individual becomes involved in some goal-directed strategic activity (Baddeley, 1992). It serves as a quasi-attentional system, being involved in selecting what will be attended to, maintaining attention, switching attention between two or more things that might be attended to, inhibiting undesired activities, effortful or strategic encoding or retrieval, the coordination of how the two 'slave' systems operate, and coordinating activities in dual task situations. This is a rather long list of functions and Baddeley conceded that the central executive can no longer be sensibly regarded as a single entity (Baddeley, Emslie, Kolodny, & Duncan, 1998).

In addition to accounting for many of the difficulties encountered by earlier conceptualizations of short-term memory, the WM model is largely based on two types of evidence. One type of evidence has been gained from studies of memory disorders (Baddeley & Wilson, 1985) and, from studies of imaging of intact brains (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991). These have helped to identify neurological basis for most of the components of the WM model. The other type of evidence, and in essence the empirical bedrock of the theory, comes from studies of patterns of interference (Logie & Marchetti, 1991; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999) that occur when two tasks (at least one of which is known to require the involvement of one component of the WM model) are performed concurrently.

Similarly in the case of driving task, any interference (distraction) by some other competing activity, will increase demand on cognitive resources and would be reflected in driving performance in terms of compromise in it. Quite some time ago now, Brown, Tickner, and Simonds (1969) investigated one such phenomenon by engaging 24 drivers who had to drive through gaps on a flat roadway. The gaps were created by positioning two 4ft high, 1.75ft wide hardboard covered frames at various distances apart: 3 inches less than the car width; the car width (5ft); and 3, 6, and 9 inches wider than the car. Drivers drove through 20 gaps, composed of random arrangements of four of each type. Before confronting each gap, the driver had to determine whether or not he could pass through it without colliding; if the latter was the decision, there was sufficient space for him to pass by the obstacles with a slight alteration in course. Simultaneously, the drivers also performed a verbal reasoning task (i.e., saying "true" or "false" to sentences such as "A follows B – BA", "B precedes A – AB", "A is followed by B – AB", "B is not followed by A – BA", "B is preceded by A – BA", "A does not precede B – BA", etc.,. This task was previously used by Baddeley (1968). When both tasks were performed concurrently, drivers drove through more impossible gaps (–3 inches: 47.2%; 0 inches: 93.0%) than when driving without performing the verbal reasoning task (–3 inches: 28.0%; 0 inches: 70.8%), and rejected more possible gaps in the concurrent condition (3 inches: 81.2%; 6 inches: 39.2%; 9 inches: 18.5%), than in a single task driving condition (3 inches: 79.5%; 6 inches: 28.5%; 9 inches: 7.7 %). Performance on the sentence-checking task was also worse in the concurrent task condition, taking on average 800 ms (1.81 seconds versus 2.60 seconds) longer and with almost twice as many errors (23.8% in single task driving condition versus 45% in the concurrent task condition).

Hearing sentences lasting a couple of seconds and maintaining some representation of the order in which the letters were said, and uttering a monosyllabic response while driving towards narrow gaps, clearly demonstrates that decision making will be severely decremented by a difficult, attention demanding task. This was one of the first studies in which the possibility was put forward that higher-order aspects of the driving task, such as those requiring some explicit decision making, also draw on some form of executive or supervisory attentional process.

Furthermore, from the perspective of WM, verbal reasoning is demanding both of the phonological loop, only to maintain the sentence in memory, and the central executive. Interestingly, Groeger, Field, and Hammond (1999) used Baddeley's (1968) verbal reasoning task and found that performance on the test predicted reliably the assessments made by driving examiners of some 100 drivers' skill levels and tendency to adopt a speed appropriate for the real road conditions in which they drove. This strengthens the suggestion that the central executive plays a role in adapting behavior to the particular demands of a situation. Interestingly, in a dual task study of driving by Duncan, Williams, Nimmo-Smith, and Brown (1992), concurrent performance of a demanding secondary task was associated with later breaking on entry to intersections, a result that perhaps corroborates the suggestion that suiting speed to the conditions in which we are driving is demanding of central resources.

Unfortunately, there has been very little research that has explicitly examined the role of visuo-spatial sketchpad in driving. Certainly, as is evident from studies carried out outside a driving context, that ability to learn and indeed to recollect a well-known route is interfered with if people are required to perform a reasonably simple tracking task at the same time

(Baddeley, 1986). There is also substantial evidence that constructing and maintaining visual images has a negative impact on perception (e.g., Craver-Lemly & Reeves, 1992; Farah, 1988). Furthermore, the close association of movement control with spatial memory processes (Logie, 1995), and the fact that movement control is clearly vital to driving, might further suggest that steering control would be interfered with by the imposition of an additional visuo-spatial task. A final speculation is that, localizing sound in space is particularly demanding of spatial WM (Merat & Groeger, 2003), and deciding where a car horn has sounded from (i.e., 'was the other driver blowing his/her horn at me?'), or determining whether-blaring emergency vehicle is behind you or ahead, may also lead to steering disruption. There is also evidence that requiring drivers to perform a complex spatial judgement has a negative impact on their ability to assess when they will arrive at a distant object towards which they are travelling (Groeger & Comte, 1999).

In a study reported by Verwey (1991), drivers were either classed as experienced (license held for at least 5 years and drive more than 10,000 km per year) or novices (license held for less than 1 year and drive less than 10,000 km ever), performed a number of paced tasks, saying when a number appeared on a screen on the dashboard, saying what the sum was of successive pairs of numbers displayed on the same screen, or reporting aloud when the same numbers were heard rather than seen. They did this before driving, and while performing six driving maneuvers (merging or exiting a motorway, driving straight ahead on a motorway, turning at a two-lane roundabout, performing a complex turn across oncoming traffic, turning—not across oncoming traffic, i.e., left in UK or right in Netherlands—driving straight ahead on a rural road). The results show that visual detection, visual detection plus addition, and auditory detection plus addition place different loads on the driver, but more importantly, the extent to which the driving task interferes with ability to perform the secondary task depends crucially on the maneuver underway. This study makes it clear that driving situations differ in the extent to which they are demanding of visual attention. Even when not being occasionally visually distracted from where they might wish to look at the road, experienced drivers' capacity to carry out the (auditory) serial addition task is reduced where turning rather than driving straight ahead. What is more evident, however is the way in which novice drivers' capacity is sharply reduced from baseline performance across all, but especially the more complex, maneuvers. Contrast the performance of the visual and auditory versions of the addition task. In each case the requirement to maintain a visual code or recode a visually presented number into a speech code, rather than maintain an auditory/speech-like code, has an effect over and above the difficulty imposed by simply adding the two numbers together. Paced auditory and visual serial addition has been shown by Merat and Groeger (2003), to be very demanding of what are generally seen as executive processes. What this study additionally shows is that the presentation of the additional task, and the addition task itself, are separate sources of competition for the resources that are also used to differing extents when driving in different situations. This implies that different information processing resources are required by different driving maneuvers, and in doing so also serve to echo a debate in the wider attention literature.

The results just considered add emphasis upon Navon and Gopher's (1979) suggestion that 'many findings would embarrass the strict model of central capacity interference'. In part, these findings reflect cases in which interference between tasks is predicted not by their difficulty, as one might expect from a simple single-central resource hypothesis, but by 'structural' overlaps between the structures of the two tasks (e.g., the codes in which stimuli are presented or processed, modalities of processing or responding). This is demonstrated in findings by Wickens (2002) among others. Studies are also reported in which, under dual task conditions, an increase in the degree of difficulty in one task does not degrade performance of the other task (e.g., Wickens, Sandry, & Vidulich, 1983). A study by Allport, Antonis, and Reynolds (1972), showed that skilled pianists could sight-read music and engage in verbal shadowing without any discernable decrement in the performance of either task, exemplifies another class of findings that posed difficulties for the unitary view, in that they appear to show perfect time sharing between tasks. In order to account for these and other findings, Wickens (1980, 1984, 2002) proposed that resources can be defined by three simple dichotomous dimensions: 'two stage-defined resources (early versus late processes), two modality-defined resources (auditory versus visual encoding), and two resources defined by processing codes (spatial versus verbal)'.

In another study, in the context of the Lane Change Test (LCT), Engström and Markkula (2007) investigated the effect of visual and cognitive distraction on driver errors. The authors, while confirming the findings of previous researches, reported that standard deviation of lateral position (SDLP) – a driving performance measure used in LCT, increased during visual distraction, whereas, cognitive distraction, in comparison with visual distraction affected detection and recognition of the sign and the ability to select the correct response. In an on-road naturalistic driving study, Harbluk, Noy, Trbovich, and Eizenman (2007b) because of safety reasons, did not induce any kind of visual distraction, however, drivers were required to perform cognitively challenging tasks. 21 participants drove a vehicle for 8 km in a city traffic under three conditions: no additional task, easy cognitive task, and difficult cognitive task. The results revealed that as compared to no task, the time spent for scanning peripheries of the road significantly reduced and the participants spent more time looking centrally ahead during difficult cognitive task. Moreover, during difficult cognitive task, drivers made fewer inspection glances to traffic lights compared to the no task condition and their scanning of intersection areas to the right was also reduced. Their results indicate that although hands-free designs for telematics devices are intended to reduce or eliminate the distraction arising from manual operation of these units, the potential for cognitive distraction associated with their use must also be considered and appropriately assessed.

Mantyla, Karlsson, and Marklund (2009) engaged teenage novice drivers in a simulated driving task and the same participants also completed six experimental tasks that tapped three basic components of executive functioning, i.e., response inhibition, WM updating, and mental shifting. They reported that WM updating is the primary predictor of driving performance in young teenage drivers. In another study on WM and distracted driving, Ross et al., (2015) examined the correlation of measures of response inhibition and WM with risky driving behavior of young novice drivers. 30 participants, with less than 1 year of driving experience, completed a simulated drive that included several risky driving measures and the results suggested that response inhibition and verbal WM were negatively associated with the standard deviation of the lateral lane position. VSWM performance related positively with yellow-light running and negatively with the minimal following distance inside the city center. In order to investigate whether higher WM capacity would lead to better lane-change task performance, Ross et al. (2014) reported that performance on LCT measures deteriorated when verbal WM load was increased and the higher the WM capacity the drivers had, better was their LCT performance. Distractions with respect to WM are often classified on the basis of sensory modalities (i.e., visual, spatial, or auditory) or on the basis of the stage of information processing (i.e., encoding or retrieval) when the distraction takes place. Logie, Zucco, and Baddeley (1990) reported greater interference when the processing task (primary task) and the interference task (secondary task) are of the same content (e.g., a visual distraction task will have a stronger detrimental effect on visual processing of WM than will have an auditory distraction task). WM capacity is closely linked to individual's ability to filter out irrelevant visual distractors (Vogel, McCollough, & Machizawa, 2005). Similarly, Fukuda and Vogel (2009), also observed that people with superior WM capacity are less susceptible to attentional capture by distractors encountered within target display. Performance of a secondary task (distractor) during memory encoding of a primary task has a large detrimental effect on the latter retrieval whereas the performance of the same secondary task during the retrieval phase has relatively lesser effect on memory performance but the performance on the secondary task gets impaired (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). However, retrieval operations are quite costly in terms of processing resources (Craik & McDowd, 1987). The possible justification for such a phenomenon could be that retrieval processing is given priority and that an increase in processing costs are borne by secondary task.

2.2. Distracted driving and gaze behavior

Examination of gaze behavior is a powerful means for investigating perceptual and cognitive demands of any task and it is being widely used in the context of driving. Understanding of the patterns of gaze behavior in the situations of distracted driving helps in designing better counter measures for alleviating the consequential effects of distracted driving. Gaze behavior (eye movements) are examined by the use of a variety of eye-trackers. The earliest eye-trackers were built in the late 1800s but they were not comfortable for the participants and were not efficiently usable. In order to keep the heads of the participant's still, Huey (1898) used a bite-bar with partially cooled sealing-wax attached to the mouth piece. During the same time period, Delabarre (1898) anaesthetized the eyeball by applying a solution containing cocaine, afterwards, a Paris ring would be attached to the eye of the participants which connected it to a mechanical level. It was only at the beginning of the twentieth century when Dodge and Cline (1901) introduced the principle of photographing the reflection of an external light source from the fovea. This is much less invasive and in recent years has become the dominating technique for recording eye movements. From around 1950, individual researchers, according to the requirements of their research, developed a variety of eye-trackers and techniques, for instance, lens systems with mirrors, though measured eye movements precisely but such systems were highly uncomfortable. The second generation of eye-trackers were electromagnetic coil systems, which measure the electromagnetic induction in a silicon contact lens placed on the anaesthetized eye. Systems with such technology were long considered the most precise method of measuring any eye movements (Collewijn, 1998), but are now known to alter the saccades of participants who wear them. Another generation of eye-trackers used electrooculography (EOG) which measures the electromagnetic variation when the dipole of the eyeball musculature moves. Such systems only measured horizontal movements, and suffered from the electromagnetic noise of surrounding muscles. In 1985, Crane and Steel designed Double-Purkinje-Image (DPI) eye tracking system which captures reflected infrared light that is projected on the eye.

Even if all the current eye-tracking systems use video-based pupil-to-corneal reflection measurement technology, depending on the purpose of the research and the environment (laboratory set-up or real life situation) in which it is conducted, different forms of eye trackers are used. Basically, a video-based eye-tracker has an infra-red illumination and an eye video camera, and typically an additional scene camera for head-mounted eye-trackers. Illumination(s) and camera(s) can be put on a table in front of the participants, or their heads. Sometimes head tracking is added to head-mounted systems. This gives us three types of eye trackers that differ not only with respect to the position of cameras and illumination, but more importantly in the type of data they produce and how we can analyze the output. Currently the following forms of eye-trackers are used:

1. The most common set-up is the *static eye tracker,* which puts both illumination and eye camera on the table, in front of the participants. There are two sub-types; *tower-mounted eye-trackers* that are in close contact with the participant, restraining head movements, and those that view from distance, known as *remote eye trackers*, with nothing or very little attached to the head. In practice, stimuli are almost always presented on a monitor, although wall projections and real scenes can easily be used with static eye-trackers.
2. Another common set-up is the *head-mounted eye-tracker,* which has put both illumination and cameras on the head of the participant, mounted on a helmet, cap, or a pair of glasses. A scene camera takes the role of recording the stimulus—the scene of view.
3. The third type of set-up adds a *head-tracker* to the head-mounted eye-tracker in order to calculate the position of head in space. This addition makes the analysis of data from head-mounted systems much easier, not many manufacturers offer this combination, however.

2.2.1. Types of eye movements

Human eyes are controlled by three pairs of muscles which are responsible for horizontal, vertical, and torsional eye movements and hence control the three-dimensional orientation of the eye. The most reported event in eye-tracking research does not in fact relate to a movement, but to the state when the eye remains still over a period of time. This is called *fixation* and lasts anywhere from some tens of milliseconds up to several seconds. It is generally considered that when we measure a fixation, we also measure attention to that position, even though exceptions exist that separate the two. The word ‘fixation’ is a bit misleading because the eye is not completely still, but has three distinct types of micro-movements: *tremor* (also called as physiological nystagmus), *microsaccades*, and *drifts*

(Martinez-Conde, Macknik, & Hubel, 2004). Tremor is a small movement of frequency around 90Hz, whose exact role is unclear; it can be imprecise muscle control. Drifts are slow movements taking the eye away from the center of fixation, and the role of microsaccades is to quickly bring the eye back to its original position.

The rapid motion of eye from one fixation to another is called a *saccade*. Saccades are very fast—the fastest movement the body can produce—typically taking 30-80 ms to complete, and it is considered safe to say that we are blind during most of the saccade. Saccades are also very often measured and reported upon. A large portion of saccades do not stop directly at the intended target, but the eye 'wobbles' a little before coming to a stop. This post-saccadic movement is called a *glissade*. Another type of eye movement is *smooth pursuit*. These are conjugate eye movements which smoothly track slowly moving objects in the visual field. They typically require a moving object to elicit them and are not usually under voluntary control. Their purpose, partly, is to stabilize moving objects on the retina thereby enabling us to perceive the object in detail.

Eye movements are motivated by the need to improve the acuity and increase the cortical processing power for (a) guiding actions, and (b) identifying objects and events (Findlay & Gilchrist, 2003; Land, 2006). The fixation act is the most effective mechanism for attention deployment. Attention and eye movements are strongly linked through shared anatomical areas in the brain (Corbetta, et al., 1998). Importantly, this strong attention-eye-movement link is complemented by a simultaneous preparation to act on the attended item (Craighero & Rizzolatti, 2005). Thus, eye movements are strongly indicative of where attention is allocated and of preparation to act on the fixated item. Looking in the wrong direction at a critical moment while driving can have disastrous consequences. Yet we cannot look exclusively at the road ahead. The continuous uptake of information by foveal (central) and peripheral vision for path and headway control has to be satisfied in the presence of other tasks requiring foveal vision, such as checking moving and stationary objects in the visual periphery, reading road signs, and monitoring in-vehicle displays. When these ‘secondary’ tasks require vision, a time-sharing behavior is exhibited with the eyes being continuously shifted back and forth between the road center and the off-path object. The main reasons to return fixations to the road center are that (a) fixating on a point on the future path about 1s ahead is the main mechanism for trajectory aiming and gives the best coordinates for steering (Wann & Swapp, 2000), and (b) fixating on the road center area also provides time-to-collision information regarding vehicles and objects in path. Drivers time-share not only between the road center and in-vehicle tasks, but also between the road center and other driving-related objects such as signs, bicyclists, mirrors, and scenery (Land, 2006). Visual behavior is also strongly responsive to driving demands. When drivers are faced with increased driving task demand during the performance of in-vehicle visual tasks, they adapt their glance behavior by increasing viewing time to the road (Senders, Kristofferson, Levison, Dietrich, & Ward, 1967; Victor, 2005) or reducing vehicle speed (Engström, Johansson, & Östlund, 2005). The fundamental importance of eye fixations for action guidance is demonstrated by the way a person’s gaze concentrates on the distant path region (i.e., the road center) during the on-road glances in visual time sharing (Victor, 2005).

2.3. Human error and distracted driving

Human error is the most undesirable aspect of life when it leads to negative consequence(s). Human’s vulnerability to commit error is so intrinsic that it exists almost in every sphere of life, be it medical surgeries, battlefield, aviation, operating power plants, chemical industries, or driving a vehicle. According to the available scientific literature, human errors are the consequences of unintended events. Every time an error occurs it may or may not result in an undesired consequence. The consequence of the error is purely dependent on the chance factor and on the surrounding environment in which the error takes place. There are two situations when the error might not meet undesired consequences: near-miss, and no-harm events. In a near-miss situation, the performer of the task realizes immediately after committing an error before it translates into an accident by performing a corrective action. In a no-harm situation, the error is not immediately recognized but fortunately, because of the surrounding environment, the adverse consequences does not occur. Human error has been a major cause of almost all of the catastrophic accidents that have occurred in the past (e.g., Tokaimura Criticality Accident 1999; Bhopal Gas Tragedy 1984; Tenerife Airport Disaster 1977 etc.). Human error is probably the major contributor to loss of life, injury to personnel, and property damage. A major cause of errors is a mismatch between the demands of the task and the resources available with the operator. The demand for resources depends on the nature of the task the operator is performing, for instance, physical demand or cognitive demand are required to a lesser or greater extent by various tasks. Many researchers have attempted to define human error but as such there is no precise definition of human error which could be universally accepted. The most popular definition of human error has been provided by Reason (1990). According to him, human error is a generic term to encompass all occasions in which a planned sequence of mental or physical activity fails to achieve its intended outcome. For over a century, human error is being studied and many error taxonomies have been provided by researchers, but because of its dynamic nature one error taxonomy does not corroborate the errors happening in other task domains. Based on different task domains, researchers have developed various error taxonomies (for e.g., Sabey & Staughton, 1975; Norman, 1981; Rasmussen, 1986; Reason, 1990; Verwey et al. 1993; Wierwille et al. 2002; Stanton & Salmon, 2009).

On the basis of various previous prominent error taxonomies, Stanton and Salmon (2009) developed a generic error taxonomy (see table 2). While proposing this taxonomy, they considered both the form which errors take and the different types of causal factors (psychological mechanisms) that lead to these errors.

Table 2

Generic driving error taxonomy (Stanton & Salmon, 2009)

Underlying Psychological Mechanism		External error mode	Example
Action errors	Action execution	Fail to act	Fail to check rear view mirror
	Action execution	Wrong action	Press accelerator instead of break
	Action execution	Action mistimed	Brake too early or too late
	Action execution	Action too much	Press the accelerator too much
	Action execution	Right action on wrong object	Press accelerator instead of break
	Action execution, Planning, and intention	Inappropriate action	Following too close, race for gap, risky overtaking, etc
Cognitive and decision making errors	Perception	Perceptual failure	Fail to see pedestrian crossing
	Perception	Wrong assumption	Wrongly assume a vehicle will not enter path
	Attention	Inattention	Nearly hit car in front when queuing
	Attention	Distraction	Distracted by secondary task e.g. mobile phone conversation
	Situation assessment	Mis-judgement	e.g. misjudged speed of oncoming vehicle,
	Perception	Looked but failed to see	Looked at road ahead but failed to see pedestrian
Observation errors	Memory and recall	Fail to observe	Failed to observe area in front of vehicle
	Memory	Observation incomplete	Failed to observe offside mirror when changing lanes
	Memory and recall	Observation mistimed.	Looked in drivers side mirror too late when changing lane
Information retrieval errors	Situation assessment	Misread information	Misread road sign, traffic control device or road markings
	Situation assessment	Misunderstood information	Perceive information correctly but misunderstand it
	Situation assessment	Wrong information retrieved	Read wrong information from road sign
Violations	Action execution, planning and intention	Intentional violation	Overtake on the inside, knowingly speed
	Action execution	Unintentional violation	Unknowingly speed

2.4. Cognitive workload and driving

Drivers' ability to capture driving related information, interpretation and timely action upon that information determines safe driving. However, the cognitive resources of the driver to perceive, interpret, and execute driving related information are limited. The limitation of cognitive resources brings the issue of CWL in focus. The mismatch between the demands of the driving situation and the limited availability of cognitive resources is a major concern for traffic safety. CWL imposed by a task or multiple tasks will depend on the cognitive resources called upon. CWL is a multidimensional construct which is concerned with the ability of an individual to meet the information processing demands imposed by a task (Wilson & Eggremeier, 2001). CWL involves at least two major components: input load and individual's effort. Input load consists of the environment and task demands placed on the individual. The load on the individual is his/her reflection to the input load in terms of the efforts. Thus a common analogy of workload is often drawn with physical load broadly comprising stress (task demand) and strain (the resulting impact upon the individual) (Young & Stanton, 2001). When the task demands increase, an individual invests more resources voluntarily to keep the performance at an acceptable standard. A high workload restricts the individual's performance in the interaction with the system (Jameson, Schafer, Weis, Berthold, & Weyrath, 1999). Performing multitasks normally require more resources than a single task and may cause overload easily (Xie, 1997). The workload experienced by one person may be different from that of another person's experience. An efficient tool for assessing CWL has two important properties: (a) sensitivity (ability to discriminate between different levels of workload) and diagnosticity (ability to distinguish different types of workload) (O'Donnell & Eggemeier, 1986). The major purpose of workload measurement is evaluation of workload levels imposed by a task or system with the objective of identifying and eliminating workload related performance decrements (Wilson & Eggremeier, 2001). By evaluating workload during the design of a new system, or iteration of an existing system, problems of inappropriate workload can be identified to maintain an optimal level. Such assessment is important for the purpose of identifying those 'bottlenecks' in system or mission performance in which demands momentarily exceeds supply and performance breakdown. As the human operator is central part of complex technological systems, the correction of these problems is necessary for the safe and efficient operation of the systems. The methods of gauging workload can be classified broadly under 3 categories: (a) subjective measures, (b) performance measures, and (c) psychophysiological measures. These methods can be used either singly or in combined form- to make assessments of workload depending upon suitability and/or feasibility of the study.

Subjective measures require the participant to determine the amount of work required to complete the task. Rating scale is the most commonly used procedure. Numerous subjective tools for workload assessment are available. Modified version of Cooper-Harper Scale (Cooper & Harper, 1969), Bedford Scale (Roscoe, 1987), National Aeronautics and Space Administration-Task Load Index (NASA-TLX) (Hart & Staveland, 1988), Subjective Workload Assessment Technique (SWAT) (Reid & Nygren, 1988), Workload Profile (Tsang & Wilson, 1997), Multiple Resources Questionnaire (Boles & Adair, 2001), and Integrated Workload Scale (Pickup, Wilson, Norris, Mitchell, & Morrisroe, 2005).

Performance measures of primary and secondary tasks are widely used in workload assessment. Primary task measures assess the capacity of the operator to perform the task or system function of primary or principal interest. Speed and accuracy measures are commonly employed, and so are assessments of multiple aspects of the operator performance (Wilson & Eggermeier, 2001). Secondary task measures assess the capability of the operator to perform the primary task or function of interest concurrently with an additional or secondary task. This method attempts to obtain direct estimates of spare capacity. Decrements in secondary-task performance are interpreted as indicating increased workload associated with increase in primary task demands (Kantowitz, 1987; Wilson & Eggermeier, 2001).

With the technological advancement, there are numerous psychophysiological measures employed by the researchers in workload measurement. These include, electroencephalography (EEG), evoked related potentials (ERPs); magnetic evoked potentials (MEPs); electrodermal response; eye movements; eye blinks; and pupillary responses; heart rate variability (HRV), electrocardiogram (ECG); pulse wave velocity; electroyomyography (EMG); electrooculogram (EOG) which have notable strength of unintrusivness on task performance (Kantowitz, 1987; Wilson & Eggermeier, 2001).

While driving a vehicle there are many factors that could potentially trigger CWL (Baldwin & Coyne, 2003). The day by day increase in traffic density and the introduction of new in-vehicle information systems (IVIS) pose new demands to the driver (Makishita & Matsunaga, 2008). In the context of driving, when there is an increase in the situation complexity (e.g., high traffic flow, intersection, etc), the CWL increases, which consequently would result in more driving errors. The demand supply relationship of cognitive resources would form the state of overload, underload, and optimal state. For a safe and efficient driving, optimal workload is a pre-requisite (Jameson, Schafer, Weis, Berthold, & Weyrath, 1999). It is observed that non-professional drivers experience higher CWL and consume more cognitive resources (Underwood et al., 2003) and have 2–4 times higher accident rates than their professional counterparts (Di Stasi et al., 2009). Falkmer and Gregersen (2005) found that novice drivers tend to experience elevated CWL due to which they have inefficient visual scanning of the road, reduced vehicle control and hazard perception. For an excellent driving performance, drivers should experience optimal driving workload which is correlated with driving experience (Lyu, Xie, Wu, Fu, & Deng, 2017). Due to changes in the driving environment, there is a change in the CWL that drivers experience (Lyu, Xie, Wu, Fu, & Deng, 2017).

Chapter 3

Experiment-1: Suppression of Articulatory Rehearsal Mechanism

3.1. Introduction

Issues related to distraction is a critical aspect of automotive human factors research. In the context of WM, researchers have not approached the complexity of suppression of ARM and the underlying dynamics of gaze behavior and performance compromise. This aspect of WM in the context of driving requires development of a new experimental paradigm for scientific investigation. Studies on distracted driving have primarily focused on issues related to effects of distractions caused by using mobile phones during driving (Horrey & Wickens, 2006; Strayer & Drews, 2007); effects of roadside advertising on attention and road safety (Herrstedt, Greibe, & Andersson, 2013); and effects of phone type and messaging on gaze behavior while driving (Young, Rudin-Brown, Patten, Ceci, & Lenne, 2014). However, there is limited evidence for its relationship with driving errors (Young & Salmon, 2012).

Most of the driving related information is visuospatial in nature (Sivak, 1996). The process of storing visuospatial information and at the same time manipulating it in order to be used in current task has been best explained by WM model (Baddeley & Hitch, 1974; Baddeley, 2000, 2007). An important aspect of WM in this context is that of ARM which recodes visual information into phonological information and rehearses it in order to prevent it from decaying (Baddeley, 2000).

3.1.1. Articulatory rehearsal mechanism (ARM) of working memory (WM) and visuospatial information in driving

Baddeley and Hitch's WM model (1974) is a multi-component system consisting of three components namely, central executive, visuospatial sketchpad, and phonological loop. Central executive, also known as the real brain of WM, controls attention and allocates resources to the two subsystems. The primary responsibility of central executive is to select information from the environment and retrieve information from long term memory (LTM) (Baddeley, 1992). Visuospatial sketchpad holds visual and spatial information that is received through senses or retrieved from LTM. The second storage system, the phonological loop, temporarily stores information related to sounds and consists of a mechanism of rehearsing the phonological information called as articulatory rehearsal mechanism (ARM) in order to prevent its rapid decay (Baddeley, 1986). With better scientific understanding, the original WM model was revised by adding fourth component to the model, known as the episodic buffer (Baddeley, 2000; 2002) which acts like an interface between memory subsystems (visuospatial sketchpad and phonological loop) and LTM. In other words, episodic buffer integrates the information from all other systems of WM and offers a unified information in order to meet the demands of the task in hand.

Phonological loop consists of a phonological store and an ARM (Baddeley, 2012). Phonological store holds speech-based information for short periods of time after which the information fades away rapidly (Baddeley, 2007). This time limitedness of the phonological store is overcome by ARM which is used to recite the information in order to prevent its rapid decay in the phonological store (Baddeley, 2007). ARM recites the phonological information making it to re-enter into the phonological store, where it starts to decay again immediately. Baddeley, Thomson, and Buchanan, (1975) described ARM as a time-based tape of fixed length which refreshes phonological information after every 2 seconds. By constantly refreshing the information, the recitation process prevents it from decaying. The process of refreshing the information is called as verbal rehearsal or articulatory rehearsal and it does not need to be overt, as people who have lost their articulation capability due to any reason may also show the signs of sub-vocal articulation (Baddeley & Wilson, 1985). The ARM does not recite or rehearse phonological information only but serves another important function of phonological/verbal recoding of visual information (Baddeley, 2007). Therefore, in driving, phonological recoding ought to play an important role in terms of processing information presented in visual form. This is primarily critical for the visual information which has a verbal label (e.g., road signboard with a right headed arrow can be labeled as right turn). Information presented in a visual form is named or labeled and the phonological information produced from this labeling process then gets access to the phonological store where it is recited again and again to stay for a longer duration. Information received through auditory senses gains direct (obligatory) access to phonological store and in order to retain the information received through visual sense for a longer time (more than 0.5-1.0 sec) it gets access to phonological store, otherwise it fades away. This makes the access of visual information to phonological store optional (Baddeley, 1983). Information once in the phonological store, verbal rehearsal operates in the same manner irrespective of the means of entrance, i.e., direct or the optional route.

Phonological coding is beneficial in the sense because remembering visual information is more difficult than remembering phonological information and that in the situations when the delay is more between encountering the information and recalling it (Henry, 2011). Last decade has seen proliferation in the use of new wireless nomadic devices that have made their way into automobiles giving rise to many new sources of distractions (for e.g., using internet, watching videos, etc.), it is highly possible that visual information might be getting suppressed from entering into phonological store for articulatory rehearsal and remembered acoustically. It makes sense to explore when the visual information is blocked from entering into the phonological store (by means of distraction) how it influences drivers' gaze behavior and driving performance.

Effect of suppression of ARM has been studied in the context of interactions with phonological variables, for example, the *phonological similarity effect* (consonants with similar sounding names such as b, g, c, v, t, p are harder to remember than dissimilar sets such as h, w, y, k, r, I); *word length effect* (memory span decreases as word length increases) and *the unattended speech effect* (memory for visually presented items gets impaired by the simultaneous presentation of spoken material). Due to suppression of ARM the unattended speech effect disappears, the word length effect gets insignificantly reduced, and the phonological similarity effect gets abolished (Baddeley, 1983). For suppressing ARM, Coltheart (1993) has used an irrelevant task in the context of phonological similarity effect where the participants were required to remember and later recall a phonemically similar list of words. During presentation of the list of words the participants had to keep counting up to 6 and then restart counting. Other studies (e.g., Richardson & Baddeley, 1975) studied the effect of suppression of ARM on free recall of list of words. In these studies, participants are instructed to say irrelevant words during the presentation of the list of words. The nature of these ARM suppression tasks is that (a) it requires minimal attentional resources and (b) the purpose is to ensure that the ARM becomes unavailable for either phonological coding or verbal rehearsal. In the context of the current study, the levels of suppression of ARM are relative to each other where Simple Suppression (SS) is an intermediate level of suppression (i.e., the drivers are engaged in a simple counting task), NS is a control (i.e., no suppression), and CS is a complex suppression where the drivers are engaged in a cognitively challenging task (i.e., counting backward).

Relevant studies concerning WM in the context of driving include effects of distraction induced by WM load on driving performance

(Engström & Markkula, 2007); impact of cognitive distraction on visual behavior and braking performance (Harbluk, Noy, Trbovich, & Eizenman, 2007b); relationship between WM capacity and driving performance (Mäntylä, Karlsson, & Marklund, 2009; Ross et al., 2015). Ross et al. (2014) reported that performance on LCT measures deteriorated when verbal WM load was increased and the higher the WM capacity the drivers had, better was their LCT performance.

Distractions with respect to WM are often classified on the basis of sensory modalities (i.e., visual, spatial, or auditory) or on the basis of the stage of information processing (i.e., encoding or retrieval) when the distraction takes place. Logie, Zucco and Baddeley (1990) reported greater interference when the processing task (primary task) and the interference task (secondary task) are of the same content (e.g., a visual distraction task will have a stronger detrimental effect on visual processing of WM than will have an auditory distraction task). WM capacity is closely linked to individual's ability to filter out irrelevant visual distractors (Vogel, McCollough, & Machizawa, 2005). Similarly, Fukuda and Vogel (2009), also observed that people with superior WM capacity are less susceptible to attentional capture by distractors encountered within target display. Performance of a secondary task (distractor) during memory encoding of a primary task has a large detrimental effect on the latter retrieval whereas the performance of the same secondary task during the retrieval phase has relatively lesser effect on memory performance but the performance on the secondary task gets impaired (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). However, retrieval operations are quite costly in terms of processing resources (Craik & McDowd, 1987). The possible justification for such a phenomenon could be that retrieval processing is given priority and that an increase in processing costs are borne by secondary task.

3.1.2. Gaze behavior during distracted driving

Visual attention involves focusing our eyes on a particular stimulus while ignoring other stimuli. Gaze behavior data reflect moment-to-moment cognitive processes (Rayner, 1998), and is an important measure of visual attention as individuals fixate their eyes on objects which attracts their visual attention (Hoffman & Subramaniam, 1995). Humans have limited cognitive resources to attend and process information at a given point of time. In driving, often drivers get bombarded by various arrays of stimuli many of which have high potential of distracting them. However, according to Moray (1990) at a given point of time drivers could attend only a single stimulus and could search up to three targets per second. But on the other hand, use of interactive devices in the vehicles and the day by day increase in the number of vehicles on the road has made driving task even more complex (Engström, Johansson, & Östlund, 2005). Failure in processing relevant information could lead to accidents (Ranney & Pulling, 1989) which can happen because the drivers temporarily focus their eyes on some other task. People look but do not see when they are involved in other mental tasks or lost in their thoughts to the extent that there is disruption in their information search patterns (Rumar, 1990).

Driving gaze behavior research has not benefitted much from the results of gaze behavior studies done in other areas like reading, picture viewing, etc. because driving involves a dynamic visual field, and the driving behavior has relevance to potential accidents. Studies on gaze behavior while driving have focused on different variables in terms of visual processing. Steering wheel angle and drivers' gaze behavior when negotiating a curve (Land & Lee, 1994); changes in driving performance and gaze behavior of novice drivers while gaining experience in the simulator (Van Leeuwen, Happee, & de Winter, 2015); research methodology for investigating drivers' eye glance behavior while interacting with in-vehicle devices (Reeves & Stevens, 1996); differences between novices and experienced drivers with respect to the distribution of visual attention under different levels of cognitive load imposed by different types of road (Crundall & Underwood, 1998); and decreased horizon of search during intentional car following (Crundall, Shenton, & Underwood, 2004).

Visual attention capacity corresponds to a fixed amount of information (Verghese, & Pelli, 1992) and when the information to be processed exceeds the capacity there are high chances that the driver will make driving errors and in extreme cases meet crashes or near crashes. As the situation becomes too demanding for the driver, fixation durations decreases (Crundall, Shenton, & Underwood, 2004); fixation sequences become less structured when scene complexity increases (Wu, Anderson, Bischof, & Kingstone, 2014) and high demand on attentional resources narrows down attentional focus size (Recarte & Nunes, 2000). Recarte and Nunes (2000) also stated that if visual scene complexity reduces attentional focus size it should also be reduced by concurrent cognitive tasks as both have attentional demands. The current study intends to investigate suppression of ARM and how it affects gaze behavior and driving performance. It is conceivable that distracted driving involving suppression of ARM ought to reduce fixation durations as it demands more cognitive resources. Should suppression of ARM lead to more demand on cognitive resources compromising fixation durations then the effect should also be reflected in terms of detrimental driving performance (i.e., increase in driving errors).

3.1.3. Human error

To err is human. It exists almost in every context of performing a task, driving a vehicle is not an exception. While some of the errors that individuals often commit in their day-to-day performing activities can have only a negligible impact, human error in another context could be disastrous. For instance, the consequences of driving error(s) can be life threatening not to self only but to other road users as well. Error refers to any deviation from a clearly specified performance standard or criterion against which a deviant response can be measured (Hollnagel, 1998). Human error is often understood based on different classification schemes. The classification schemes are either used proactively, i.e., to anticipate error in advance, or retrospectively, i.e., to analyze errors after they have occurred. Human error identification (HEI) techniques such as Systematic Human Error Reduction Approach (SHERPA) (Embrey, 1986) are used to predict human error in advance and the retrospective analysis is done on the basis of underlying psychological mechanisms (e.g., Stanton & Salmon, 2009). However, human errors could also be due to physiological limitations. There are various taxonomic frameworks of human error like Sabey and Staughton (1975) driver error classification; Norman's (1981) error categorization; Rasmussen's (1986) skill, rule, and knowledge error classification; Reason's (1990) slips, lapses, mistakes, and violations classification; Verwey et al.'s (1993) driver errors associated with accident scenarios; Wierwille et al.'s (2002) taxonomy of driver errors. There are three taxonomic frameworks of human error that are widely employed by researchers — (a) Norman's (1981) error categorization, (b) Rasmussen's skill, rule, and knowledge error classification (1986), and (c) Reason's (1990) slips, lapses, mistakes, and violations classification. In order to analyze the effect of suppression of ARM on driving performance, this research incorporates Reason's (1990) slips and lapses. Within this framework when slips and lapses occur the individual's intentions (plans) are correct, but the execution is flawed. When the action is carried out incorrectly, the error is termed as slip (comprised of- changing lanes wrongly, doing lane excursions, and over/under speeding in the current experiment) and when the action is simply omitted or not carried out at all, the error is termed as lapse (comprised of- forgetting to indicate lane change, forgetting to execute lane change, and forgetting to turn off the indicator after changing the lane in the current experiment). According to Reason (1990), slips are one of the most common human errors.

Researchers have investigated different types of errors and their contribution to traffic accidents (Brown, 1990; Lenard & Hill, 2004). Sabey and Staughton (1975) reported 3,704 driver errors which were subjectively assessed as a causal factor for 2,130 accidents. Human errors are often byproducts of problems in human information processing (Parker, Reason, Manstead, & Stradling, 1995) thus cognitive aspects of error research is important. Broadbent, Cooper, FibGerald and Parkes (1982) pointed out that some people report a relatively high number of memory lapses and instances of inattention. In the context of this study issues related to WM are emphasized as mentioned above. More complex secondary tasks result in greater interference with lane keeping and thus potentially increase the risk of accidents (Tijerina, Parmer, & Goodman, 1998).

3.2. Hypotheses

In the light of the literature and the above-mentioned issues of gaze behavior and driving error, the main objective of the present study was to investigate the role of suppressed ARM in drivers' gaze behavior and driving performance. Accordingly following hypotheses were formulated and investigated in this study.

H1. Under Complex Suppression (CS) drivers face more difficulties (i.e., reduced fixation durations and fixation counts on areas of interest (AOI)) as compared to SS and NS.

H2. Driving performance is compromised more under CS as compared to Simple Suppression (SS) and Non-Suppression (NS).

3.3. Materials and methods

3.3.1. Direction following in distracted driving – suppression of articulatory rehearsal mechanism (D3-SARM*)*

For this study (experiment-1), distraction was induced by suppressing the Articulatory Rehearsal Mechanism (SARM) and the existing D3 paradigm was called as '*Direction Following in Distracted Driving – Suppression of Articulatory Rehearsal Mechanism (D3-SARM*)'. Drivers were assigned to one of the three levels of suppression of ARM (*distraction inducement*) and they drove an instrumented vehicle on a two-lane track. NS group of participants was not exposed to any kind of suppression of ARM so it served as a control group. The other two groups were exposed to CS of ARM and SS of ARM. In the case of CS, the drivers were instructed to start count down rapidly from 50 as soon as they first time look at the signboard. In the case of SS, the drivers were supposed to count rapidly from 1-30 (contrasted with counting down from 50 in case of CS) as soon as they first time look at the signboard. This process continued after crossing every direction signboard for both CS as well as for SS.

This study was performed by taking into consideration the maximum speed limits suggested by Tingvall and Haworth (1999) guidelines. The lowest speed assigned for residential roads is 30 km/h and for semi urban roads it is 50 km/h, now since the drivers were distracted the investigators reduced the highest limits and kept the range of 20 to 45 km/h.

3.3.2. Design

This experiment employs a 3 Suppression of ARM (NS vs. SS vs. CS) between-groups design. The manipulation of levels of suppression (i.e., SS vs CS) is based on the basic understanding that counting 1-30 relatively requires minimal attentional resources as compared to counting backwards from 50. On the basis of the requirement of attentional resources, the levels of suppression of ARM are called as SS and CS. The drivers do not necessarily require to reach the maximum limits of counting (i.e., 1 to 30 in case of simple suppression and 50 to 1 in case of complex suppression), rather they are instructed to keep counting till they cross the direction signboard irrespective of how far they count (e.g., depending on how fast they counted, some participants could count down up to 40 while some up to 35). They were instructed to restart the counting once they saw a new direction signboard. It is important to maintain that distraction in terms of suppression of ARM remains within the framework of WM (Injoque-Ricle, Barreyro, Formoso, & Jaicheno, 2015).

3.3.3. Instrumentation

Data for this experiment was collected through an instrumented vehicle (Volkswagon POLO, 2015 Model, Hatchback 1.2 petrol highline, right hand drive), Video Velocity Box (20Hz GPS video data logger with a 4 camera video system) recorded data related to driving performance in terms of the following parameters

1. Lane excursions,
2. Over/under speeding,
3. Changing lanes wrongly,
4. Forgetting to indicate lane change,
5. Forgetting to execute lane change, and
6. Forgetting to turn off the indicator after changing the lane.

In order to capture the front view of driving, one camera was attached to the top of the dashboard near the windshield of the car; to capture the usage of direction indicators, one camera was attached to the steering column of the car (fixed portion of the steering wheel which does not move); the third and fourth cameras were attached on the left and right side of the bonnet of the car in order to capture the lane excursions to the left and right side respectively. The GPS antenna was attached to the center of the roof of the vehicle.

Tobii glasses 1 eye tracker was used to capture the gaze behavior of the drivers throughout the driving session. To ensure that calibration was good throughout the session, following measures were taken- (1) the glasses rests on the nose and strap of the glasses was adjusted firmly around the head without causing discomfort (in such a way that the glasses do not move on its own), (2) participants were instructed not to move the glasses after the calibration is done, (3) post- session recalibration was done for those participants whose calibration was notified as invalid by the device (Tobii glasses recording assistant).

3.3.4. Analysis of gaze behavior and driving performance

Gaze behavior was analyzed in terms of fixation durations, fixation counts, and visit counts on the Areas of Interest (AOI) that is, direction signboards. Tobii glasses eye tracker collects raw gaze data points at the sample rate of 30 Hz. Each data point is identified with a timestamp and X,Y coordinates by the Tobii studio software. For visualizing the gaze data, the X,Y coordinates are then processed further into fixations and imposed on the video recording of the driving scene. This process is done by applying Tobii fixation filter algorithm to the data. Fixation filters determine how fixation data, for example, fixation duration, or fixation counts are calculated. The Tobii fixation filter implements the classification algorithm proposed by Olsson (2007) which is very efficient in detecting quick changes in the gaze point. Fixation durations and fixation counts are calculated by marking the AOI (i.e., 4 direction signboards installed on the track, for a representative image see Fig. 1 (a) and (b)) manually on every frame of video data collected by the eye tracking device. Fixation duration and fixation counts are then counted by Tobii studio on each instance of eye fixation on the AOI.

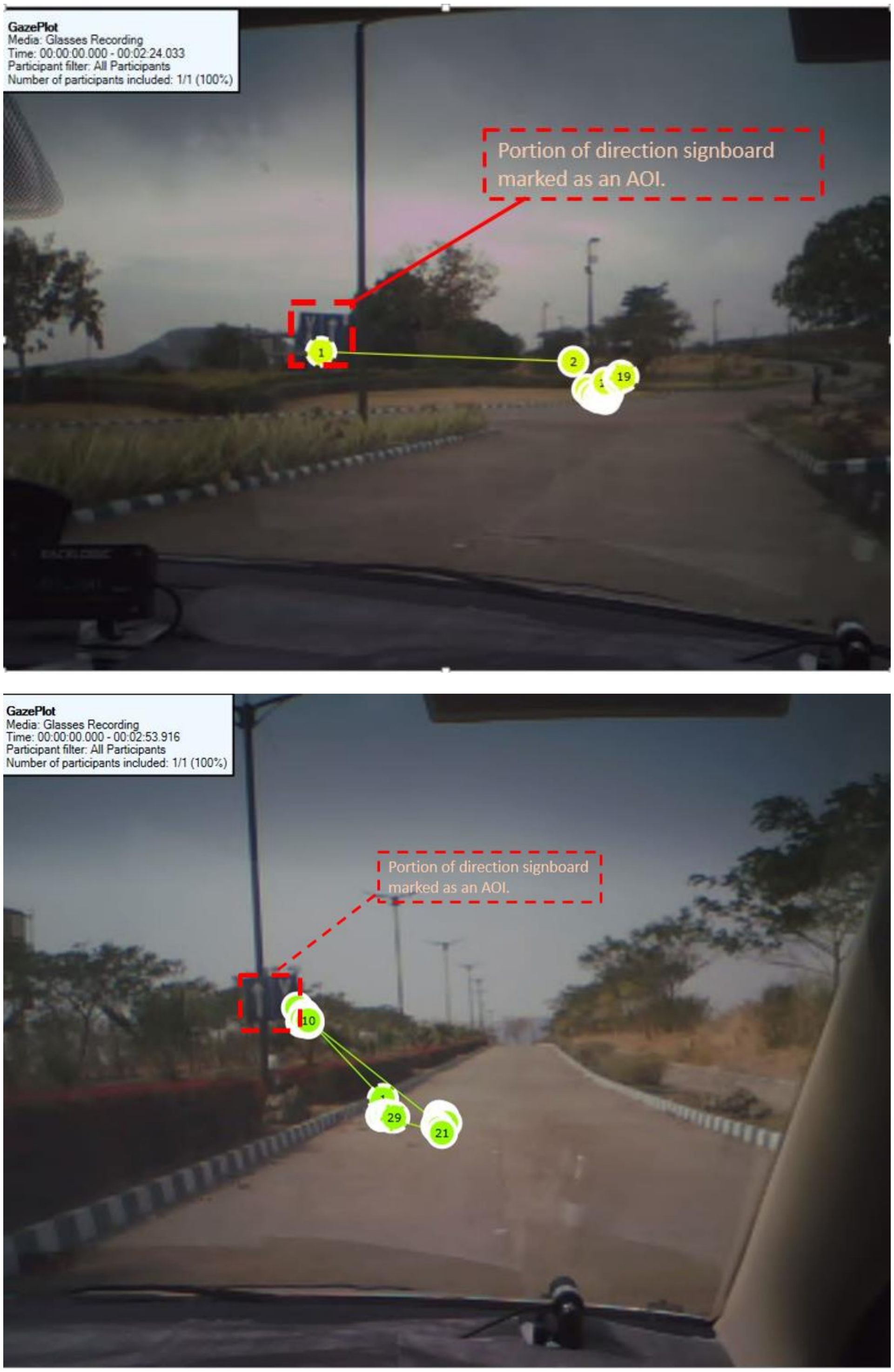


Figure 1 (a) and (b). Representation of fixation of a participant on two separate AOIs (direction signboards)

The recording assistant (a device of eye tracking system) of Tobii glasses 1 allows the researcher to check the quality of the data at two stages (a) the calibration stage, and (b) the end of the data recording session, in terms of tracking score and accuracy score. After the calibration is done, a message can be seen on the screen of the data recording device with a quality rating for both tracking score and accuracy score (ranging from 1 to 5 stars, see Fig. 2 (a)). In the cases of a bad calibration, the recording assistant displays a red colored star and the second lowest calibration score is displayed as a yellow star. In other words the more the stars the better is the calibration. A score of five stars for a calibration means that more than 80% of the recorded samples possess usable features, whereas one star means less than 19% of the samples possess usable features. After recording a session, the recording assistant allows the researcher to get an overview about the quality of the recorded session by showing the score in terms of stars. From the tracking or the accuracy score, only one score (whichever is lower) is shown (see Fig. 2 (b)). If the session has scored three stars, it indicates that either the accuracy, or the tracking score has three stars and the data has an average quality. Another level of check for the quality of gaze data was with respect to sample rates. Any participant whose gaze data sample rate was less than 60% was not included in the analysis.

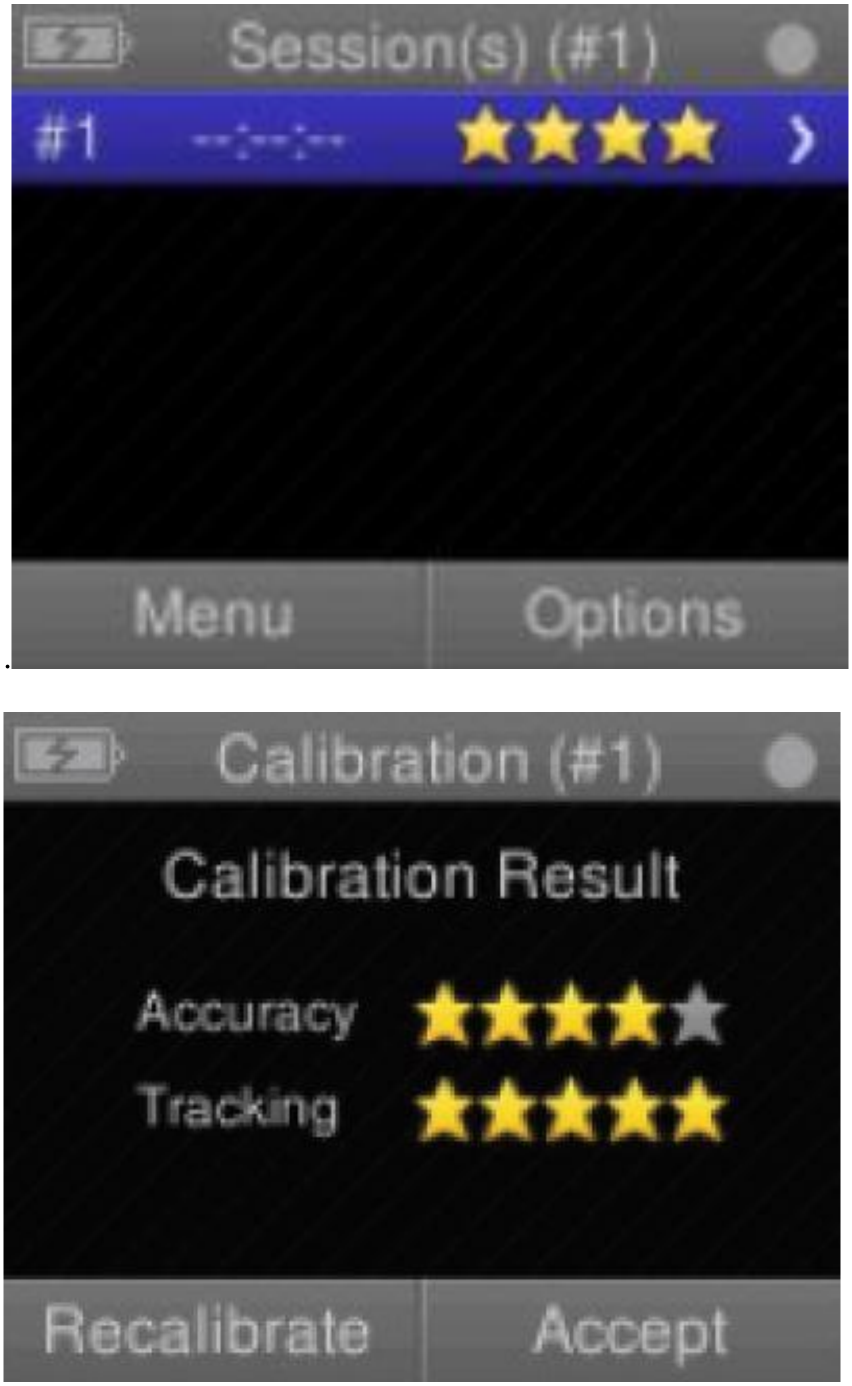


Figure 2 (a) and (b). Screenshot of data recording device displaying (a) the quality of tracking and accuracy after calibration, and (b) the quality of data after recording the session

3.3.5. Participants

Participation to this test-track distracted driving study was open to only those who possessed valid driving license and had normal vision. A total of 45 participants, irrespective of their experience, age and gender, voluntarily participated in this experiment. Among the 45 participants, data sets from 15 participants were discarded due to one of the following reasons: (a) less than 60% sample rates of the gaze data, (b) poor calibration or data not recorded properly, (c) any untoward incident on the experimental track like falling down of the signboard due to fast wind. A valid set of data collected from 30 male drivers were analyzed (M = 30.16 years; SD = 7.66; range = 19–43 years). The participants received 250 INR each for their voluntary participation in the study (alternatively a participant who was not engaged on payment basis received a T-shirt) and 10 participants in each group were randomly assigned to experimental conditions.

3.3.6. Procedure

Prior to engagement of human participants, the investigators defended the experimental protocol of this study before research progress committee that monitors the flow of research for ethical and standards compliance. Participants were briefly explained about the task they had to undergo so that they could arrive at an informed decision about their participation in the study. Before they participated in the experiment, they provided their informed consent for participation following which the vital information sheet was filled up by the researcher. Eye tracker was calibrated with the eyes of each participant before they could go for driving and in case the calibration was invalid (which was notified by the Tobii glasses recording assistant, recalibration was done post-data collection session). Each participant first went through a practice trail so that he/she can get accustomed with the instrumented vehicle. The participants were taken to the experimental track (for actual data recording) only when they were confident about all the functions of the instrumented vehicle. The experimenter was seated in the front passenger seat (next to driver) so that he could start and stop the recording devices, to instruct the participant to start and stop driving, also for experimental observation and planning for consequent appropriate debriefing. Post-data collection, each participant was asked some probing questions about his/her experience while driving.

3.4. Results

Alpha level of .05 was used to infer statistical significance throughout this chapter.

3.4.1. Gaze behavior

The study examined the effect of suppression of ARM on gaze behavior of drivers. Gaze behavior was analyzed on the parameters of fixation durations, fixation counts, and visit counts on the AOI of direction input (in this case, 4 twin signboards). The whole area of a signboard was considered as an AOI. An ANOVA was carried out for 3 Suppression of ARM (NS vs. SS vs. CS) between-groups design.

Fixation durations are measured as the period of time when the eye is relatively still and fixating on the AOI (Tobii, 2012) and this measure was calculated by computing total fixation durations in seconds within AOI (i.e., for all the signboards serving as direction input in this study) from the moment it was visible to the participant. The analysis revealed a significant difference among the three levels of suppression of ARM (NS, $M = 11.587$, $SD = 6.949$; SS, $M = 10.961$, $SD = 5.822$; and CS, $M = 5.112$, $SD = 3.620$), $F(2, 27) = 4.014$, $p = .030$, $\eta_p^2 = .229$. Fig. 3 illustrates the nature of the difference between the means of the fixation durations at the three levels of suppression.

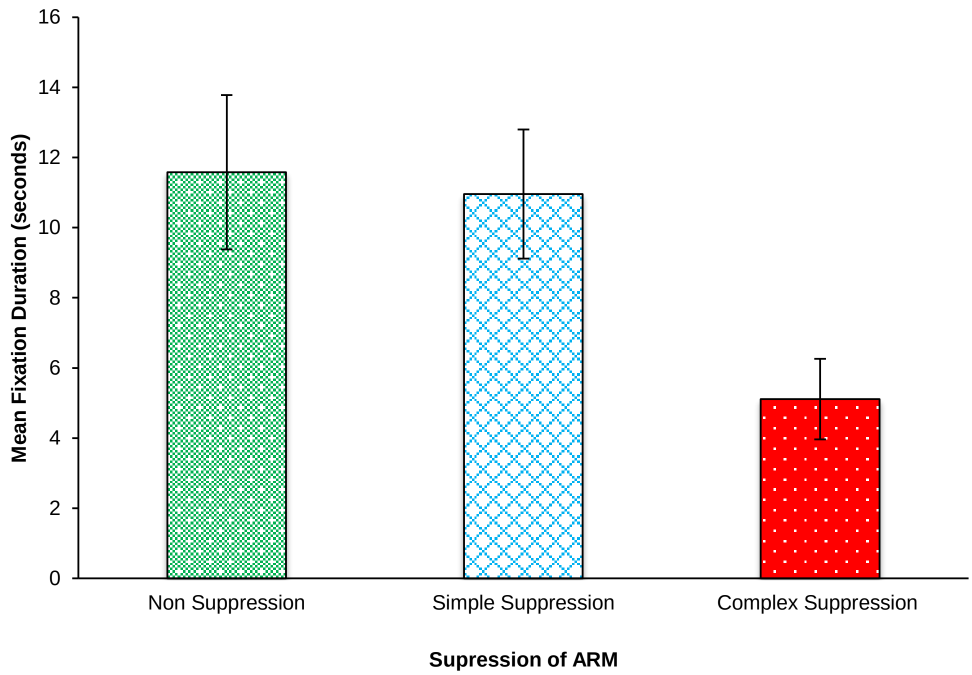


Figure 3. Fixation durations as a function of suppression of ARM. Error bars denote SE.

Fisher's Least Significance Difference (LSD) was used in order to identify which pairs of treatment conditions are statistically different. LSD analysis reveals that CS and NS are different, p = .016; and CS and SS are also different, p = .028. There is no significant difference between the means of SS (10.961) and NS (11.587). Fixation counts were calculated as the number of times (counts) the participant fixates on AOI (i.e., for all the direction signboards) from the moment they were visible to the participant. As shown in Fig. 4, statistical analysis of the fixation counts data showed a significant difference among the three levels of suppression of ARM (NS, M = 360.300, SD = 215.892; SS, M = 351.400, SD = 170.183; CS, M = 161.600, SD = 112.708), $F(2, 27) = 4.281$, $p = .024$, $\eta_p^2 = 0.241$. LSD analysis reveals that CS and NS are different, p = .015; and the CS and SS are also different p = .020. The difference between the means of NS (360.300) and SS (351.400) is not significant.

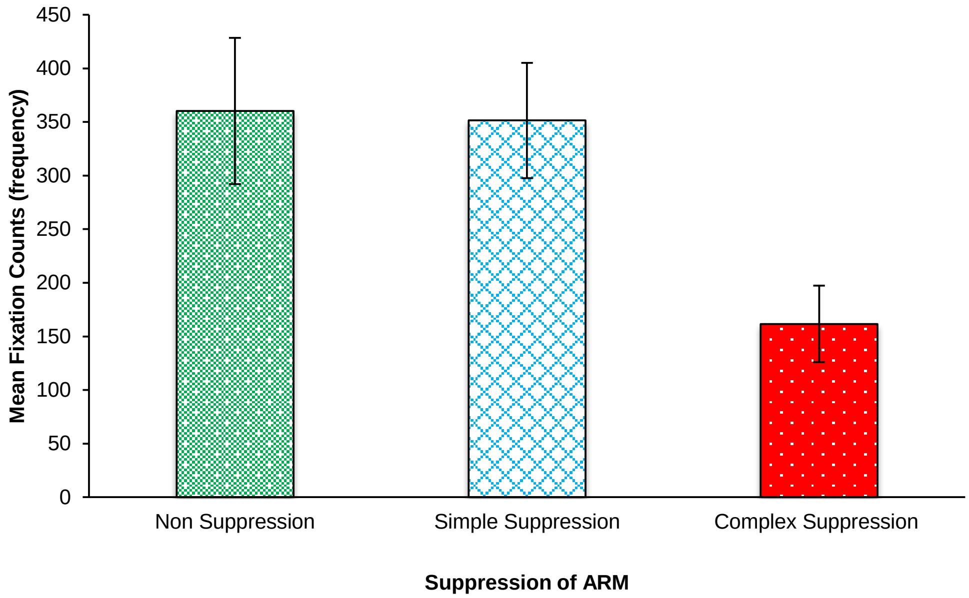


Figure 4. Fixation Counts as a function of suppression of ARM. Error bars denote SE.

Another measure of gaze behavior of drivers used in this study is visit counts. Visit counts are the number of visits (counts) within an AOI or an AOI group (i.e., for all the direction signboards). There was no statistically significant difference among the three levels of suppression with respect to their effect on visit counts (NS, M = 48.600, SD = 25.657; SS, M = 53.850, SD = 22.092; and CS, M = 36.000, SD = 18.307), $F(2, 27) = 1.704$, p = .201, η_p^2= .112. LSD analysis also revealed that there is no significant difference between any pair of suppression of ARM. Fig. 5 shows the means of visit counts at three levels of suppression.

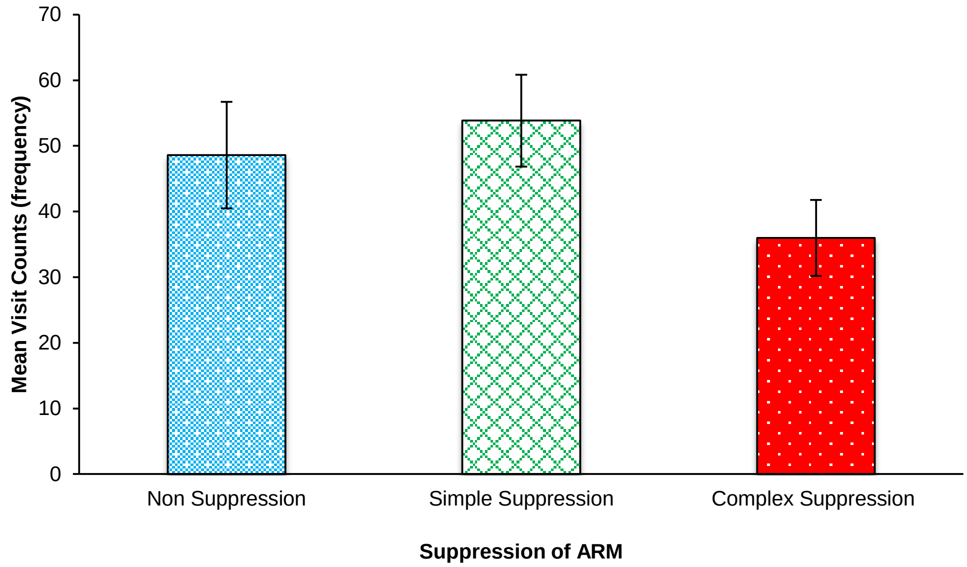


Figure 5. Visit counts as a function of suppression of ARM. Error bars denote SE.

3.4.2. Driving errors

Analysis of driving errors is based on video data captured by Video Velocity Box (20Hz GPS video data logger with a 4 camera video system). Any incidence of slips and lapses are analyzed. When the individual's intentions (plans) are correct, but the execution is flawed, slips and lapses are treated to have occurred. If an action is carried out incorrectly, it is determined as a slip and in the current study it is calculated on the basis of the parameters of lane excursions (wheels crossing the lane demarcating line), over/under speeding (driving beyond the specified speed limit), and changing lanes wrongly (changing lanes contrary to the signs shown on the direction signboard). When the action is simply omitted or not carried out at all, a lapse is treated to have occurred and in this study it is determined on the basis of the parameters of forgetting to indicate lane change (i.e., the driver does not indicate lane change though he performs a lane change), forgetting to execute lane change, and forgetting to turn off the indicator after changing the lane. The first level analysis focused on overall driving error with respect to the three levels of suppression of ARM. It was done by performing ANOVA for 3 suppression of ARM (NS vs. SS vs. CS) having between-groups design. Fig. 6 shows comparison of overall driving error for three levels of suppression. The analysis revealed that there is a statistically significant difference among the three levels of suppression with respect to their effect on driving performance (driving errors), (NS, *M* = 1.433, *SD* = 0.846; SS, *M* = 3.766, *SD* = 2.166; and CS, *M* = 4.933, *SD* = 1.561), $F(2, 27) = 12.138$, $p = .001$, $\eta_p^2 = .473$. LSD analysis reveals a significant difference between CS and NS, $p = .001$; and NS and SS also differ significantly $p = .003$. LSD analysis also indicated that there is no significant difference between SS and CS.

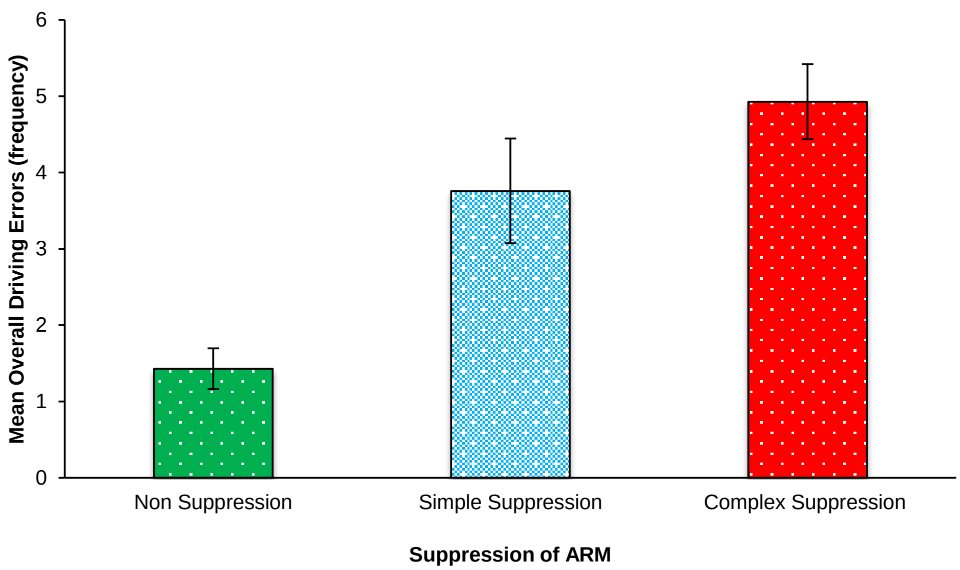


Figure 6. Overall driving errors as a function of suppression of ARM. Error bars denote SE.

In order to investigate whether it is the slips or the lapses that are committed more during the suppression of ARM, a MANOVA was performed. The analysis revealed that there is a significant difference between slips and lapses based on the three levels of suppression, $F(10, 46) = 5.309$, $p = .001$; Wilk's $\Lambda = 0.215$, $\eta_p^2 = 0.530$. It was also found that in comparison to lapses (*M* = 0.955, *SD* = 0.869), it was the slips (*M* = 2.422, *SD* = 1.528) that are committed more by the drivers. In order to find out whether the three levels of suppression differ from each other with respect to their effect on slips and lapses separately, an ANOVA was carried out. It was found that there is a significant difference among the three levels of suppression with respect to their effect on slips (NS, $M = 1.167$, $SD = 0.549$; SS, $M = 2.790$, $SD = 1.765$; and CS, $M = 3.290$, $SD = 1.159$), $F(2, 27) = 7.841$, $p = .002$, $\eta_p^2 = 0.367$. LSD analysis reveals a highly significant difference between CS and NS, $p = .001$; whereas the differences between NS and SS, and SS and CS are insignificant. The three levels of suppression also significantly differ with respect to their effect on lapses (NS, $M = 0.267$, $SD = 0.466$; SS, $M = 0.967$, $SD = 0.808$; and CS, $M = 1.633$, $SD = 0.727$), $F(2, 27) = 10.00$, $p = .001$, $\eta_p^2 = 0.426$. Like slips, LSD analysis for lapses also reveals that CS and NS are significantly different, $p = .001$ whereas the differences between NS and SS, and SS and CS are insignificant. Fig. 7 shows the comparison of means of slips and lapses at the three levels of suppression and Fig. 8 shows the percentage of slips and lapses in overall driving error.

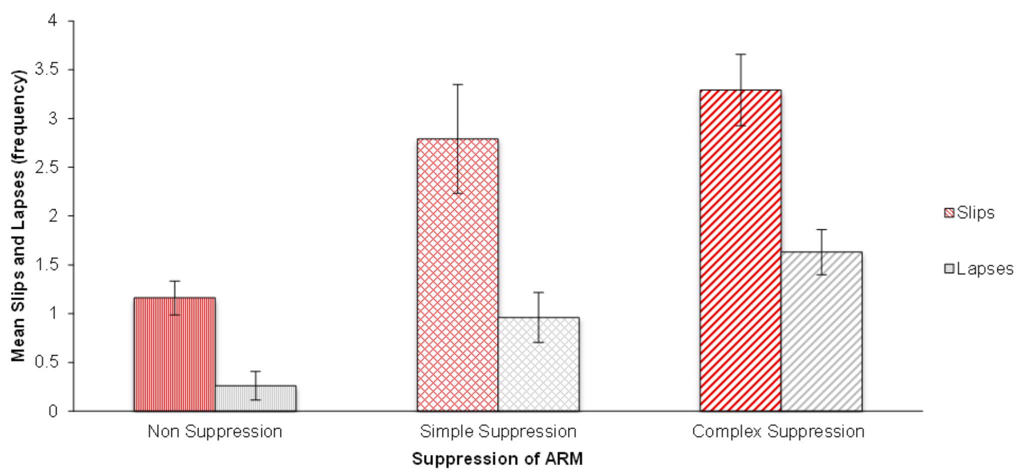


Figure 7. Comparison of Slips and Lapses at three levels of suppression of ARM. Error bars denote SE.

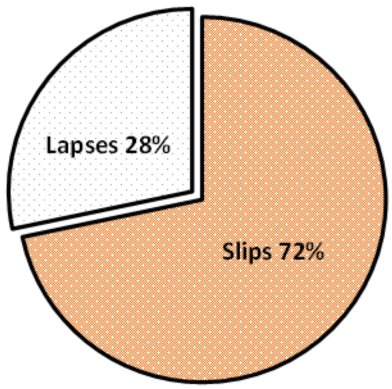


Figure 8. Proportion of slips and lapses in overall driving error

3.5. Other measures

The 4 twin signboards were placed along the experimental track in order to find out whether it is the left side or the right side of the road from where the drivers get most of the driving related information, a paired *t*-test was carried out. The results show a significant difference between fixation durations on the left side direction signboards (*M* = 6.093, *SD* = 5.026) and right side direction signboards (*M* = 3.208, *SD* = 3.383), t (29) = 2.645, p = .013. This indicates that drivers capture driving related information more from their left side. This could be attributed to the fact that the Indian drivers are habituated to get information from the left side because on Indian roads the traffic is left side oriented and the oncoming vehicles (on right side of the road) could block the view on the right side of the road.

In order to arrive at a precise speed limit for the scenarios of distracted driving, the drivers in the current study were instructed to drive within the speed limits of 20-45 km/h. After averaging out the speed of all drivers, it was found that the drivers drove at an average of 31 km/h. This speed limit will be useful for future studies.

3.6. Discussion

This study investigates the effect of suppression of ARM on drivers' gaze behavior and driving errors. Gaze behavior of the participants is analyzed in terms of fixation durations, fixation counts, and visit counts on the AOI (i.e., direction signboards). The results demonstrates that fixation durations and fixation counts are significantly reduced during the CS of ARM as compared to the other two levels of suppression. This is in alignment with the understanding that the more cognitive resources required to perform a driving irrelevant cognitive task, the less often the drivers tend to look away from the road. (Harbluk & Noy, 2002; Recarte & Nunes, 2000).

An interesting observation is that unlike fixation durations and fixation counts, there is no significant difference in case of visit counts across three levels of suppression. In other words, irrespective of three levels of suppression, drivers have undifferentiated visit counts on AOI. This indicates that whether distracted or not, the drivers look at the direction signboard but does not actually process the information displayed on the direction signboard which is evident from reductions in fixation durations and fixation counts during CS. In literature this phenomenon is often called as looked but did not see (Ottawa, 2013). This implies that all the drivers attempted to visually process target information (i.e., direction displayed on signboards), however, could not get sufficient opportunity to devote attention for further visual processing. This is in congruence with the finding that there is decrease of fixation durations and fixation counts under suppressed ARM (i.e., SS and CS) as compared to NS. Therefore, in a dynamic environment like driving, when distraction is induced by suppression of ARM it will increase situation complexity (associated with variation in CWL) thus shorter fixation durations and less fixation counts on AOI is ought to manifest. With respect to fixation durations and fixation counts, the results indicate a significant difference between NS and CS but insignificant difference between NS and SS. This difference could be attributed to the more attentional demand during CS as compared to SS and NS. The difference in gaze behavior when the participants are exposed to NS and SS is insignificant because during SS the counting task (1-30) do not demand much cognitive resources and the drivers were able to focus on the driving task. The observed phenomenon can be explained by Wickens's multiple resource model (Wickens, 2002) which states that for achieving a given level of performance on a task, the demanded resources are not fixed rather are allocated as per the demand of the task. The leftover resources (residual resources) can be used in performing concurrent task, accordingly if a task demands more resources (as in the case of CS), it will interfere more with a concurrent task.

The current study also provides insights into understanding of issues related to suppression of ARM and driving errors. As expected, the results of the study reveals that overall driving error occurred significantly more under CS followed by SS and NS. Proportion of overall driving error is almost double of what is observed under CS as compared to that of SS. An important point to be noted is that drivers commit errors even in the absence of suppression of ARM (i.e., NS), though the frequency and severity is not as high as it is during suppression of ARM (i.e., SS and CS). This finding is in line with Young, Salmon, and Cornellison (2013) who reported that even if the drivers were not distracted they still committed errors.

Further understanding in terms of driving error is that occurrence of slips are more prominent during distracted driving as compared to the lapses. In general it is often the case that slips are the most common error types (Reason, 1990). Both slips and lapses are affected differently by the three levels of suppression. The observation of participants by the experimenter during driving and debriefing after the experimental task, their subjective reports (to probing questions) reveal that they experienced more frustration during CS of ARM than the other two levels (for instance, display of annoyance in terms of verbal gestures and expressing concerns over their performance).

It may be noted that there is rapid technological advancement taking place in terms of use of in-vehicle interactive systems. Future research could focus on issues pertaining to other aspects of WM system. In the context of distracted driving one of the important issues is that of distractions related to visual and spatial processing of information. Visual and spatial information is processed by different cognitive systems (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Hecker & Mapperson, 1997; Logie & Marchetti, 1991; Tresch, Sinnamon, & Seamon, 1993), and by different areas of the brain (Nelson et al. 2000; Courtney, Ungerleider, Keil & Haxby, 1996; Munk et al. 2002). Visual processing deals with information related to *object appearance* (such as visual appearance of an object or scene, its color, shape, contrast, size, and visual texture) whereas the spatial processing deals with information related to *object location in space* such as (the processes of change in the perceived relative locations of objects that occur when an observer moves – physically or in a mental image – from one viewpoint to another, or sequences of movements from one location to another in the scene) (Della Sala & Logie, 2002).

Furthermore, designing effective countermeasures for mitigating its effect will be important avenue of research endeavor. The researchers need to understand whether the error recovery strategies of the driver also get affected by distraction, if yes, how? It is relevant to explore the relationship between distracted driving and error recovery of the driver which might include detecting error, choosing and implementing a response for recovering from the error.

3.7. Conclusion

This study set out with the understanding that ARM plays an important role in processing visual information. It intended to determine how gaze behavior is affected in distracted driving that involves suppression of ARM. The driving scenario of the study required drivers to perform direction following (based on direction signboards). The results of the study (in terms of fixation durations and fixation counts) suggest that drivers have difficulty in maintaining fixation on target visual information when there is substantial suppression of ARM. Visit counts do not follow the trend implying that drivers make an attempt to pay attention to direction signboards regardless of distraction or not. In terms of driving errors, the finding of the study substantiate the prominence of slips. Drivers are more vulnerable to slips as compared to lapses. Overall, in a dynamic environment such as driving, issues related to human error is more concerning when distraction is in play. The paradigm presented in this study will have relevance in both the scenarios of using instrumented vehicle or driving simulator in the lab. It may be beneficial for the readers to know that there are certain advantages and disadvantages of both naturalistic driving studies and simulated driving studies. In the case of this study investigators have adopted more naturalistic test-track driving emphasizing on the advantage of ecological validity (naturalistic test-track driving will have high generalizability of results to be valid for real-life situations as compared to simulated driving). However, a lab with well-equipped advanced simulator will enable researchers to generate data faster and it will be easier to have experimental control in a lab environment. It will be scientifically robust to use both the approaches strategically considering issues being addressed and the context including resources investigators have. This also implies that a researcher must exercise appropriate scientific judgement at the time of developing methodological framework and protocol of a particular study (situations could be that researchers to choose either naturalistic driving study or simulated driving study or both accordingly).

Chapter 4

Experiment-2: In-vehicle Object and Spatial Distraction

4.1. Introduction

Driving is a complex task which involves performance of multiple tasks. Despite its complexity, drivers still perform driving irrelevant tasks, which according to Gordon (2009) poses as potential cause for driving errors, crashes or near crashes. Previous experiment (Experiment-1) has demonstrated that in order for a distraction to have a significant effect on driving performance and gaze behavior, it needs to have a substantial demand on cognitive resources. The current experiment examines the issues related to drivers' interaction with in-vehicle interactive systems (object and spatial) and driving expertise in affecting driving performance, CWL, and gaze behavior of drivers. Bayly, Young, and Regan (2009) reviewed the effect of different in-vehicle distractions on driving performance measures and reported that deficits vary across different in-vehicle distractions. The reported deficits in driving performance measures included increased reaction time for hazard perception, degraded longitudinal and lateral control, reduced side mirror checks, and impaired visual scanning of the peripheries of the road. In addition to the physical and cognitive distraction, use of in-vehicle devices distract the driver visuo-spatially also.

4.1.1. Visuospatial information and driving

According to Baddeley (2000) visuospatial sketchpad of WM temporarily stores information related to object appearance and its location in the space. There is ample research conducted on VSWM (Baddeley, 2007; Mammarella, Pazzaglia, & Cornoldi, 2008). Logie and Pearson (1997) distinguished between a visual store (Visual Cache) which temporarily stores visual information about the object properties (e.g., visual appearance of an object or scene, its color, shape, contrast, size, and visual texture) and inner scribe that stores information about sequences of spatial information, i.e., the processes of change in the perceived relative locations of objects that occur when an observer moves – physically or in a mental image – from one viewpoint to another. This dissociation between object and spatial memory has been supported from different fields, e.g., on the basis of selective interference paradigm (Logie & Marchetti, 1991; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999), neuropsychological evidence (Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001), and on developmental data (Gathercole & Pickering, 2000; Hamilton, Coates, & Heffernan, 2003; Pickering, Gathercole, & Peaker, 1998). There is also scientific evidence supporting that object information and spatial information are processed by different cognitive systems (Hecker & Mapperson, 1997; Logie & Marchetti, 1991; Tresch, Sinnamon, & Seamon, 1993), and by different areas of the brain like parietal and dorsolateral frontal cortex play a significant role in processing the spatial location of objects, and that the ventral areas of the temporal and frontal lobes are mainly involved in processing the visual properties of objects (Corbetta, Miezin, Dobmeyer, Shulman, & Petersen, 1991; Courtney, Ungerleider, Keil, & Haxby, 1996; Munk et al., 2002; Nelson et al., 2000). In the light of this understanding, the current experiment intends to examine object and spatial distractions in terms of their effect on driving performance and gaze behavior of drivers. Drivers are involved in performing an in-vehicle distracting task. Under object distraction drivers are required to process object appearance information. In case of spatial distraction, drivers are required to process spatial information. Engaging the participant in processing object appearance information would selectively interfere with driving related object appearance information (gocognitive, 2011). Similarly, spatial distraction would selectively interfere with driving related spatial information. According to Postle, D'Esposito, and Corkin, (2005) in order to keep the object appearance information alive in WM for a longer time period, verbal coding mechanisms are used by WM whereas processing space related information by spatial WM does not involve any such processing. Since the process of verbal coding would demand extra cognitive resources, in the context of driving as comparison with spatial distraction, if the drivers are distracted while processing object related information, it is expected to have more detrimental effect on driving performance. Further, this experiment incorporates analysis of gaze behavior of drivers. Should object distraction have a more detrimental effect on driving performance as compared to spatial distraction, the effect should also be manifested in gaze behavior (in terms of reduced fixation durations on AOI) of drivers. According to Lavie's Load Theory (Lavie, Hirst, Fockert, & Viding, 2004; Lavie, 1995; Lavie & Tsal, 1994), cognitive resources are consumed according to the demand of the task, that is, the more demand of cognitive resources a task has, the less cognitive resources would be unused. In contrary, the tasks that would demand less cognitive resources would relatively leave more cognitive resources unused. Therefore, current study also examines whether object processing or spatial processing of driving related information demands more cognitive resources. In this context, it is conceivable that CWL has a role to play if there is a significant difference between object distraction and spatial distraction in terms of their effect on driving performance and gaze behavior.

4.1.2. Expertise and gaze behavior in driving

Besides investigating the effect of in-vehicle distraction, the current study also investigates the effect of driving expertise on driving performance and gaze behavior of drivers. Expertise is an important individual characteristic in driving studies. Expertise refers to those characteristics, skills, and knowledge set that develop with experience in a domain across time (Ericsson, 2006a). As a person gains more experience in a particular domain, his/her expertise increases; and the same diminishes outside the specific domain (Shanteau & Stewart, 1992). The facts which are unrelated at the initial stages of the expertise start getting integrated into the mental schema through repeated occurrences. Through the repetition of the occurrences, reasoning processes of the experts are refined, and the usefulness and rigidity of rules are learned. According to Ericsson (2006b) experts have psychophysiological adaptations in response to the demands of the activity. With experience and practice, operations that are initially slow, serial, and demand conscious attention, become fast, less deliberate and can run in parallel with other processes (Schneider & Shiffrin, 1977). As expertise is gained, the character of cognitive operations change in a manner that it (a) improves the speed and smoothness of the operations, and (b) decreases the cognitive demands of the operations, thus releasing cognitive (e.g., attentional) resources for other (often higher) functions (e.g., planning, self-monitoring) (Feltovich, Prietula, & Ericsson, 2006).

Visuospatial information processing abilities involve cognitively processing and interpreting information about the appearance of objects and their location in space relative to each other. Such abilities are acquired through training and experience (Wojtasinski, 2018). Studies have shown that the higher the level of expertise, the better would be the visuospatial information processing abilities (Burmeister, Saito, Yoshikawa, & Wiles, 2000). Burmeister et al., (2000) in their study on visuospatial abilities of the 'game of Go' players found that expert players have better spatial organization at various levels of complexity and their eye-movement data suggest that they take into account the minute details of the game that a novice eye cannot see. As compared to novices, there is an increased level of neuronal activity in the brain parts of experts responsible for processing visuospatial information (Ouchi et al., 2005).

With respect to gaze behavior, compared to the road scanning patterns of experienced drivers, novice drivers fixate their gaze on central dual-carriageways (Underwood, Chapman, Bowden, & Crundall, 2002). Mourant and Rockwell (1972) analyzed gaze behavior patterns of novice and experienced drivers. They found that experienced drivers look further ahead, often check their side mirrors, and scan a wider area of the road. However, the novice drivers were preoccupied with lane maintenance and quite often looked at the road close to their car. The gaze behavior of novice drivers reveal that they look more on the ahead direction and less on the peripheries of the road. They also keep their gaze aligned with the heading of the car at the time of negotiating a curve whereas their instructors looked as much as 50^{o} into the bend, as soon as they started turning the steering wheel (Land & Hughes, as cited in Land 2006). Driving experience is a key predictor of on-road crash rates (Gregersen & Bjurulf, 1996), with higher crash rates among young novice drivers (Clarke, Ward, Bartle, & Truman, 2006; Neyens & Boyle, 2008). The reason of higher crashes among novice drivers (in low visibility conditions) is their inefficiency in deploying visual attention (both foveal and peripheral) which increases as the person gains more experience. Underwood (2007) suggests that visual search strategy is one of the basic skills that marks the transition from novice to experienced driver. During learning phase, the subtasks of driving (e.g., steering, braking, gear changing, using the rear-view mirror, following traffic signs, etc.) require attentive monitoring, but as the novice drivers gain experience many of the subtasks become at least partially automatic (i.e., the subtasks require relatively lesser conscious monitoring), so that more attentional resources can be devoted to the less predictable aspects of driving, notably the behavior of other road users (Duncan, Williams, & Brown, 1991).

Rahimi, Briggs, and Thom (1990) reported that because of the increased demand, drivers have more number of fixations at the busy intersections than the quite junctions, which suggests a corresponding reductions in fixation durations. As the complexity of the driving situation increases fixation duration decreases (Crundall, Shenton, & Underwood, 2004), fixation sequences become less structured (Wu, Anderson, Bischof, & Kingstone, 2014), and attentional focus size is narrowed down (Recarte & Nunes, 2000). In the context of the current study, the drivers are involved in direction following and simultaneously responding to distracting stimuli (object and spatial). Should expert drivers be able to manage multiple tasks demanding for attention better as compared to novices, a reduction in fixation durations is ought to occur for novices as compared to experts.

4.1.3. Cognitive workload and driving error

Driving error is an important contributing factor in road crashes or near crashes (Treat et al., 1979). Despite its pervasiveness, still there are many aspects of driving error which need to be explored in terms of the role of different kinds of errors in crashes or near crashes, the factors or mechanisms that cause driving errors, and the counter measures that can minimize the prevalence of driving errors or alleviate their effects (Salmon, Young, Lenné, Williamson, & Tomesevic, 2010). Distracted driving is one of the factors that contribute to driving errors (Sandin, 2009). Staubach (2009) interviewed 584 drivers involved in 474 accidents and found that a significant number of lane departure and same direction accidents were caused by distracted driving. The more complex the secondary task is the greater it interferes with lane keeping and thus potentially increases the risk of accidents (Tijerina, Parmer, & Goodman, 1998). Recarte and Nunes (2000) also reported that if the complexity in driving situation narrows down attentional focus size it should also be reduced by concurrent cognitive tasks (as both have attentional demands) and subsequently lead to more driving errors. According to American Association of State Highway and Transportation Officials (AASHTO, 2011), with an increase in the amount of information to be processed, there is an increase in drivers' reaction time for performing a relevant driving maneuver. They also reported that as the reaction time increases, there are higher chances for driving errors. Several studies have investigated variations in CWL and the associated effects on driving errors (e.g., Cnossen et al., 2000; Steyvers and De Waard, 2000). They examined CWL as a function of traffic flow and road layout. Their results revealed that an increased traffic flow is associated with increased CWL and performance impairments.

In addition to this, the traditional approaches, (e.g., Wiener Fahrprobe Method (Chaloupka & Risser, 1995) and self-report measures such as the Driver Behavior Questionnaire (DBQ) (Reason, 1990)) of investigating the distraction-induced error are inefficient in objectively and accurately determining if a driver is distracted or not. Therefore, for collecting data about driving errors under carefully controlled distraction conditions more objective approaches are required. One such recent approach involves the use of instrumented vehicles (both on-road or on test-tracks) which does real-time recording of driving errors and studies their underlying mechanisms (Young et al., 2013). The current study involves the development of an experimental paradigm and uses an instrumented vehicle for investigating how the gaze behavior and driving performance are affected by in-vehicle object and spatial distraction in a test-track driving scenario. As in experiment-1, in the context of the present study, driving performance is analyzed with respect to Reason's (1990) slips and lapses.

4.2. Hypotheses

In the light of the aforementioned issues of in-vehicle object and spatial distractions, expertise, and workload, the following hypotheses were formulated and investigated in the present study (experiment-2):

H3. As compared to in-vehicle spatial distractions, drivers face more difficulties in fixating gaze on AOI during in-vehicle object distractions.

H4. In-vehicle object distractions have more detrimental effect on driving performance as compared to in-vehicle spatial distractions.

H5. Novices face more difficulties in fixating gaze on AOI as compared to experts.

H6. Novices have more compromise in driving performance as compared to experts.

H7. Drivers experience higher level of CWL during in-vehicle object distractions than during in-vehicle spatial distractions.

4.3. Materials and methods

4.3.1. Direction following in distracted driving – object and spatial (D3-OS)

In the current study, drivers were distracted by means of in-vehicle object and spatial distractions and the existing D3 paradigm (as described in section 1.3.2) is named as *'Direction Following in Distracted Driving – Object and Spatial (D3-OS)'*. Since the drivers were required to interact with an in-vehicle display system, which is relatively more challenging as compared to the distractions used in experiment-1, the speed range for this study was set at 25-35 km/h. Unlike experiment-1, the direction signboards were installed only on the left side of the two-lane track.

Drivers were distracted by means of *'Distracting Stimuli Regulator–Object and Spatial (DSR–OS)'* a program coded on MATLAB platform. DSR–OS was run on a DELL Inspiron 11.6 inch HD display laptop which was attached to the dashboard (on the left side of the driver) with the help of a monitor holder (see figure 9). When the program is run, 30 randomly placed squares appear on the display in such a manner that they do not overlap or touch each other. Among the 30 randomly placed squares letter 'P' appears randomly in one of the squares. The font size 48 of the letter 'P' was maintained throughout this study (during trial runs drivers faced difficulty in perceiving font sizes smaller than 48 and the font sizes larger than 48 could not fit in the squares). The appearance (i.e., typeface and color) and the location (i.e., the square in which it appears) would randomly change. The program is characterized by two phases: (a) *stimulus phase*, and (b) *probing phase*. In stimulus phase, the letter ‘P’ appears accompanied by experimenter’s recorded voice saying “1”, and in the probing phase, the letter ‘P’ appears accompanied by experimenter’s recorded voice saying “2”. Depending on the treatment condition, if the participant is in object distraction group, whenever he/she hears “1” he/she is required to look at the display and remember the appearance (typeface and color) of the letter ‘P’. After a delay time of 3 seconds the letter ‘P’ would reappear accompanied by the voice saying “2”. This time the participant is required to look at the monitor and judge whether the previous ‘P’ (which appeared in stimulus phase) matches with the current ‘P’ or not, if it matches, he/she has to verbally say “yes”, otherwise he/she has to say “no”. Figure 10 shows the presentation of experimental task stimuli for in-vehicle object distraction phase by using DSR–OS.

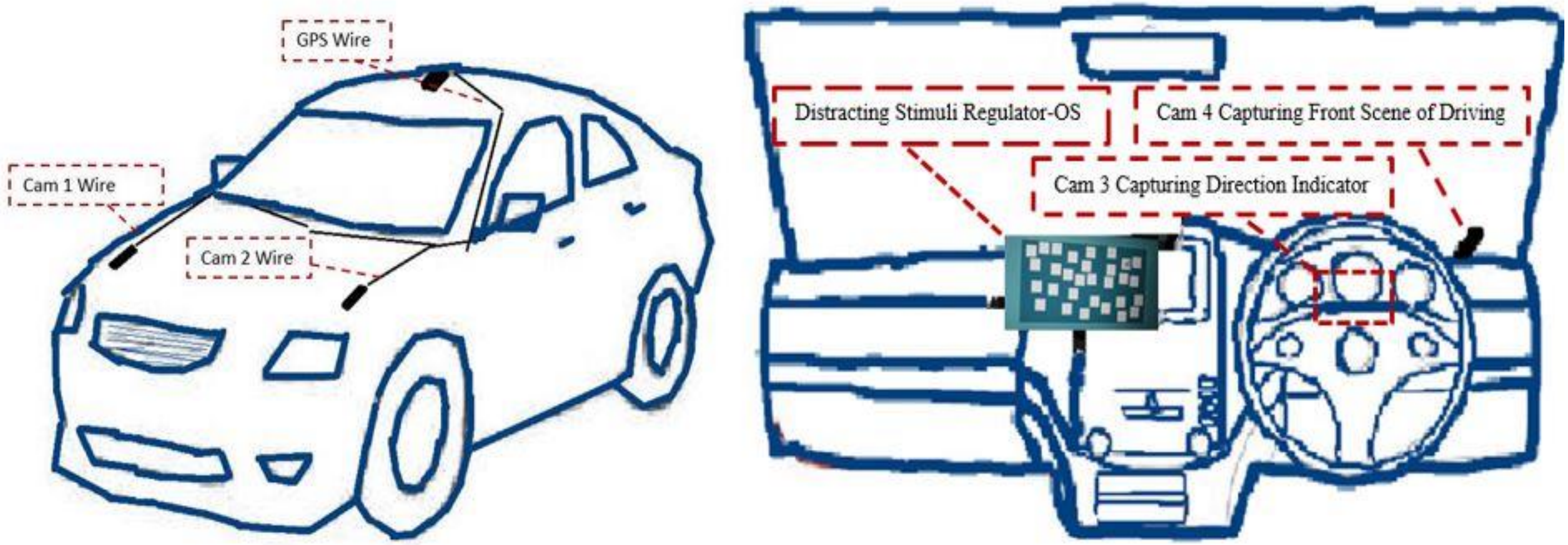


Figure 9. Placement of recording systems externally and internally attached to the vehicle.

Similarly, if the participant belongs to spatial distraction group whenever he/she hears “1” he/she has to look at the display and remember the location (the square in which the letter ‘P’ appears). After a delay time of 3 seconds the letter ‘P’ would reappear accompanied by the voice saying “2”. This time the participant is required to look at the monitor and judge whether the location of the previous ‘P’ and the current ‘P’ matches or not, if it matches he/she has to verbally say “yes”, otherwise he/she has to say “no”. The on screen time for the letter ‘P’ was 4 seconds and the delay time (time duration between the disappearance of the previous ‘P’ and the appearance of the next ‘P’) was 3 seconds. The onscreen time and the delay time were decided on the basis of the feedback received from the participants during initial trial test. Figure 11 shows the presentation of experimental task stimuli for in-vehicle spatial distraction phase by using DSR–OS.

For matching the letter ‘P’ of the probing phase with the stimulus phase in terms of the appearance and location, there are four possible situations, i.e., same location but different appearance, different location but same appearance, same location and same appearance, and different location and different appearance (having equal proportion of four situations, i.e., 25% each situation). The participants who were assigned to object distraction were clearly instructed to concentrate on the appearance of the letter ‘P’ (while ignoring its location) and to respond by saying Yes/No indicating whether the probe letter ‘P’ was the same or different in appearance from that of stimulus phase. Similarly, the participants assigned to spatial distraction were instructed to ignore the appearance of the letter ‘P’ and concentrate on the location of it and respond by saying Yes/No indicating whether the probe letter ‘P’ was in the same or in a different location.

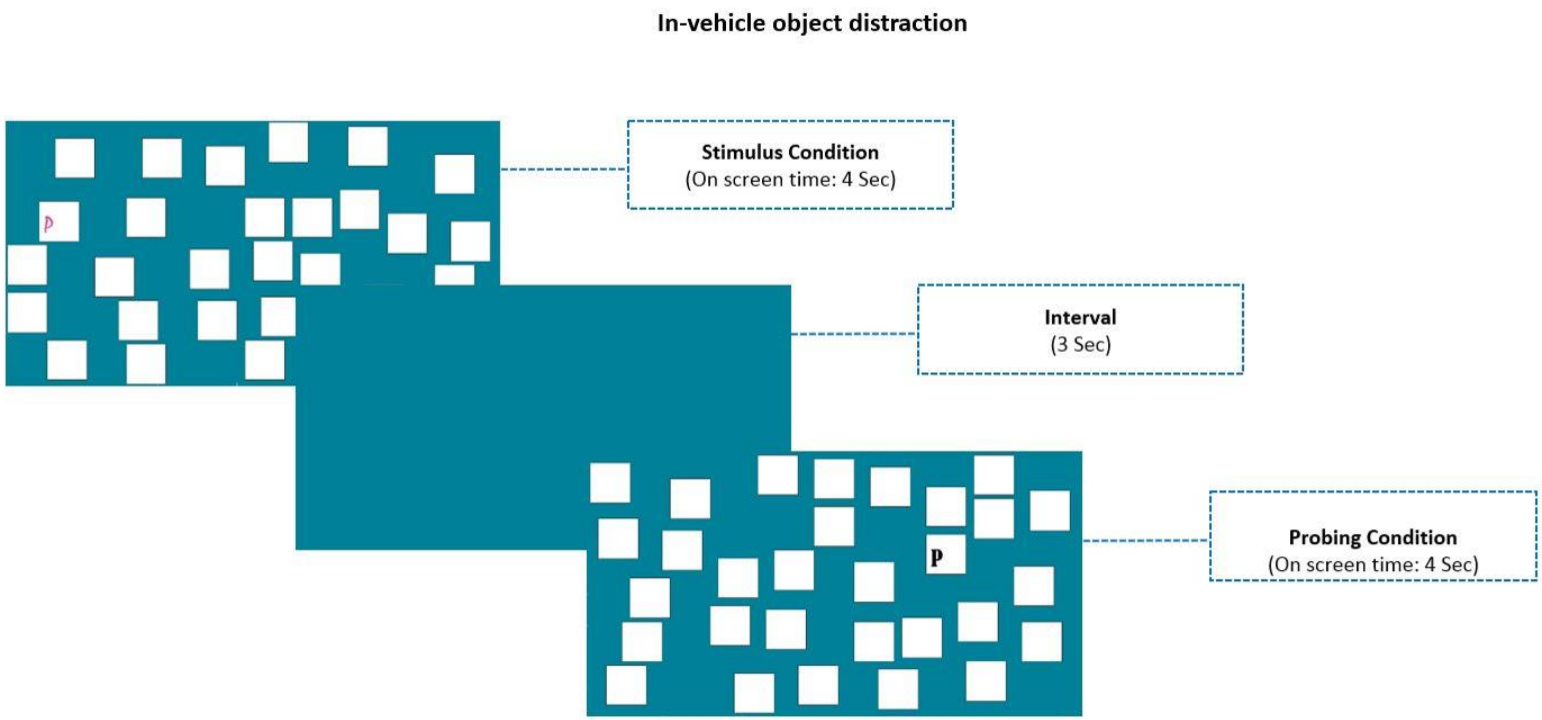


Figure 10. Presentation of experimental task stimuli for in-vehicle object distraction phase by using DSR–OS. In this instance the response is ‘no’.

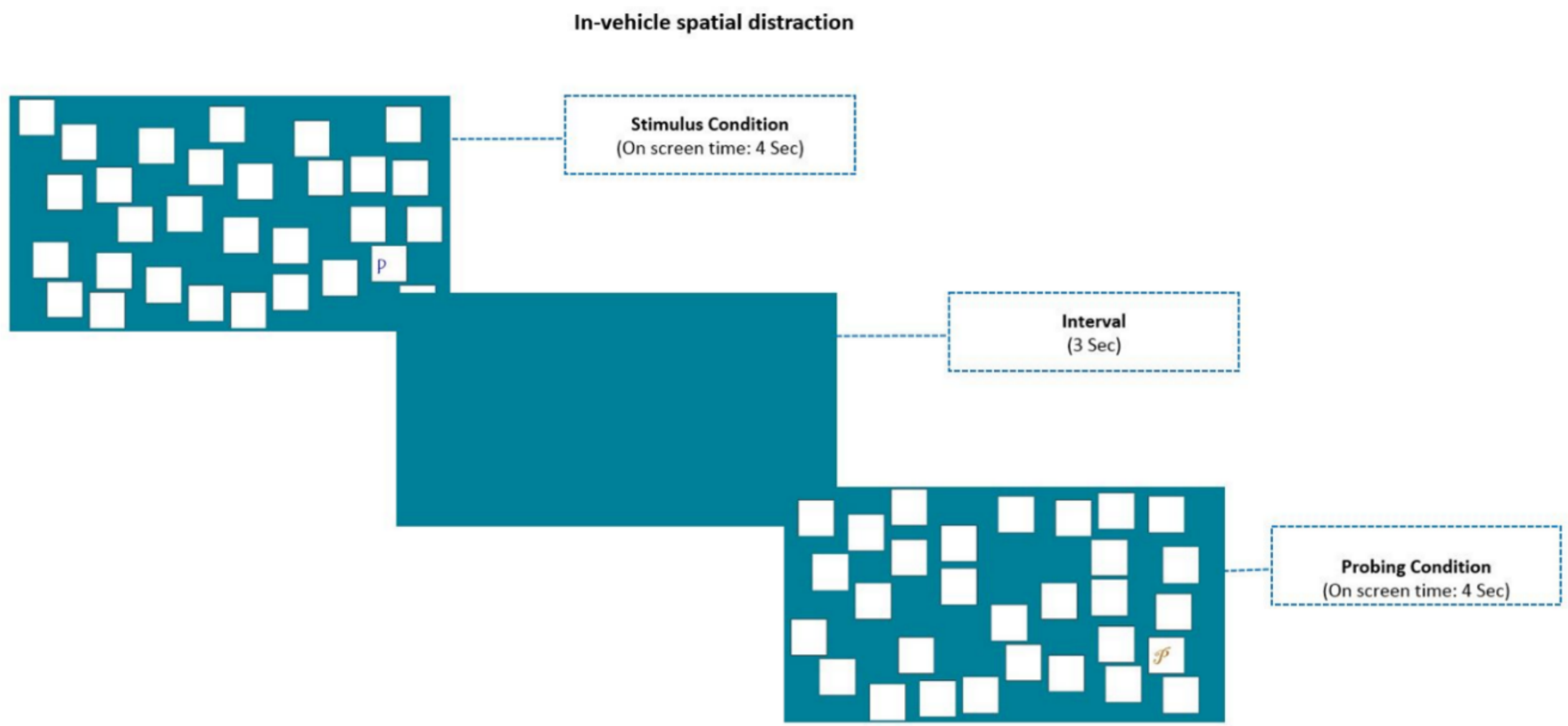


Figure 11. Presentation of experimental task stimuli for in-vehicle spatial distraction phase by using DSR–OS. In this instance the response is 'yes'.

4.3.2. Design

This experiment use a 2 in-vehicle distraction (object vs. spatial) X 2 expertise (novice vs. expert) between-groups design. The reason for adopting between-groups design is to reduce the learning/practice effect that would arise if the participant is exposed more than once to the experimental setup (in particular, direction signboards). Since only 4 direction signboards were used in this study it is highly likely that the directions would be remembered by the participants in one go. Furthermore, since the length of the track was only 1 km, exposing the participant to both treatment conditions (i.e., object and spatial distraction) in a single drive would mean that the drivers have to drive for only 500 meters in each treatment condition, which would not be a sufficient distance for investigating this phenomenon. In the current study, relative approach (Chi, 2006) was used to operationalize expertise. In this approach experts are defined as relative to novices on a continuum and it assumes that expertise develops as a function of time spent within the domain. A driver was treated as an expert if his/her license was older than three years (van Leeuwen, Happee, & de Winter, 2015; Bos et al., 2015) and was driving on regular basis (i.e., professional bus drivers of authors' educational institute and nearby educational institutions). Participants whose license was not older than three years and had limited driving experience (i.e., drive occasionally, with total driving experience of less than 15,000 km). Novice drivers consisted of bus conductors of the nearby educational institutes and PhD students of the authors' educational institute. In order to further check whether the participant is a novice or an expert, they were asked to give their subjective evaluation of their driving expertise. A participant was treated as novice on the basis of following parameters: (a) if the license was not older than three years, after fulfilling parameter (a) researchers would ask him/her (b) if he/she considers him/herself as novice or expert driver. The purpose of subjective evaluation is to avoid any mismatch in the form of either of the following scenarios: (1) one considers himself/herself to be an expert without fulfilling parameters (a) or (b), (2) one considers himself/herself to be a novice even after fulfilling parameters (a) and (b). In any of these two scenarios, no participant will qualify to participate in the study.

Gaze behavior was analyzed in terms of fixation durations on the Areas of Interest (AOI), i.e., direction signboards. Fixation duration is measured as the period of time when the eye is relatively still and fixating on the AOI, (i.e., signboards for direction input) (Tobii, 2012). Driving performance was measured in terms of slips and lapses (Reason, 1990). Slips and lapses were measured on the basis of three parameters each. Lane excursions, over/under speeding, and changing lanes wrongly were considered as slips and forgetting to indicate lane change, forgetting to execute lane change, and forgetting to turn off the indicator after changing the lane were considered as lapses.

4.3.3. Instrumentation

Video Velocity Box (VV Box) a data logger with a set of 4 cameras was installed in a vehicle (Volkswagon POLO, 2015 Model, Hatchback 1.2 petrol highline, right hand drive). The cameras were installed in such a manner that the data related to all 6 parameters is collected. For capturing data related to the parameters of lane excursions and wrong lane changes, two cameras were attached on the left and right side of the bonnet of the car. Data related to indicator usage was captured by a camera installed on the fixed portion of the steering column. The fourth camera was installed to the top of the dashboard near the windshield of the car so that the front view of driving especially the direction signboards could be captured. Over/under speeding of the instrumented vehicle was captured by a GPS antenna which was installed on the center of the roof of the vehicle (see figure 9).

Gaze behavior data of the drivers was collected by Tobii glasses 1 eye tracker. 9 point calibration was done before the participants were taken to the experimental track for driving. The drivers were instructed not to move the glasses after the calibration is done.

DELL Inspiron laptop (Core i3 processor, 11.6 inch touch HD display, 360 degree rotatable screen) was attached to the dashboard with the help of a suction based (suctioned with windshield) monitor holder (see figure 9).

4.3.4. Participants

A group of 47 drivers (46 males and 1 female) voluntarily participated in this distracted driving study. Data from 7 participants was considered as invalid due to one (or more) of the following reasons: (a) less than 60% sample rates of the gaze data, and (b) poor calibration or data not recorded properly. The data from remaining 40 participants consisted of two groups (novices and experts). In first group there were 20 novice drivers between the age range of 20 and 34 years (M = 26.95; SD = 3.56) and a mean of 2.32 years' driving experience since passing the driving test (with all drivers having less than 3 years' driving experience). The second group was composed of 20 expert drivers within the age range of 23 and 48 years (M = 33.45; SD = 7.74) and a mean of 12.10 years' driving experience. Participants were recruited from the investigators' campus and nearby educational institutions. Each participant was given 250 INR as compensation for their voluntary participation in the study. The participants were made aware of the purpose of the study. They were assured that the data collected from them will be used purely for research purpose and complete confidentiality will be maintained. Thereafter, written consent of all the participants was taken.

4.3.5. Procedure

A brief description of the task was given to all participants so that they can make an informed decision about their participation in the study. After taking their informed consent all participants filled out vital information sheet. A demo of the experimental task was given to each participant. A 9 point calibration of eye movements was done for each participant before they could go for driving. They were then instructed to adjust the driving seat as per their comfort and wear seat belt for safety reasons. Each participant first went through a practice trail so that he/she can get accustomed with the instrumented vehicle. In order to facilitate the understanding of the task, the practice trails took place on a different track where a demo direction signboard was installed. The participants were taken to the experimental track (for actual data recording) only when they were confident about all the functions of the instrumented vehicle and had clearly understood the task. At the starting point of the track the experimenter (seated in the co-passenger seat) connected the VVBox, started – recording of gaze behavior through eye tracking glasses, the DSR–OS, and screen recording of DSR–OS (for analyzing the responses of the participants). After connecting all the recording instruments, the experimenter would confirm readiness of the participant followed by loudly saying ‘start’ and the driver would start driving. The voice feature of the DSR–OS (saying “1” and “2”) was muted for the grace distance of the track so that the participants do not respond to it and it was unmuted once the instrumented vehicle reached the starting point of the track where from data needed to be recorded. The experimenter disconnected all the recording devices once the instrumented vehicle crossed the finishing line of the experimental track. Post- data collection, each participant was asked some probing questions about his/her experience while driving.

4.4. Results

An alpha level of .05 was used to infer statistical significance throughout this chapter.

4.4.1. Gaze behavior

This study investigated the effect of object and spatial distraction on gaze behavior of drivers. Gaze behavior was analyzed in terms of fixation durations and fixation counts on the AOI. In this study the whole area of direction signboards were marked as AOI. A two-way ANOVA was carried out for 2 in-vehicle distraction (object vs. spatial) × 2 expertise (novice vs. expert) between-groups design.

Fixation durations were calculated as the period of time (in seconds) when the eyes were fixating on the AOI (i.e., all the direction signboards). The analysis revealed a significant main effect of in-vehicle distraction on fixation durations with lesser fixation durations on AOI during object distraction (object, M = 1.015, SD = 1.056), than spatial distraction (spatial, M = 2.009, SD =1.816, see Fig. 12), $F(1,36) = 4.347$, $p = .044$, $\eta p^2 = 0.108$. There was no significant main effect of expertise on fixation durations (novices, M = 1.300, SD = 1.109, experts, M = 1.724, SD =1.900, see Fig. 12), $F(1,36) = 0.788$, $p = .381$, $\eta p^2 = 0.021$. There was no significant interaction between in-vehicle distraction and expertise, $F(1,36) = 0.070$, $p = .792$, $\eta p^2 = 0.002$.

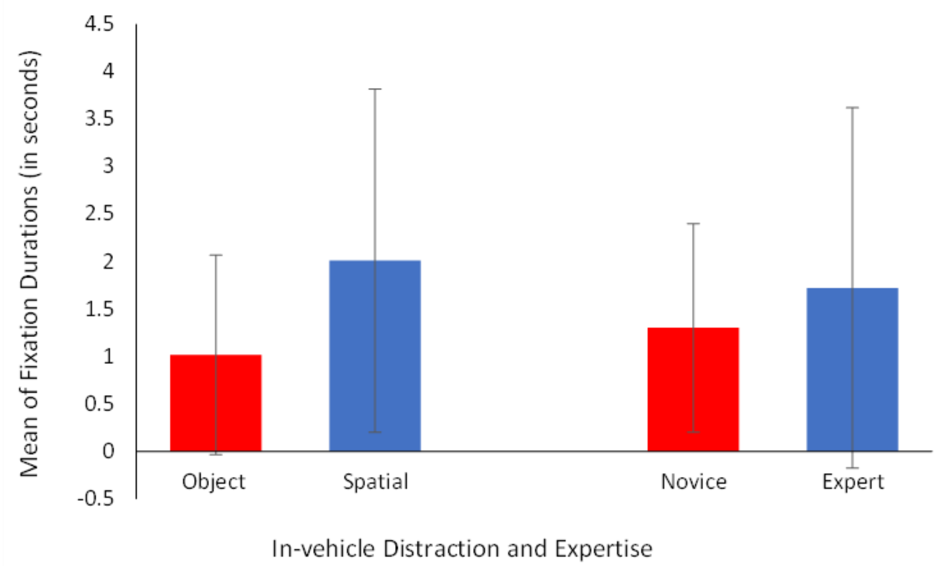


Figure 12. Fixation durations as a function of in-vehicle distraction and expertise. Error bars denote standard deviation.

With respect to fixation counts, statistical analysis showed a significant main effect of in-vehicle distraction on fixation counts with lesser counts on AOI during object distraction (*M* = 33.050, *SD* = 33.689) than spatial distraction (*M* = 64.850, *SD* = 57.699), $F(1,36) = 4.400$, $p = .043$, $\eta_p^2 = 0.109$, (see Fig. 13). The analysis also revealed that there was no significant main effect of expertise on fixation counts with novices having lesser fixation counts on AOI (*M* = 42.200, *SD* = 35.710) than experts (*M* = 55.700, *SD* = 60.210, see Fig. 13), $F(1,36) = 0.793$, $p = .379$, $\eta_p^2 = 0.022$. There was no significant interaction between in-vehicle distraction and expertise with respect to their interactive effect on fixation counts on AOI, $F(1,36) = 0.109$, $p = .743$, $\eta_p^2 = 0.003$.

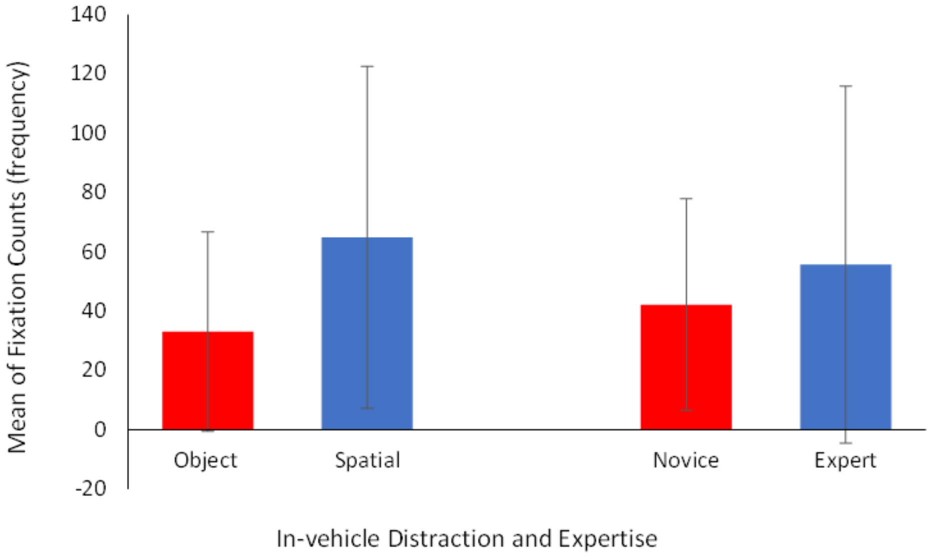


Figure 13. Fixation counts as a function of in-vehicle distraction and expertise. Error bars denote standard deviation.

4.4.2. Driving errors

Driving errors were analyzed on the basis of the data recorded by VVBox. To examine driving errors the cases of slips and lapses were measured. According to Reason (1990) when the task performer's plans are correct but the execution is flawed, slips and lapses are treated to have occurred. If an action is carried out incorrectly, it is calculated as a slip and in the current study it is measured on the basis of the parameters of lane excursions (wheels crossing the lane demarcating line), over/under speeding (driving beyond the specified speed limit), and changing lanes wrongly (changing lanes contrary to the signs shown on the direction signboard). When the action is simply omitted or not carried out at all, a lapse is treated to have occurred and in this study it is determined on the basis of the parameters of forgetting to indicate lane change (i.e., the driver does not indicate lane change though he performs a lane change), forgetting to execute lane change, and forgetting to turn off the indicator after changing the lane.

To examine overall driving error (irrespective of slips and lapses) a two-way ANOVA was carried out for 2 in-vehicle distraction (object vs. spatial) X 2 expertise (novices vs. experts) between-groups design. The results revealed that there is a significant main effect of in-vehicle distraction on the overall error committed by drivers. Drivers committed more overall error during object distraction (M = 10.200, SD = 8.345) than spatial distraction (M = 6.960, SD = 4.729), $F(1,36) = 5.840$, $p = .021$, $\eta_p^2 = 0.140$, (see Fig. 14). The statistical analysis also revealed a significant main effect of expertise on overall driving error with novices committing more overall driving error (M = 13.600, SD = 6.361) than experts (M = 3.550, SD = 1.986), $F(1,36) = 55.845$, $p = .001$, $\eta_p^2 = .608$, (see Fig. 14). The results show a significant interaction between in-vehicle distraction and expertise in affecting overall driving error, (see Fig. 15), $F(1,36) = 4.812$, $p = .035$, $\eta p^2 = 0.118$, such that novices committed more overall driving errors during object distraction than spatial distraction but with experienced drivers the trend is absent.

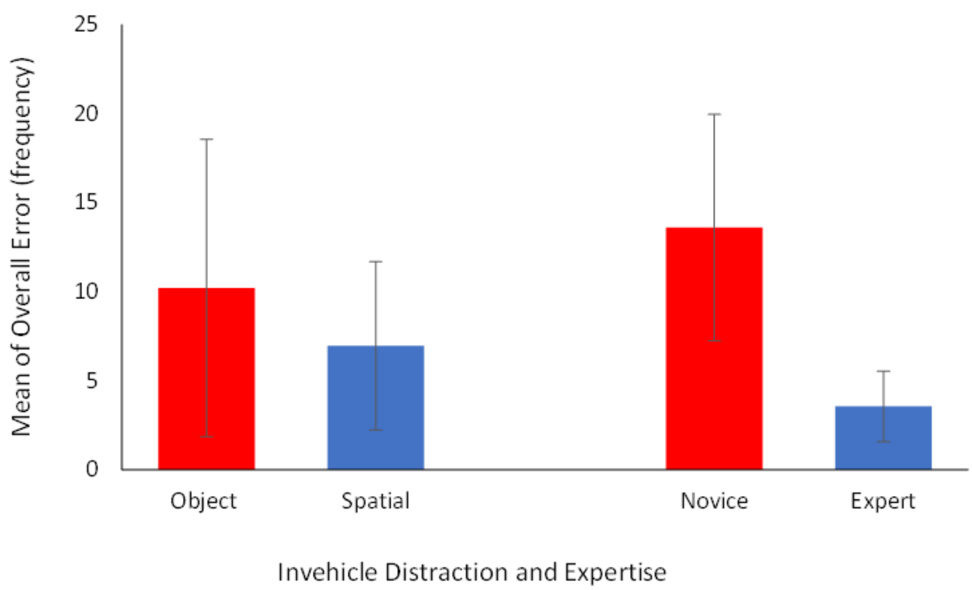


Figure 14. Overall error as a function of in-vehicle distraction and expertise. Error bars denote standard deviation.

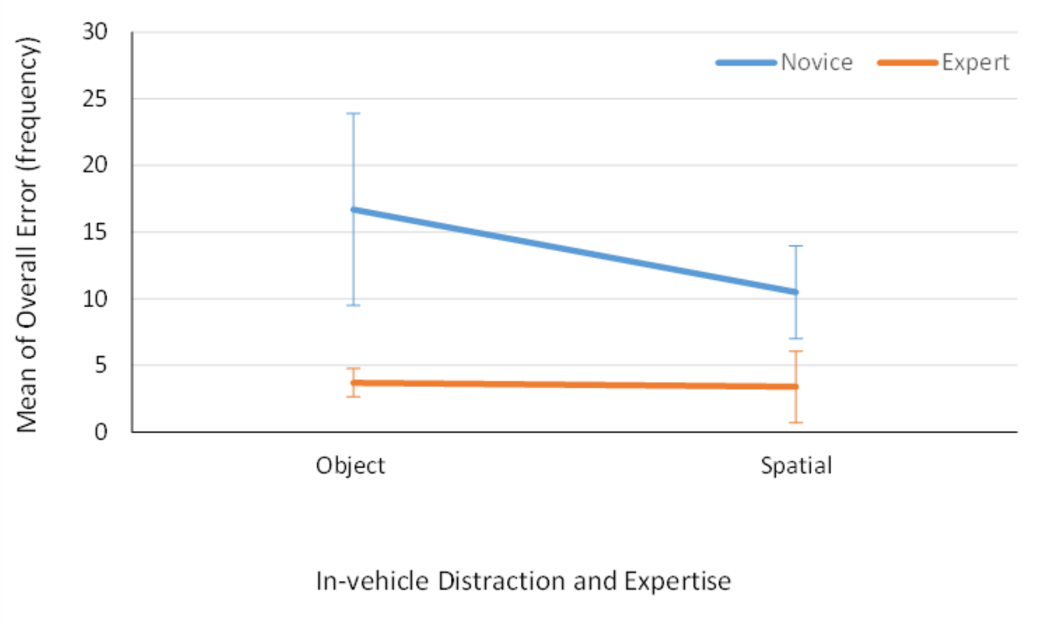


Figure 15. Overall error as a function of interaction between in-vehicle distraction and expertise. Error bars denote standard deviation.

Further error analysis was performed using a 2 way ANOVA in order to examine the effect of in-vehicle distraction (object vs. spatial) and expertise (novices vs. experts) on slips and lapses. The analysis revealed a significant main effect of in-vehicle distraction on slips, $F(1,36) = 4.456$, $p = .042$, $\eta_p^2 = 0.110$, with more occurrence of slips during object distraction ($M = 2.633$, $SD = 2.296$) than spatial distraction ($M = 1.867$, $SD = 1.373$), (see Fig. 16). Expertise also has a significant main effect on slips. As shown in Fig. 16, novice drivers committed more slips ($M = 3.683$, $SD = 1.687$) than expert drivers ($M = 0.816$, $SD = 0.545$), $F(1,36) = 62.297$, $p = .001$, $\eta_p^2 = 0.634$. In-vehicle distraction and expertise showed a significant interaction in affecting the occurrence of slips (see Fig. 17), $F(1,36) = 4.852$, $p = .034$, $\eta_p^2 = 0.119$, such that novices committed more slips during object distraction than spatial distraction but with experienced drivers the trend is absent.

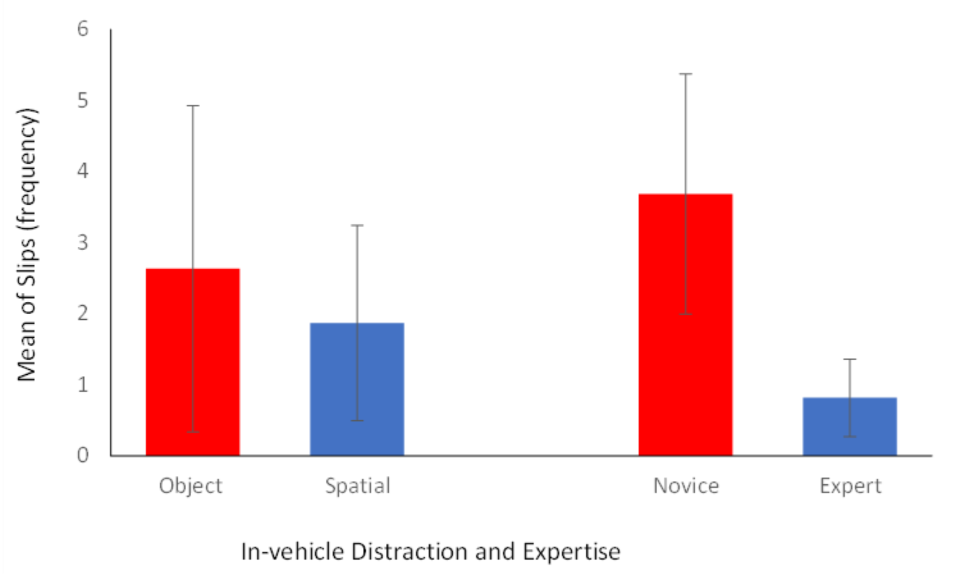


Figure 16. Slips as a function of in-vehicle distraction and expertise. Error bars denote standard deviation.

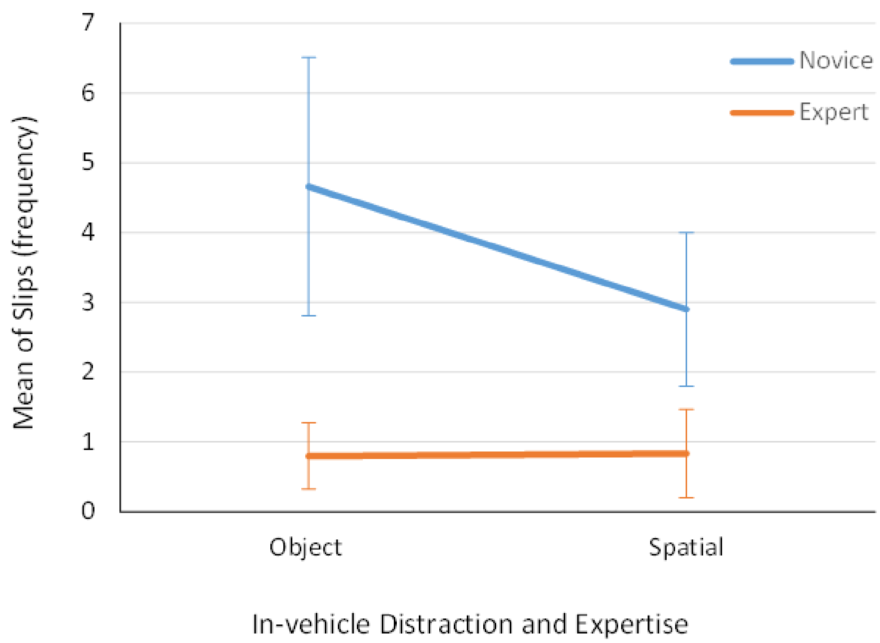


Figure 17. Slips as a function of interaction between in-vehicle distraction and expertise. Error bars denote standard deviation.

As shown in Fig. 18, there is a significant main effect of in-vehicle distraction on lapses, with more number of lapses during object distraction

(M = 0.767, SD = 0.631) than spatial distraction (M = 0.449, SD = 0.436), $F(1,36) = 4.236$, $p = 0.047$, $\eta_p^2 = 0.105$. The statistical analysis also revealed a significant main effect of expertise on lapses. Novice drivers committed significantly more number of lapses (M = 0.850, SD = 0.587) than their expert counterparts (M = 0.367, SD = 0.417, see Fig. 18), $F(1,36) = 9.868$, $p = .003$, $\eta_p^2 = 0.215$. The analysis did not show any effect of interaction between in-vehicle distraction and expertise on lapses, $F(1,36) = 1.420$, $p = .241$, $\eta_p^2 = 0.038$.

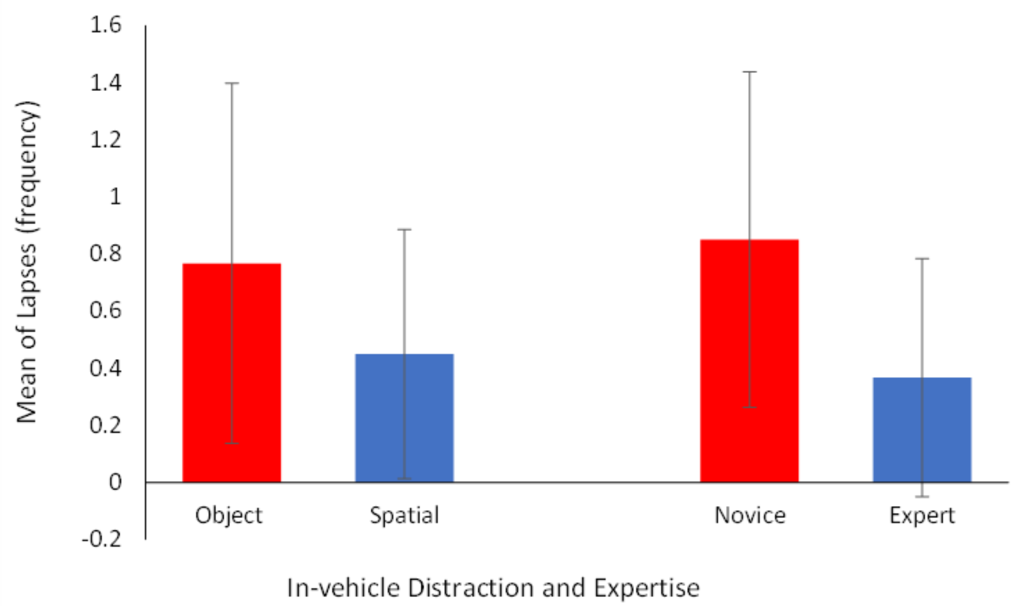


Figure 18. Lapses as a function of in-vehicle distraction and expertise. Error bars denote standard deviation.

4.4.3. Workload analysis

CWL was assessed by using an android based NASA-TLX application (version 1.0.1, developed by Backgate app developers). NASA-TLX has six dimensions (subscales): mental demand, physical demand, temporal demand, performance, effort, and frustration level. Among the six dimensions of the scale, the first three (i.e., mental demand, physical demand, and temporal demand) relate to the demands of the task imposed on the task performer, and the other three (i.e., performance, effort, and frustration level) relate to the interaction of the performer with the task. In this form of NASA-TLX, the participant rates each dimension of the scale by assigning a number (in terms of percentage) according to the workload that he/she has experienced while performing the task. The rating scale ranges from ‘very low’ to ‘very high’ for all dimensions except for the ‘performance dimension’ which ranges from ‘perfect’ to ‘failure’. After filling in the basic information, each participant rated the six dimensions according to the workload he/she experienced, following which, they evaluated the weighting of each of the six factors through 15 pair-wise comparisons. After the scores are submitted, the workload for each dimension as well as the overall CWL is automatically calculated by the NASA-TLX app.

A two-way ANOVA was performed on overall CWL score for 2 in-vehicle distraction (object vs. spatial) X 2 expertise (novices vs. experts) between groups design. The analysis revealed that there is a significant main effect of in-vehicle distraction, object (M = 62.730) and spatial (M = 50.663) on CWL, $F(1,36) = 17.349$, $p = .001$, $\eta p^2 = 0.325$ (see figure 19). The statistical analysis also revealed a significant main effect of expertise, novice (M = 67.923) and experts (M = 45.470) on CWL, $F(1,36) = 60.071$, $p = .001$, $\eta p^2 = 0.625$ (see figure 19). The analysis did not show any effect of interaction between in-vehicle distraction and expertise on CWL, $F(1,36) = 1.135$, $p = .294$, $\eta p^2 = 0.031$.

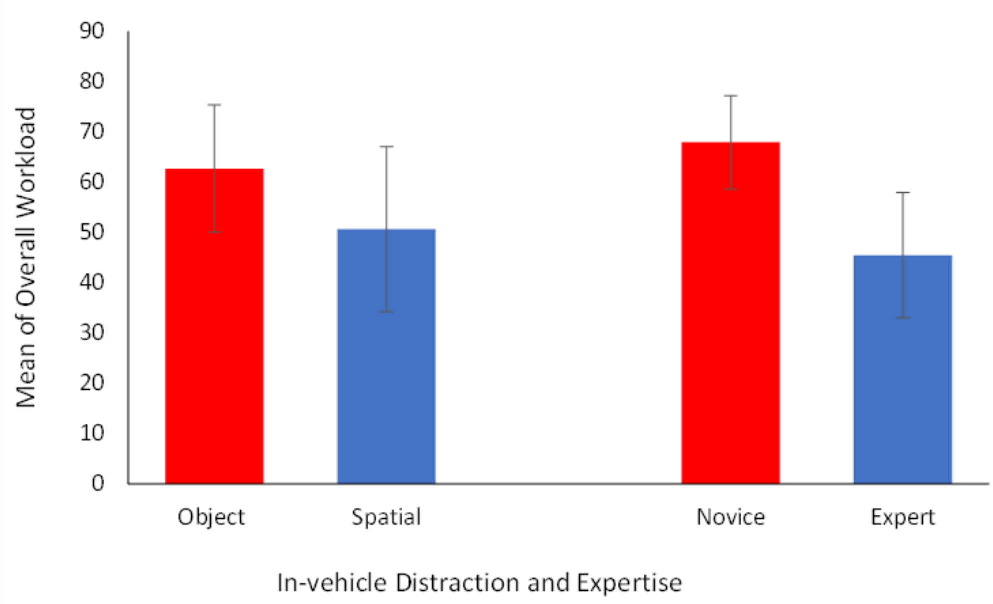


Figure 19. Overall workload as a function of in-vehicle distraction and expertise. Error bars denote standard deviation.

In order to examine which of the six dimensions of NASA-TLX have significantly contributed to the overall workload, a multiple regression analysis was performed. Using the enter method, a significant model emerged: F (6,33) = 66.196, $p < 0.01$. The model explains 90.9% of the variance (Adjusted $R^2 = 0.909$). Table 3 gives information of the predictor variables entered into the model. Temporal demand, effort, and performance dimensions are significant predictors of overall CWL, but the other three dimensions are not.

For deeper analysis of CWL experienced by drivers, the proportion of variance contributed by each dimension of NASA-TLX was calculated. As shown in table 4, a stepwise analysis of the dimensions of NASA-TLX showed that temporal demand is the most important factor which contributed to 85% of the workload variance, F (3,36) = 138.126, $p < 0.01$. Adjusted $R^2 = 0.913$. Temporal demand, $\beta = .854$, $p < 0.01$. Effort, $\beta = .049$, $p < 0.01$. Performance, $\beta = .014$, $p < 0.01$. Table 5 shows the coefficients of regression.

Table 3

The unstandardized and standardized regression coefficients for the variables entered into the model (Enter method)

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.376	7.673		.179	.859
	Mental Demand	23.711	21.894	.058	1.083	.287
	Physical Demand	-.003	.075	-.002	-.036	.972
	Temporal Demand	.466	.063	.651	7.394	.000
	Performance	.102	.043	.161	2.387	.023
	Effort	.248	.055	.439	4.548	.000
	Frustration	.031	.078	.029	.400	.692

Table 4

Model summary of dimensions which significantly contributed to variance in CWL (Stepwise method).

					Change Statistics				
Model	R	R^2	Adjusted R^2	SE of the Estimate	R^2 Change	F Change	df1	df1	Sig. F Change
1	.926[a]	.857	.854	6.00551	.857	228.570	1	38	.000
2	.952[b]	.906	.901	4.93519	.049	19.270	1	37	.000
3	.959[c]	.920	.913	4.62028	.014	6.216	1	36	.017

a. Predictors: (Constant), Temporal Demand
b. Predictors: (Constant), Temporal Demand, Effort
c. Predictors: (Constant), Temporal Demand, Effort, Performance

Table 5

Summary of regression coefficients for dimensions which significantly contributed to CWL (Stepwise method)

Model	Dimensions	Unstandardized Coefficients		Standardized Coefficients
		B	Std. Error	Beta
1	(Constant)	16.370	2.831	
	Temporal Demand	.663	.044	.926
2	(Constant)	18.219	2.365	
	Temporal Demand	.474	.056	.663
	Effort	.194	.044	.344
3	(Constant)	8.454	4.499	
	Temporal Demand	.491	.053	.686
	Effort	.235	.045	.416
	Performance	.094	.038	.148

4.4.4. In-vehicle task performance (object processing and spatial processing)

Drivers' performance in terms of in-vehicle distraction task, i.e., participants' responses to distracting stimuli, were measured in terms of correct responses, incorrect responses, and no responses. The presentation of distracting stimuli and the participants' responses to them were captured through screen recording of the laptop through which the stimuli were presented. In case of object distractions, participant's response was marked as correct if he/she correctly matched the appearance of the letter 'P' (color and typeface) presented in the probing phase with the one previously shown in the stimulus phase. Similarly, it was marked as incorrect, if he/she incorrectly matched the appearance of the letter 'P' presented in the probing phase with the one previously shown in the stimulus phase. If the participant failed to provide a response, it was marked as no response. The same procedure was used in the case of spatial distraction. If the participant correctly matched the location (square containing letter ‘P’) in the probing phase with the one previously shown in the stimulus phase, the response was marked as correct, if it did not match it was marked as incorrect and if the participant failed to provide a response, it was marked as no response. Table 6 shows the means and standard deviations of correct, incorrect and no responses to distracting stimuli.

Table 6

Means and standard deviations of correct, incorrect and no responses to distracting stimuli

Response	**Information Processing**	**Expertise**	**Mean**	**SD**	**N**
Correct	Object	Novice	3.700	1.636	10
		Experts	5.100	1.523	10
		Total	4.400	1.698	20
	Spatial	Novice	3.4000	.699	10
		Experts	3.6000	1.261	10
		Total	3.5000	1.000	20
Incorrect	Object	Novice	1.400	.699	10
		Experts	1.100	.316	10
		Total	1.250	.550	20
	Spatial	Novice	1.700	.948	10
		Experts	1.400	.843	10
		Total	1.550	.887	20
No responses	Object	Novice	2.500	.971	10
		Experts	1.300	.823	10
		Total	1.900	1.071	20
	Spatial	Novice	2.300	1.251	10
		Experts	2.000	2.538	10
		Total	2.150	1.954	20

4.4.5. Correlation between driving performance and CWL

Furthermore, after controlling the effect of expertise, the results of partial correlation demonstrate that there is a statistically significant positive correlation between CWL and slips (r = .323, p = .045) and CWL and lapses (r = .439, p = .005), indicating that an increase in CWL leads to an increase in the occurrence of slips and lapses.

4.5. Discussion

This study investigated the effects of in-vehicle distraction (object vs spatial) and expertise (novice vs experts) on driving performance (in terms of errors). The results of the current study demonstrate that object and spatial distractions have significantly different effect on driving performance. In case of object distraction, compared to spatial distraction, drivers committed more slips and lapses. In other words object distraction (i.e., if the driver gets distracted while processing object related information) has more detrimental effects on driving performance. This finding of the study is attributed to the fact that processing object related information by object WM involves verbal coding mechanisms whereas processing space related information by spatial WM does not (Postle, D'Esposito, & Corkin, 2005). Postle, Stern, Rosen, and Corkin (2000) posit that while processing object appearance information humans use the strategy of verbal coding and the mechanism of verbal coding is so strong that it can be done even for non-verbalizable irregular or asymmetrical shapes. By means of distraction if the process of verbal coding is prevented (as in the present study), the memory for object identity gets significantly affected, however, the memory for spatial configuration of the objects remains unaffected (Simons, 1996). Another line of thought for object distraction being more detrimental is from the perspective of CWL. In a scenario of handling multiple tasks demanding for attention, if the operator gets distracted while performing the task(s) that have high demands of cognitive resources, the performance compromise in either of the tasks ought to happen (Lavie, 1995; 2001). In the context of the current study, more driving errors during object distraction indicates that processing object related information consumed more cognitive resources and left very less resources unused (Lavie, 1995), whereas, lesser number of driving errors during spatial distraction indicates that processing space related information relatively consumed less cognitive resources and the residual cognitive resources were utilized in performing the in-vehicle distraction task. During post- experimental debriefing, the participants in the object distraction group requested to have another trial as they felt they did not perform well and their subjective reports (to probing questions) reveal that they experienced more CWL than the spatial distraction group.

In terms of expertise and driving performance, the study shows expected results. The frequency of committing slips and lapses is significantly higher in novices than experienced drivers. Unlike novices, undifferentiated overall error and slips in terms of object distraction or spatial distraction for experts indicate that experts are able to handle distraction better (irrespective of object or spatial). In general, any non-routine or novel task requires controlled and conscious monitoring and driving is not exceptional. Since driving is a complex task and has relevance to survival, novice drivers because of their insufficient exposure and driving practice, require a substantial proportion of available cognitive capacity in order to manage safe driving, whereas in the case of experienced drivers they have automatized the subtasks of driving (McKenna & Farrand, 1999). The reason behind less incidents of slips and lapses and better performance in secondary task in the case of experienced drivers is that they utilized the residual cognitive resources left unused because of the automatization of the driving subtasks. Novice drivers fail to identify and respond to hazards (Pradhan, Fisher, & Pollatsek, 2006), and experience greater CWL under complex driving conditions (Crundall & Underwood, 1998). In a distracted driving scenario, novice drivers performed poorly than their experienced counterparts on intersection management and gaze behavior measures (Olsen, Simons-Morton, & Lee, 2006).

The analysis of NASA-TLX data also supports the finding that compared to spatial distraction, drivers experience more CWL if they are distracted while processing object related information. Moreover, as expected, expertise has a significant main effect on CWL. In comparison with expert drivers, novice drivers experienced higher level of CWL. In terms of the proportion of variance contributed by the six dimensions of NASA-TLX, the analysis revealed that temporal demand, effort, and performance dimensions have significantly contributed in the overall CWL of drivers. Temporal demand emerged to be the most determining factor of drivers' CWL when they are engaged in object and spatial distracted driving.

Gaze behavior was measured in terms of fixation durations on AOI, i.e., direction signboards. The results demonstrated that compared to spatial distraction, object distraction caused a significant decrease in fixation durations on AOI. This is consistent with the understanding that as the complexity of the scene increases, the number of saccades also increases and consequently the fixation duration decrease. Previous studies have also reported that eye movements increase in heavy traffic situations (Rutley & Mace, 1968) and increased complexity of the visual input task leads to more visual searches (Robinson, Erickson, Thurston, & Clark, 1972). Rahimi et al., (1990) found more number of fixations (i.e., more saccades) at busy intersection than the quite intersection and they concluded that as the demand of driving task increased (busy intersection) fixation durations reduced. In the context of the present study, this indicates that processing object related information (i.e., appearance) is more complex than processing spatial information (i.e., location of the object). The results of the current study also demonstrated that there is no significant difference between novice and experienced drivers with respect to fixation durations on AOI. It is evident from table 6 that as compared to novice drivers, experts have performed relatively better on in-vehicle distraction task (in terms of more correct responses, lesser incorrect and no responses). From novice drivers' performance on secondary task, it can be inferred that they have not cognitively processed the information about in-vehicle distraction task and might have looked at the display monitor for a lesser time period, instead they looked at the direction signboards, thus the difference between experts and novice drivers with respect to fixation durations on AOI reduced. In a multitasking situation, if the tasks demand common attentional resources (visual attention), performance in either of the task gets deteriorated (Wickens, 2002). In this case novices' performance on in-vehicle distraction task was compromised, however the experts, because of their expertise in driving could relatively perform better on both tasks.

Furthermore, a significant positive correlation of CWL with incidences of slips and lapses indicates that an increase in CWL is associated with an increase in the occurrences of slips and lapses (i.e., compromise is driving performance). This is because of limited cognitive capability of processing information and this manifest more prominently when an individual is involved in simultaneously performing two or more tasks that require common attentional resources (Wickens, 2002). Therefore, under such circumstances of handling multiple tasks CWL plays a role with respect to performance compromise (i.e., higher chances of committing errors). The analysis of CWL data also demonstrates that during object distraction the drivers experienced more CWL as compared to CWL experienced by the drivers during spatial distraction. This indicates that processing object appearance related information demands more cognitive resources as compared to processing spatial information.

It will be beneficial for future research to explore issues related to spatial processing in WM system by looking at different aspects of spatial processing itself. Therefore dissociation (further break-up) of spatial processing (for instance, spatial-simultaneous and spatial-sequential) will be relevant (Mammarella et al., 2006; Mammarella et al., 2008). Spatial-simultaneous processing of information deals with the tasks that require a recall of locations presented simultaneously (e.g., in the context of driving at an intersection, a driver is required to gather and process information about the location and movement of many vehicles simultaneously), whereas, spatial-sequential deals with tasks that require a person to handle the information about a series of locations presented to him/her sequentially (e.g., on a two way busy road where vehicles would continuously keep passing, a driver is required to perceive and judge the distance (location) of sequentially oncoming vehicles and carefully navigate the lane keeping maneuver of his/her vehicle accordingly).

4.6. Conclusion

The study was conceptualized with the understanding that if object information and spatial information are differently processed by our cognitive system involving different brain areas, then in the context of driving, object and spatial distraction should affect gaze behavior of drivers and their driving performance differently. The study investigated how the in-vehicle distraction (object and spatial) during driving affects gaze behavior and driving performance in a test-track driving environment. The results of the study suggest that as compared to spatial distraction, object distraction has more detrimental effect on driving performance. The point is that with respect to gaze behavior, drivers' fixation duration on AOI reduces under object distraction increasing vulnerability to driving errors. With respect to expertise, novice drivers committed significantly more number of slips and lapses as compared to their experienced counterparts. In summary, the results demonstrate that object distraction (as compared to spatial distraction) is more challenging for drivers irrespective of expertise. However, novice drivers face more detrimental effect as compared to expert drivers.

Chapter 5

Experiment-3: In-vehicle Spatial – simultaneous and – sequential Distractions

5.1. Introduction

In the context of driving, spatial cognition of drivers is very critical, in the sense that it is used to acquire, represent, organize, understand and navigate the driving environment; attend to specific traffic related information and mentally manipulate it (Spence & Feng, 2010). Considering, the multifaceted nature of spatial cognition there is no consensus on a common definition of it. Defined broadly, it is the study of knowledge concerning the interconnections among people, objects and space (Devlin, 2001). According to Burgess (2008), it holds a collection of representations supporting visuospatial perception, spatial memory, mental imagery, and navigation. In other words, it relates to the capacity to process and interpret visual information about the locations of objects in space (Kolb & Whishaw, 1985). It determines an individual's ability to move around in an environment and adapt properly. Spatial cognition is also involved in the capacity to exactly reach for objects within the visual field and the capacity to move the gaze to different points in space (Kolb & Whishaw, 1985). Visuospatial information can be either categorical or coordinate; categorical representations are abstract and propositional, whereas coordinate relations specify metric information on the relative locations of objects (van der Ham & Borst, 2011; Reese & Stiles, 2005). Given this, mental imagery may be looked at as a quasi-perceptual experience, as it may be considered as the capacity to rely on a spatial medium in order to mentally represent and exploit spatial information (Kosslyn, 1994). Mental imagery consists of the mental rotation and mental search of spatial images, and also allows configurational knowledge of the environment to be created into a mental image (i.e., a cognitive map). In a larger scale approach, two other aspects of spatial cognition can be recognized: spatial memory and the elusive concept of "navigation". The domain of spatial memory is large and heterogeneous, and consists of a wide range of processes and factors (Ruggiero, Sergi, Iachini, 2008). The key features of spatial memory are the capability to remember the location of objects in the environment, the ability to remember the spatial context of a given memory, and the ability to recall the topographical aspects of a given environment (e.g., landmarks, scenes). Moreover, spatial memory can be regarded as an essential component for both mental imagery and spatial navigation. The latter is the most serious challenge encountered by the spatial cognitive systems, which are applied when a route is followed to a familiar location (i.e., wayfinding), when a route is learned to a new goal (i.e., route learning), and when an object is located in an environment but cannot be observed directly (Moffat, 2009). Finally, in the spatial domain, the frame of reference can be either allocentric or egocentric. In allocentric spatial memory, an individual's position is based on an external reference system, while in the egocentric spatial memory, the individual uses a frame of reference centered on his or her own self (Moffat, 2009).

Spatial cognition is an important aspect for understanding distracted driving. In the present line of research, the previous two experiments (mentioned in chapter 3 and chapter 4) investigated issues related to suppression of ARM and in-vehicle object and spatial distractions with respect to their effect on gaze behavior and driving performance respectively. For deeper understanding of distracted driving, it is important to understand the issues related to in-vehicle spatial distraction and its underlying dynamics of gaze behavior and driving errors as they have not received much research attention. There is scientific evidence of neuroimaging and experimental studies which suggests that spatial processes can be further bifurcated into spatial-simultaneous and spatial-sequential processes (Mammarella, Borella, Pastore, & Pazzaglia, 2013; Mammarella et al., 2006; Mammarella, Pazzaglia, & Cornoldi, 2008; Lecerf & de Ribaupierre, 2005). Spatial-simultaneous processing of information deals with the tasks that require a recall of locations presented simultaneously (e.g., in the context of driving at an intersection, a driver is required to gather and process information about the location and movement of many vehicles simultaneously), whereas, spatial-sequential processes deals with tasks that require a person to handle the information about a series of locations presented to him/her sequentially (e.g., on a two way busy road where vehicles would continuously keep passing, a driver is required to perceive and judge the distance (location) of sequentially oncoming vehicles and carefully navigate the lane keeping maneuver of his/her vehicle accordingly). Mammarella, Pazzaglia, and Cornoldi (2008) developed a test battery named as 'the visuospatial working memory test battery' for investigating VSWM abilities with reference to spatial-sequential and spatial-simultaneous processes.

With this understanding, the current experiment examines and compares spatial-simultaneous and spatial-sequential distractions with respect to their effect on gaze behavior and driving performance. In this experiment the participants are required to respond to an in-vehicle distracting task. The in-vehicle distracting task is in terms of spatial-simultaneous and spatial-sequential distractions. Under spatial-simultaneous distractions drivers are required to process spatial information displayed on an in-vehicle monitor from multiple locations simultaneously. In case of spatial-sequential distractions they are required to process spatial information sequentially presented to them on an in-vehicle monitor. Furthermore, the current study also examines whether it is spatial-simultaneous processing or spatial-sequential processing of driving related information that demands more cognitive resources. In this context, it is conceivable that CWL has a role to play if there is a significant difference between spatial-simultaneous processing and spatial-sequential processing in terms of gaze behavior and driving performance.

The priorities of visual attention changes according to the demand of the driving situation. Fixation durations on AOI are reduced as the complexity of driving situation is increased due to which the driver would have difficulty in processing the information that he/she has seen, and would eventually lead to compromise in driving performance. In the context of the current study, the drivers are involved in direction following and simultaneously responding to in-vehicle distracting stimuli either spatial-simultaneous or spatial-sequential. It is expected that there will be reduced fixation durations on AOI (visual target outside the vehicle, i.e., direction signboards) when drivers are engaged in in-vehicle spatial-simultaneous distraction as compared to spatial-sequential distraction. This is because of the fact that in case of spatial-simultaneous distraction, a driver needs to attend the stimuli from multiple locations simultaneously and by doing so his/her attention would be divided, thus fixation durations on AIOs (direction signboards) ought to reduce. As a result of more demand on cognitive resources during spatial-simultaneous distraction, should the drivers face difficulties in fixating gaze on AOI then the effect should also be reflected in terms of detrimental driving performance (i.e., increase in driving errors).

5.2. Hypotheses

The present experiment investigated the following hypotheses:

- H8. Drivers face more difficulties in fixating on AOI during in-vehicle spatial-simultaneous distractions as compared to spatial-sequential distractions.
- H9. There is more detrimental effect on driving performance during in-vehicle spatial-simultaneous distractions as compared to spatial-sequential distractions.

5.3. Materials and methods

5.3.1. Direction following in distracted driving: spatial – simultaneous and – sequential (D3–SSS)

In this study third variant of D3 experimental paradigm named as '*Direction Following in Distracted Driving: Spatial – Simultaneous and – Sequential (D3–SSS)*' is used. Drivers were distracted by means of *'Distracting Stimuli Regulator-Spatial (DSR–S)*' a program coded on MATLAB platform. Like DSR–OS, DSR–S was also run on a DELL Inspiron 11.6 inch HD display laptop which was attached to the dashboard (on the left side of the driver) with the help of a monitor holder. When the program is run, 30 randomly placed squares appear on the display in such a manner that they do not overlap or touch each other. In this study also, the program is characterized by two phases: (a) *stimulus phase,* and (b) *probing phase*. In stimulus phase, the letter 'P' appears accompanied by experimenter's recorded voice saying "1", and in the probing phase, the letter 'P' appears accompanied by experimenter's recorded voice saying "2". For spatial-simultaneous distraction, whenever a participant hears '1' he/she is required to look at the display and remember the location of three "P"s appearing simultaneously in three separate squares. After a delay time of 4 seconds three 'P's would reappear simultaneously in three separate squares accompanied by the voice saying "2". This time the participant is required to look at the monitor and judge whether the location of previous three 'P's (which appeared in stimulus phase) matches with the location of the current three 'P's or not, if it matches, he/she has to verbally say "yes", otherwise he/she has to say "no" (figure 20 shows the presentation of experimental task stimuli for spatial-simultaneous distraction condition by using DSR–S). Similarly, if the participant belongs to spatial-sequential distraction group, in the stimulus phase, the participant would hear '1' consecutively three times accompanied by the display of letter "P" in three separate squares. After a delay time of 4 seconds three 'P's would consecutively reappear (one at a time) accompanied by the voice saying "2".

The participant has to match the location of the first, second and third "P" of the probe phase with the location of the first, second and third "P" of the stimulus phase respectively. If they match, he/she has to verbally say "yes", otherwise he/she has to say "no" (figure 21 shows the presentation of experimental task stimuli for spatial-sequential distraction condition by using DSR–S). In spatial-simultaneous condition, the on screen time for the letter 'P' was 4 seconds, whereas, in spatial-sequential condition it was 3 seconds. Irrespective of the distracting condition, the delay time (time duration between the disappearance of the letter 'P' in stimulus phase and the appearance of the letter 'P' in probing phase) was 4 seconds. For spatial-sequential distraction the delay time between any two 'P's of the stimulus phase or the probing phase was 3 seconds. The onscreen time and the delay time were decided on the basis of the feedback received from the participants during initial trial test.

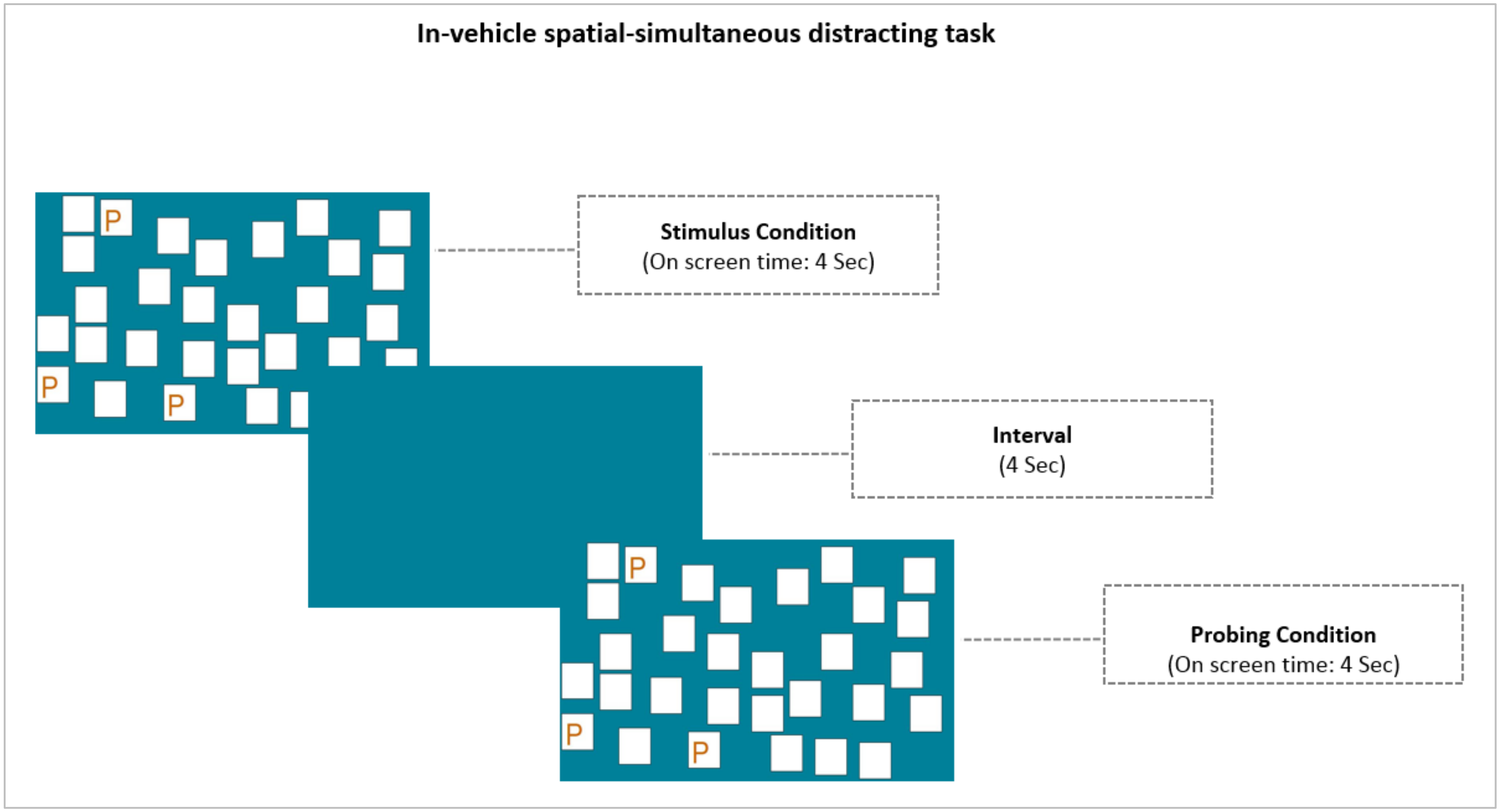


Figure 20. Presentation of experimental task stimuli by using DSR–S (spatial-simultaneous distraction condition).

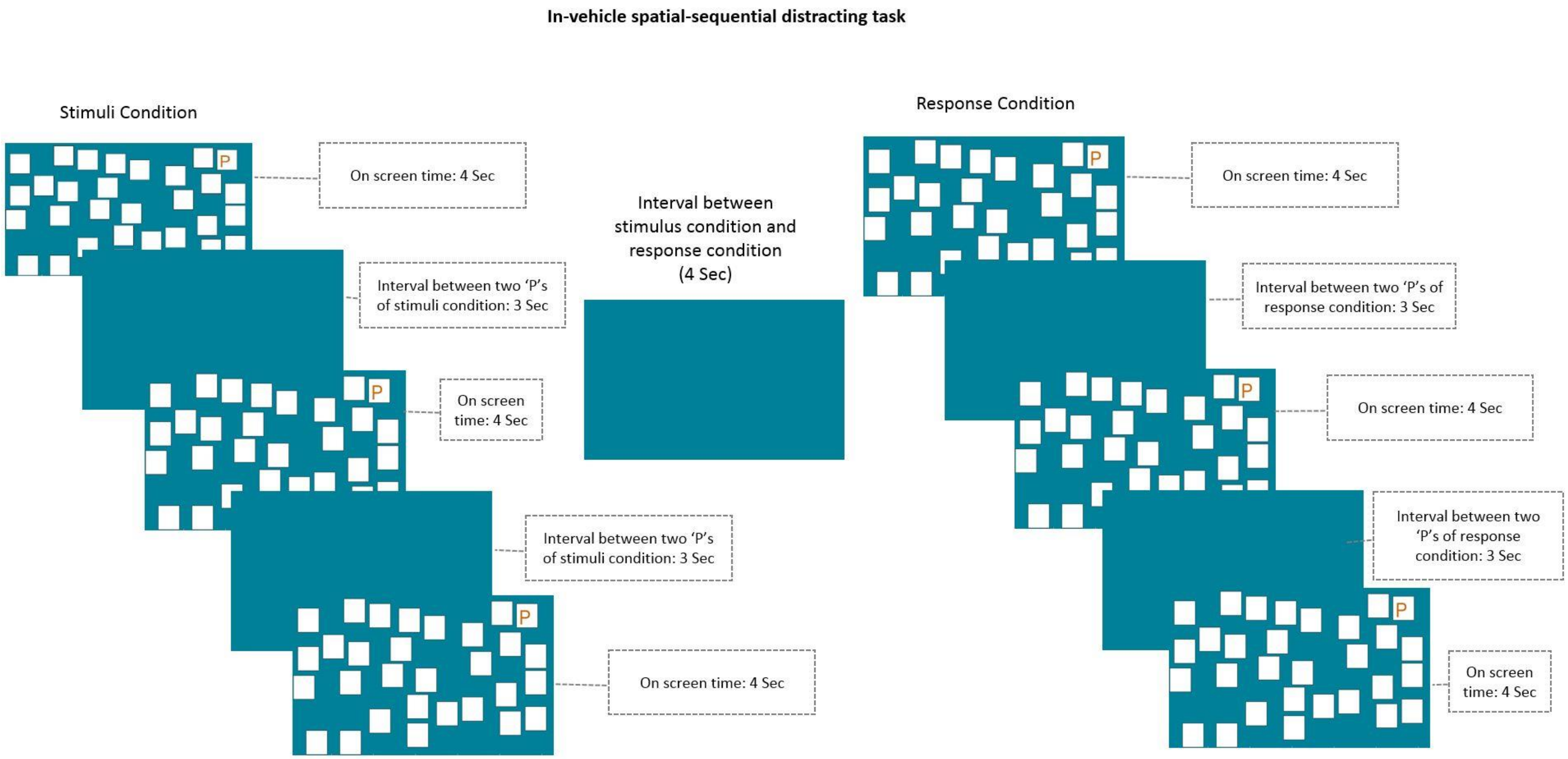


Figure 21. Presentation of experimental task stimuli by using DSR–S (spatial-sequential distraction condition).

5.3.2. Design

In this experiment a 2 in-vehicle spatial distraction (spatial-simultaneous vs spatial-sequential) between groups design is employed. It is pertinent to mention that in the current framework, the in-vehicle spatial distraction in terms of spatial-simultaneous and spatial-sequential remained within the framework of WM (Injoque-Ricle, Barreyro, Formoso, & Jaicheno, 2015).

With this understanding, the current experiment examines and compares spatial-Data regarding gaze behavior and driving performance was collected by using same setup of instruments as mentioned in section 4.3.3, and the methodology used for analyzing the gaze behavior and driving performance data is same as mentioned in sections 3.4.1 and 3.4.2 respectively.

5.3.3. Participants

A group of 27 male participants voluntarily participated in this distracted driving study. Data evaluation process revealed that data from 7 participants was invalid due to one (or more) of the following reasons: (a) poor or invalid calibration, (b) less than 60% sample rates of the gaze data, and (c) data not recorded properly due to some technical glitch in the recording devices. The data from remaining 20 participants consisted of two groups (spatial-simultaneous and spatial-sequential) 10 in each group. The age range of participants in spatial-simultaneous group is 21-50 years (*M* = 36; *SD* = 10.033) and a mean of 13.666 years' driving experience since passing the driving test. Another group was composed of 10 drivers within the age range of 22 and 44 years (*M* = 28.700; *SD* = 6.111) and a mean of 10.20 years' driving experience. Participants were recruited from the investigators' campus and nearby educational institutions. Each participant was given 250 INR as compensation for their voluntary participation in the study. The participants were made aware of the purpose of the study. They were assured that the data collected from them will be used purely for research purpose and complete confidentiality will be maintained. Thereafter, written consent of all the participants was taken.

5.3.4. Procedure

Before engaging the participants in the data collection process, they were given a brief description about the task so that they can make an informed decision. The participants were given a demonstration of the experimental task followed by a nine-point calibration of the eye tracker with participants' eyes. They were then taken to the instrumented vehicle and instructed to adjust the driving seat as per their comfort and wear seat belt for safety reasons. In order to ensure that the driving performance is not affected because of the unfamiliarity of the functions of the instrumented vehicle, the participants had a practice session until they gained familiarity. The practice trails took place on a different track where a demo direction signboard was installed. All the data recording devices, i.e., eye tracker, VV Box, DSR–S, and screen recording of DSR–S (for analyzing the responses of the participants) were turned on at the beginning point of the track by the experimenter (who was seated in the front co-passenger seat). The experimenter took confirmation about the readiness of the participants for executing the driving task and to mark the beginning of the recording the experimenter would loudly say 'start' and the driver would start driving. All the recording devices were disconnected by the experimenter once the instrumented vehicle reached finishing line of the experimental track. At the end of the drive, probing questions (about their experience during trial) were asked to each participant.

5.4. Results

A significance level of .05 is used throughout this chapter.

5.4.1. Gaze behavior

This study investigated the effect of in-vehicle spatial-simultaneous and spatial-sequential distraction on drivers' gaze behavior. Gaze behavior was analyzed in terms of fixation durations, fixation counts and visit counts on the AOI (i.e., whole area of direction signboards). An independent samples t-test was carried out for 2 in-vehicle distraction (spatial-simultaneous vs spatial-sequential) between-groups design. Fixation durations were calculated as the period of time (in seconds) when the eyes were fixating on the AOI. As shown in Fig. 22, the statistical analysis of the fixation durations data showed a significant difference between the two in-vehicle spatial distractions (spatial-simultaneous, M =1.587, SD = 1.207 and spatial-sequential, M = 4.646, SD = 4.138), $t(18) = -2.244$, p = .038.

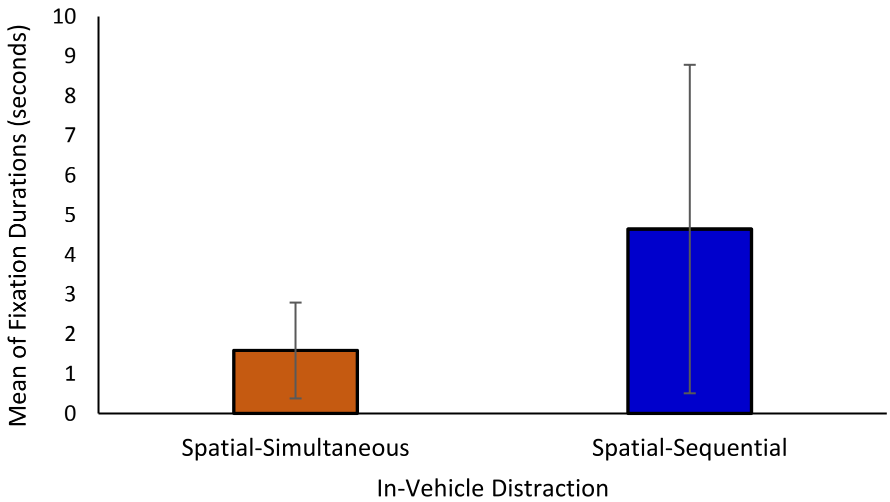


Figure 22. Fixation durations as a function of in-vehicle spatial distraction. Error bars represents SD.

An independent samples t-test was performed to analyze the fixation counts (another gaze behavior measure) on AOI. Fixation counts were calculated as the number of times (counts) the participant has fixated on AOI. The analysis revealed a significant difference between the two in-vehicle spatial distractions (spatial-simultaneous, M

= 50.800, *SD* = 38.421 and spatial-sequential, *M* =145.900, *SD* = 127.725; see Figure. 23), $t(18) = -2.255$, $p = .037$.

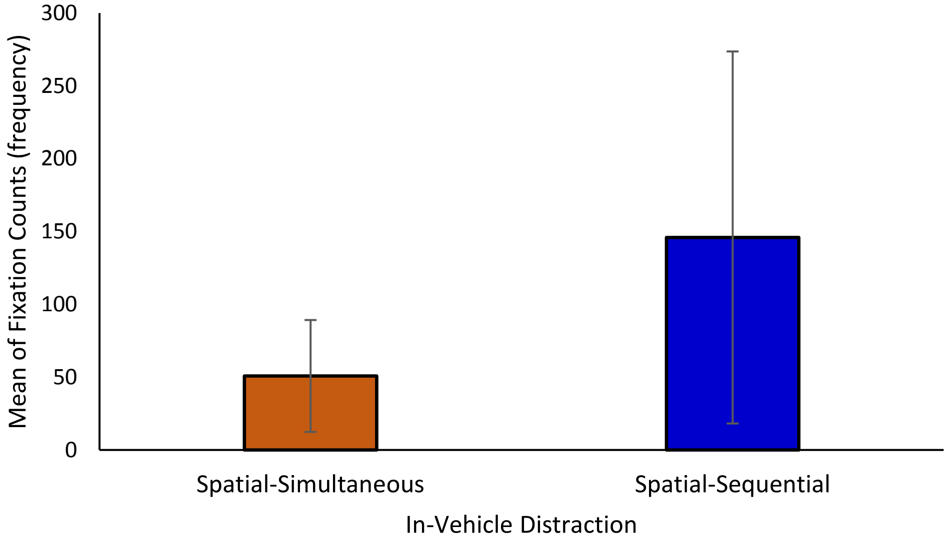


Figure 23. Fixation counts as a function of in-vehicle spatial distraction. Error bars represents SD.

Gaze behavior of drivers was also examined in terms of visit counts on AOI. Visit counts are the number of visits (counts) the drivers made to an AOI. As shown in Figure 24, the analysis revealed that there is no statistically significant difference between the two in-vehicle spatial distractions (spatial-simultaneous, *M* = 14.000, *SD* = 9.921 and spatial-sequential, *M* = 26.100, *SD* = 16.529), $t(18) = -1.985$, $p = .063$.

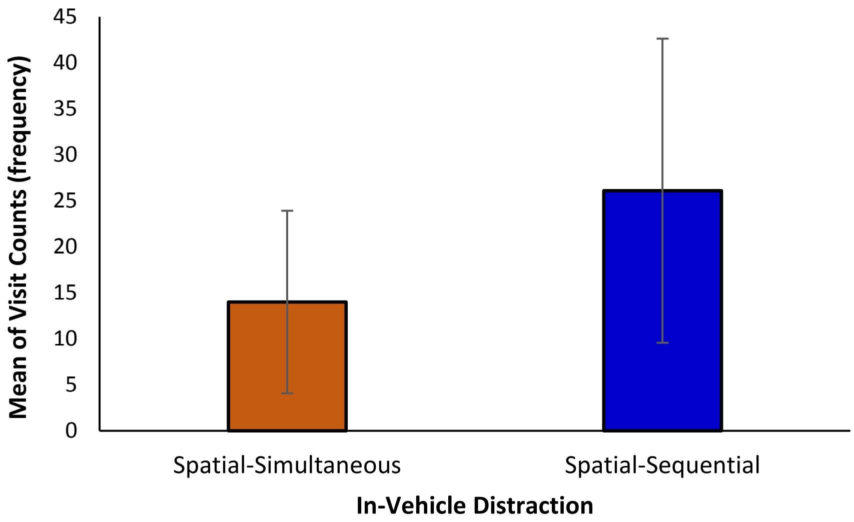


Figure 24. Visit counts as a function of in-vehicle spatial distraction. Error bars represents SD.

5.4.2. Driving errors

Driving performance was analyzed in terms of driving errors on the basis of the data recorded by VV Box. In the context of the present study driving errors are analyzed with respect to Reason's (1990) categorization of slips and lapses. Details about operationalization of slips and lapses are given in section 3.1.3. In order to find out whether it is the slips or the lapses that are committed more during the in-vehicle spatial distraction, a MANOVA was performed. The results revealed that there is a significant difference between spatial-simultaneous and spatial-sequential in-vehicle distractions in terms of their effect on slips and lapses, $F(2, 17) = 4.986$, $p = .020$; Wilk's $\Lambda = 0.63$, $\eta p^2 = 0.370$. The results also reveal that in comparison to lapses ($M = .800$, $SD = 0.867$), it was the slips ($M = 2.383$, $SD = 1.619$) that are committed more by the drivers. To examine overall driving error (irrespective of slips and lapses) an independent samples t-test was carried out for 2 in-vehicle spatial distraction (spatial-simultaneous vs spatial-sequential) between-groups design. The results reveal that there is a significant difference between spatial-simultaneous ($M = 12.800$, $SD = 5.672$) and spatial-sequential ($M = 6.300$, $SD = 3.465$) distraction with respect to their effect on overall driving error, *t*(18) = 3.092, *p* = .006 (see Figure 25).

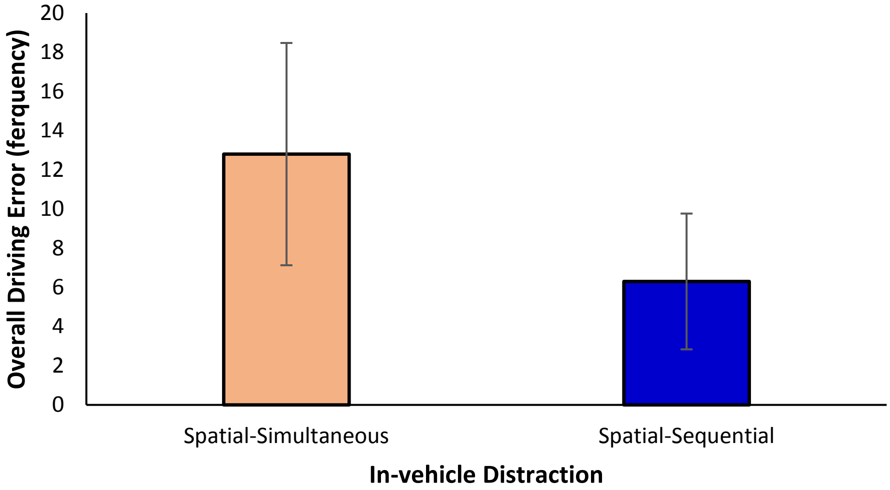


Figure 25. Overall driving error as a function of in-vehicle spatial distraction. Error bars represents SD.

Further error analysis was performed using an independent samples t-test in order to examine the effect of in-vehicle spatial distraction (spatial-simultaneous vs spatial-sequential) on slips and lapses separately. The analysis revealed a significant difference between 2 in-vehicle spatial distractions (spatial-simultaneous, *M* = 3.100, *SD* = 1.859 and spatial-sequential, *M* = 1.666, *SD* = 0.968) on slips, *t(*18) = 2.162, *p* = .044 (see Figure 26). With respect to the effect of spatial-simultaneous and spatial-sequential distractions on lapses, the analysis revealed that there is a difference leaning towards significance, (spatial-simultaneous, *M* = 1.166, *SD* = 1.021 and spatial-sequential, *M* = .433, *SD* = 0.498; see Figure 26) *t*(18) = 2.041, *p* = .056.

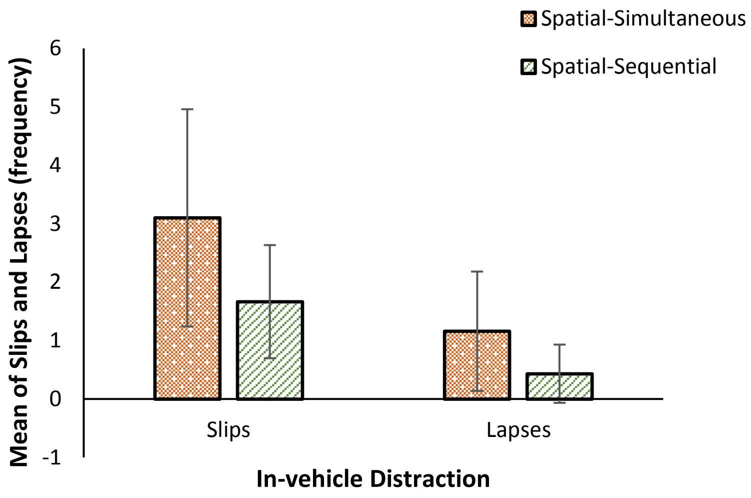


Figure 26. Slips and lapses as a function of in-vehicle spatial distraction. Error bars represents SD.

5.4.3. In-vehicle task performance (spatial-simultaneous distraction and spatial-sequential distraction)

Performance on in-vehicle distraction task was measured in terms of correct responses, incorrect responses, and no responses. The presentation of distracting stimuli and the participants' responses to them were captured through screen recording of the laptop through which the stimuli were presented. In case of spatial-simultaneous distractions, participant's response was marked as correct if he/she correctly matched the location of all the three 'P's presented in the probing phase with the ones previously shown in the stimulus phase. Similarly, it was marked as incorrect, if he/she incorrectly matched the location of 'P's presented in the probing phase with the ones previously shown in the stimulus phase. If the participant failed to provide a response, it was marked as no response. The same procedure was used in the case of spatial-sequential distraction. If the participant correctly matched the location of three 'P's presented sequentially in the probing phase with the ones previously shown in the stimulus phase, the responses were marked as correct, if they did not match, it was marked as incorrect and if the participant failed to provide a response, it was marked as no response.

In order to examine whether the participants responded differently to the in-vehicle spatial distracting task, an independent samples t-test was carried out for a 2 in-vehicle spatial distraction (spatial-simultaneous vs spatial-sequential) between groups design. As shown in Figure 27, the analysis revealed that the responses to spatial-simultaneous distractions, *M* = 4.000 and spatial-sequential distractions, *M* = 3.400 do not differ significantly.

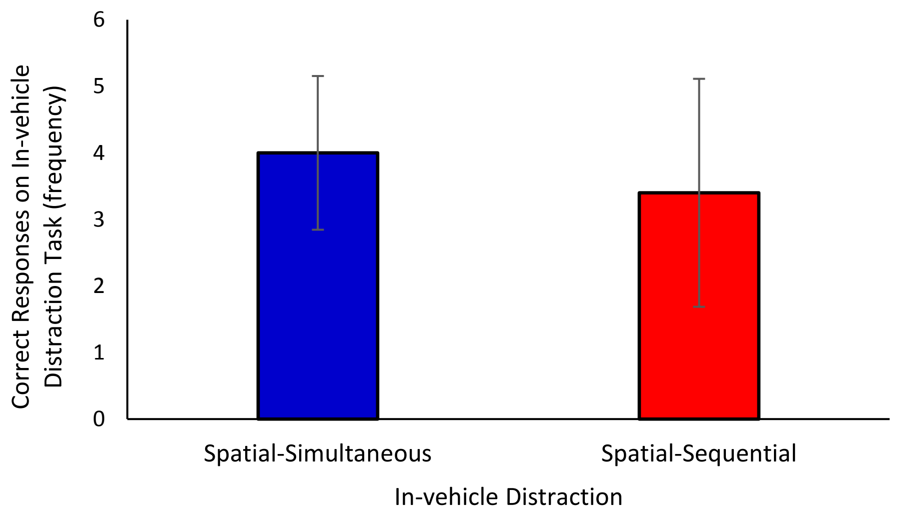


Figure 27. Correct responses as a function of in-vehicle distraction. Error bars represents SD.

5.5. Discussion and conclusion

This experiment investigates the effect of in-vehicle spatial distractions on drivers' gaze behavior and driving errors. It is observed that compared to spatial-sequential distractions, fixation durations and fixation counts are significantly reduced during spatial-simultaneous distractions. This follows the line of thought that the more cognitive resources needed for performing a driving irrelevant cognitive task, the more the drivers tend to make lesser fixations on the peripheries of the road and instead spent more time looking at the center of the road (Harbluk & Noy, 2002; Recarte & Nunes, 2000). The results also revealed an insignificant difference in terms of the correct responses provided by participants to the spatial-simultaneous and spatial-sequential distracting stimuli, which means that if the participants attend the distracting stimuli of both conditions almost equally, the fixation durations and fixation counts are significantly affected during spatial-simultaneous processing of information. This indicates that compared to spatial-sequential processes there is more demand of cognitive resources during spatial-simultaneous processing of information. The results also indicate that there is no significant difference between spatial-simultaneous and spatial-sequential processing of information in terms of visit counts. This suggests that the gaze of drivers visit the direction signboards during spatial-simultaneous and spatial-sequential processing of information alike, but during spatial-simultaneous processing of information, due to more demand on cognitive resources they are not able to actually process the information displayed on the direction signboards. In other words, though the participants look at the direction signboards during spatial-simultaneous processing, they face difficulty in fixating gaze on the direction signboards, hence reductions in fixation durations and fixation counts. This is often referred to as looked but did not see phenomenon whereby driver's ability to scan the road seizes and stops inspecting side and rearview mirrors (Ottawa, 2013). Looked but did not see errors are among the most frequent causal factors involved in the accidents (Brown 2002).

In terms of issues related to in-vehicle spatial distractions and driving performance (in terms of errors), the results reveal that as compared to spatial-sequential distraction, overall driving error (i.e., irrespective of slips and lapses) occurred significantly more during spatial-simultaneous distraction. Further understanding in terms of driving error is that of occurrence of slips and lapses. In case of spatial-simultaneous distraction, drivers committed significantly more number of slips than the participants in the spatial-sequential distraction group. The results also demonstrate that there are more incidents of lapses during spatial-simultaneous distraction than due to spatial-sequential distraction. Performance compromise during spatial-simultaneous distraction is substantiated by the fact that the drivers had to attend the stimuli from multiple locations simultaneously which compared to spatial-sequential distraction consumed more cognitive resources. This observation is interesting in the sense that as the area under observation (attentional focus) increases (as in the case of spatial-simultaneous distraction in the current study), the efficiency for processing the stimuli present in that area decreases (Castiello & Umilta, 1990). Undifferentiated correct responses of spatial-simultaneous and spatial-sequential distractions reflect that the participants devoted their attention equally to both distracting conditions, however, due to more demand of cognitive resources in spatial-simultaneous distraction the performance on driving task got compromised. Eriksen and St. James (1986) reported an increase in reaction time (RT) as the area of the stimuli increased. Similarly, RT of participants is found to be fast with fewer errors when the region of interest is small whereas RT slows down and having more errors when the information is to be processed from a larger region of interest (Muller et al. 2003). Moreover, in the current scenario the driver had to devote attention to in-vehicle task while driving that involves following directions (as shown on signboards). In such situations, if a task has a high demand of cognitive resources, the performance compromise in either of the tasks ought to happen (Lavie, 1995; 2001). In the context of the current study, more driving errors during spatial-simultaneous distraction indicates that processing information simultaneously from multiple locations consumed more cognitive resources and left very less resources unused (Lavie, 1995), whereas, lesser number of driving errors during spatial-sequential distraction indicates that there is less demand of cognitive resources when one is involved in processing information sequentially. Interestingly, the results also demonstrate that the drivers have vulnerability to errors irrespective of spatial-simultaneous and spatial-sequential in-vehicle distractions. This understanding is important considering significant difference between spatial-simultaneous distracting condition and spatial-sequential distracting condition in terms of slips and difference between the two in terms of lapses leaning closely towards critical value of significance.

Chapter 6

General Discussion

The present dissertation (on the whole) addresses the role of cognitive processes underlying driver distractions in affecting drivers' gaze behavior, driving performance and CWL. The cognitive processes underlying driver distractions are related to visuospatial information processing. As evident from previous chapters, increasing line of research has contributed to our knowledge of various aspects of distracted driving and the current research is an effort to pursue this avenue for further scientific progress by taking into consideration different processes of WM. In particular, this research emphasizes on how the suppressed ARM, object and spatial distractions, and spatial–simultaneous and –sequential distractions affect drivers' gaze behavior, driving performance (driving error) and CWL in a test-track driving environment. The current chapter unifies and reflects on the findings of the present research in the light of the available literature and relevant insights.

6.1. Gaze behavior

Drivers are required to constantly process and respond to a variety of predominantly visuospatial events, e.g., lead vehicles braking, traffic signs, sharp curves, behavior of other road users, and so on. Vehicle control metrics (for e.g., lateral and longitudinal control, gap acceptance, reaction time, etc.) successfully capture some aspects of the impact of distraction on driver performance. However, as the body of research evidence has increased, it has become evident that in order to capture the impact of driver distraction and design better counter measures for alleviating its effects, vehicle control metrics are not sufficient by themselves. Since types of distraction and their manifestations vary, the measurement of distraction must also be protean to the extent that it captures all the manifestations. Metrics based on driver's gaze behavior and the ability to detect relevant objects and events provide an important component in a "toolbox" of distraction assessment methods. The present research developed three variants of an experimental paradigm named as 'Direction Following in Distracting Driving (D3)' that allowed to capture the gaze behavior of drivers in a test-track driving environment. Gaze behavior of drivers, in this research, is analyzed on the measures of fixation durations, fixation counts, and visit counts on the AOI, i.e., direction signboards installed on the track.

With respect to gaze behavior, the results of experiment-1 demonstrate that fixation durations and fixation counts are significantly reduced during the CS of ARM as compared to the other two levels of suppression (i.e., SS and NS). In the context of the current research, reduced fixation durations and fixations counts on AOI indicates that as the complexity of driving irrelevant cognitive task increased, the drivers faced difficulty in looking at the peripheries of the road. The results conform to the hypothesis (H1) of the study. Another observation of experiment-1 is that unlike fixation durations and fixation counts, the insignificant difference in case of visit counts across three levels of suppression suggests that drivers have undifferentiated visit counts on the AOI. This indicates that whether distracted or not, the drivers look at the direction signboard but does not actually process the information displayed on the direction signboard which is evident from reductions in fixation durations and fixation counts during CS. This implies that all the drivers attempted to visually process target information (i.e., direction displayed on signboards), however, could not get sufficient opportunity to devote attention for further visual processing. This is in congruence with the finding that there is decrease of fixation durations and fixation counts under suppressed ARM (i.e., SS and CS) as compared to NS. Therefore, in a dynamic environment like driving, when distraction is induced by suppression of ARM it will increase situation complexity (associated with variation in CWL) thus shorter fixation durations and less fixation counts on AOI is ought to manifest. In general, the available scientific literature suggests that drivers tend to look at the center of the road as the complexity of the driving scene increases (Harbluk & Noy, 2002; Recarte & Nunes, 2000). Increased cognitive workload would lead to perceptual narrowing of the foveated information and consequently shrinks the peripheral visual field. Due to reduction in peripheral field of view the drivers would miss driving related information which is significantly important and which otherwise would warn them of hazardous situations, thus increasing the likelihood of driving errors, crashes or near crashes.

With respect to fixation durations and fixation counts in experiment-1, the results indicate a significant difference between NS and CS but insignificant difference between NS and SS. This difference could be attributed to the more attentional demand during CS as compared to SS and NS. The difference in gaze behavior when the participants are exposed to NS and SS is insignificant because during SS the counting task (1–30) do not demand much cognitive resources and the drivers were able to focus on the driving task. The observed phenomenon can be explained by Wicken's multiple resource model (Wickens, 2002) which states that for achieving a given level of performance on a task, the demanded resources are not fixed rather are allocated as per the demand of the task. The leftover resources (residual resources) can be used in performing concurrent task, accordingly if a task demands more resources (as in the case of CS), it will interfere more with a concurrent task.

As mentioned above, the nature of driving related information is predominantly visuospatial, which is processed by different cognitive processes and by different brain areas. In this perspective, one of the objectives of second experiment was to investigate, how does the in-vehicle distraction affect driver's gaze behavior while he/she is processing object and spatial information. The results show that compared to processing of spatial information, it is the processing of object related information during which, if distraction takes place, fixation durations and fixation counts on AOI gets significantly reduced (H3). This is attributed to the fact that processing object related information is more complex, hence demands more cognitive resources and relatively leaves less cognitive resources unused. In challenging driving scenarios (e.g., heavy traffic situations and at busy intersections), because of the increased flow of driving related information, which demands more cognitive resources, the rate of eye movements (i.e., more saccades and less fixations) of drivers increases (Rutley & Mace, 1968; Rahimi et al., 1990) and the drivers have more vulnerability of committing errors.

In this research, further understanding about drivers' gaze behavior in a distracted scenario comes from issues related to in-vehicle spatial distractions. It has been scientifically demonstrated that spatial-simultaneous and spatial-sequential recognition tasks involve different types of cognitive processes (Lecerf & de Ribaupierre, 2005). Based on this assumption, another experiment (experiment-3) is conducted in order to find out whether it is the spatial-simultaneous or spatial-sequential processes that if distracted during driving hampers more in processing driving related information. It is found that compared to spatial-sequential processes, it is the spatial-simultaneous processes that if distracted, reduces fixation durations and fixation counts on AOI (H8). This indicates that processing spatial-simultaneous information relatively consumes more cognitive resources. In such situations if a driver is distracted, fixation durations on AOI ought to reduce.

In experiment-2, another issue of investigation is related to gaze behavior with respect to driving expertise. Accident analysis reports suggest that during first few months of issuance of driving license, accident rates are high in novice drivers and decline as they gain experience (Mayhew, Simpson, & Pak, 2003; McGwin, & Brown, 1999). Because of the under developed vehicle control skills, and less spare attentional capacity, novice drivers relatively face difficulties in identifying and anticipating driving hazards and are inefficient in adapting their visual search to the environmental situation (Crundall & Underwood, 1998). They also tend to look at the immediate vicinity (Mourant & Rockwell, 1972) and less variability is observed in their fixation patterns (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). It is a general observation that gaze behavior of novice drivers improve as they gain experience. In a distracted driving scenario, novice drivers as compared to their experienced counterparts, tend to look away from the roadway, but over a period of 12 months of driving experience this difference decreases (O'Brien, Klauer, Ehsani, & Simons-Morton, 2016). However, the results of the current study demonstrated an insignificant difference between novice and experienced drivers with respect to fixation durations on AOI, thus rejecting the hypothesis which suggests novices face more difficulties in fixating gaze on AOI as compared to experts (H5). The analysis of performance on in-vehicle distracting task revealed that experts have relatively outperformed novice drivers, i.e., they have provided more number of correct responses, lesser number of incorrect and no responses, which indicates that the novice drivers have not cognitively processed the information about in-vehicle distraction task but instead spent more time looking at the direction signboards. Thus the difference between experts and novice drivers with respect to fixation durations and fixation counts on AOI reduced. Furthermore, in a multitasking situation, if the tasks demand common attentional resources (visual attention), performance in either of the task gets deteriorated (Wickens, 2002). In this case novices' performance on in-vehicle distraction task was compromised, however the experts, because of their expertise (automatization of driving skills) in driving could relatively perform better on both tasks.

6.2. Driving performance

Memory processes are one of the most basic constructs involved in performing any kind of task and driving is not exceptional. Drivers need to remember the route, constantly update about the locations and current traffic situations, and to execute situation-specific maneuvers. Now-a-days more and more interactive devices are available inside the vehicles and drivers not only drive but also interact with them. Humans have finite cognitive resources and this has direct implication in situations when the drivers are engaged in performing concurrent tasks while driving. In general, the literature suggests that drivers are vulnerable to performance decrements when engaged in driving irrelevant task. The performance decrements are, for instance, in terms of impaired lateral and headway control. One explanation for degraded driving performance while drivers are engaged in concurrent tasks is that they divert drivers' attention away from driving task (Strayer & Johnston, 2001). Another possibility is that the performance of concurrent task(s) decreases the availability of WM resources that otherwise could have been devoted to driving. The detrimental effect on driving performance depends upon the complexity of the secondary task (executed concurrently while driving) and the complexity of the driving situation in which the secondary task is concurrently executed. This is a reflection of what is observed in the first experiment. The results of experiment-1 demonstrate that mere distraction does not have a harmful effect on driving performance unless it has a substantial demand of cognitive resources (H2). In other words, mere suppression of ARM (i.e., distraction as in case of SS) does not have a significantly detrimental effect on driving performance, for it needs to have a substantial demand on WM resources (as in case of CS) in order for it to be detrimental for driving performance. As mentioned above, humans have limited cognitive resources and substantial demand on cognitive resources due to challenging distracting conditions have implications in terms of inattentional blindness and change blindness. Both involve a failure to detect an object or event (change), or notice features of an object that otherwise would have been noticeable. Inattentional blindness (IB) describes driving situations which are associated with a failure of attention. Such situations are comprised of "looked but did not see" phenomenon. For example, a driver may look at the direction signboard but might not be able to cognitively process the directions shown on it. Change blindness describes a failure to notice the changes happening in the driving environment (Simons, 2000). For example, drivers may fail to notice the sudden appearance of a pedestrian from behind a parked vehicle because their attention was diverted away momentarily.

Further understanding of the role of cognitive processes underlying driver distractions in driving performance and cognitive workload is in terms of in-vehicle object and spatial distractions. The results of experiment-2 provide an evidence that distractions while processing object related information is more detrimental for driving (H4). Postle, D'Esposito, and Corkin (2005) found that after perceiving object appearance information, verbal coding mechanisms are involved for further processing it whereas spatial information does not require any further recoding. In a distracted driving scenario, by means of distraction if the verbal coding mechanism is not able to process object related information, drivers would face difficulties in acting upon crucial driving related information and consequently driving performance ought to be compromised. Analysis of subjective ratings on NASA-TLX reveal that the participants experienced higher level of CWL during object distraction than spatial distraction (H7). This also suggests that processing object related information while driving is more challenging for drivers and any kind of distraction during such processing demands additional cognitive resources. As compared to spatial distraction, more number of driving errors during object distraction indicates that processing object related information consumed more cognitive resources and left very less resources unused (Lavie, Beck, & Konstantinou, 2014), whereas, lesser number of driving errors during spatial distraction indicates that processing space related information relatively consumed less cognitive resources and the residual cognitive resources were utilized in performing the in-vehicle distraction task.

Another important issue concerning driving performance investigated in this research is that of expertise. This issue was investigated in experiment-2 and the results are as expected. There is a significant difference between novice and expert drivers with respect to all measures of driving performance, i.e., overall error, slips and lapses (H6). For experienced drivers, activation of internal representations of events, stimuli, or perceived relationships in long term store is automatic and the increasing automation of information processing with experience, results in strengthening of the representation in memory. Attended stimuli are encoded into long term storage more elaborately. Some encoded representations (e.g. approaching a curve) may be linked directly to behavioral responses (e.g. turning the steering wheel) while some events (e.g. a flock of sheep crossing the road) may be sufficiently novel or relevant to be activated to a level that results in attention or conscious awareness being directed towards the internal representation or event. Such an event would require conscious processing on the part of the driver before a response could be generated, so utilizing some of the limited available processing capacity. In other words, as the drivers gain more experience with a range of conditions and the generation of successful behavioral responses to those situations, linkages between event representations and behaviors become stronger and the behavioral response becomes increasingly automatic. This is consistent with Logan's (1988) view that automation of responses results from repeated instances of linkage between environmental events and behavioral responses that strengthen the learned relationship to the point where the behavior follows automatically from the event. The inexperienced drivers, however, face a more difficult task as more internal representations or events are likely to attract attentional involvement due to their novelty or the lack of automatic links between internal representations of common driving situations and behavioral responses.

McKenna and Farrand (1999) also observed that novice drivers because of their insufficient exposure and driving practice, require a substantial proportion of available cognitive capacity in order to manage safe driving, whereas in the case of experienced drivers they have automatized the subtasks of driving. Further, the analysis of interaction between in-vehicle distractions and expertise with respect to overall error and slips indicates that as compared to expert drivers, novices committed more slips and overall errors during object distraction than spatial distraction. Such observations are also reported by previous studies which report that novice and experienced drivers differ in various ways. For example, novice drivers generally have under developed vehicle control skills and less spare attentional capacity than experienced drivers (Lee, 2007; Duncan, Williams, & Brown, 1991). Furthermore, novice drivers have a relatively poor ability to identify and anticipate traffic hazards (McKnight & McKnight, 2003; Pradhan et al. 2005) compared to their experienced counterparts. In case of novice drivers, the increasing reliance on automatic responses while still gaining experience as a driver may account for the increase in driving errors, crashes or near crashes (Brown, 1982). As drivers develop some automatic responses and rely on them increasingly, there may be occasions when an automatic response is not available for a particular set of circumstances. The generation of a response more appropriate for another, similar set of circumstances via some form of stimulus generalization may result in an incorrect, risky response. Until the novice driver has sufficient instances of a wide range of experiences to provide a wide range of automatic behavioral responses, they are vulnerable to commit more driving errors.

The present research also investigated the effect of in-vehicle spatial distractions on driving performance. The spatial distractions were presented to drivers in terms of spatial-simultaneous and spatial-sequential distracting stimuli. The results demonstrate that as compared to in-vehicle spatial-sequential distraction, all driving performance measures, i.e., overall error, slips, and lapses occurred significantly more during spatial-simultaneous distraction (H9). This indicates that while processing spatial information coming from multiple locations simultaneously, if a driver gets distracted, his/her driving performance gets compromised. It is because of the fact that by simultaneously processing information from multiple locations, the attentional resources of drivers gets divided. This study throws some light at the issues of frequent driving errors at intersections. Drivers often commit errors at intersections in the form of speed errors (e.g., driving too fast for turn, approaching intersection at a fast speed), signal errors (e.g., changing lanes without indicating, failure in noticing indicator, activating indicator too late), traffic light errors (e.g., crossing red light, delay in recognizing green light), etc. As is suggested by the results of the current study, the possible reason for such type of errors is that there is more demand for cognitive resources while processing driving related information simultaneously coming from multiple locations, meanwhile, if the driver gets distract it complicates the driving situation further and compromises his/her driving performance.

Chapter 7

Summary and Conclusions

This chapter summarizes the major findings of the current research. It also discusses the implications of the findings, limitations of the present research, and provides insights for future research.

7.1. An overview of the findings

- This dissertation provides an understanding of the role of visuospatial distractions in affecting drivers' gaze behavior, CWL, and driving performance in a test-track driving environment. For scientifically investigating driver distractions involving WM processes, there is a fundamental requirement of WM process specific experimental paradigms. This research developed three variants of an experimental procedure named as direction following in distracted driving (D3). The three variants of D3 investigates the role of distractions involving three different WM processes in affecting drivers' gaze behavior, CWL, and driving performance.
- The results of the present research demonstrates that the drivers face difficulty in processing visual target information (direction signboards) during CS of ARM as compared to the other two levels of suppression, i.e., SS and NS. This suggests that the more cognitive resources required to perform a driving irrelevant cognitive task, the less often the drivers tend to look at the peripheries of the road. Irrespective of the level of suppression, the drivers paid undifferentiated visits to direction signboards, which indicates that whether distracted or not, the drivers look at the

direction signboard but does not actually process the information when the situation is cognitively demanding for drivers.

- It is observed that drivers commit errors even in the absence of suppression of ARM (i.e., NS), though the frequency and severity is not as high as it is during suppression of ARM (i.e., SS and CS). Under CS of ARM the proportion of overall driving error is almost double as compared to that of SS.
- Further understanding with respect to driving error is that as compared to lapses, drivers committed more slips. Moreover, the research also demonstrates that slips and lapses are affected differently by the three levels of suppression of ARM.
- In-vehicle Object and spatial distractions have significantly different effect on driving performance. In comparison with spatial distraction, object distraction has more detrimental effect on driving performance. More driving errors during object distraction indicates that processing object related information consumed more cognitive resources and left very less resources unused, whereas, lesser number of driving errors during spatial distraction indicates that processing space related information relatively consumed less cognitive resources and the residual cognitive resources were utilized in performing the in-vehicle distraction task.
- Another important issue concerning driving performance is that of expertise. Experts have outperformed novices substantiating a superior driving performance. Novice drivers because of their insufficient exposure and driving practice, required a substantial proportion of the available cognitive resources in order to manage safe driving, whereas the experienced drivers, because of the automatization of the subtasks of driving utilized the residual cognitive resources left unused in performing the distracting task, thus lesser compromise in driving performance.
- Unlike driving performance there is no significant difference between novice and experienced drivers with respect to fixation durations and fixation counts on AOI. In a multitasking situation, if

the tasks demand common attentional resources (visual attention), performance in either of the task gets deteriorated. In this case novices' performance on in-vehicle distraction task was compromised, instead they spent time in processing driving related visual information, however, the experts, because of their expertise in driving could relatively perform better on both tasks. In addition to this, as in the case of driving performance, compared to spatial distraction, fixation duration and fixation counts was significantly reduced during object distraction. This indicates that processing object appearance information is more complex than processing spatial information (i.e., location of the object).

- There is a significant positive correlation between CWL and slips and CWL and lapses, indicating that an increase in CWL leads to an increase in the occurrence of slips and lapses.
- With respect to in-vehicle spatial distractions, the results are similar to the case of CS of ARM, it was observed that compared to spatial-sequential distractions, fixation durations and fixation counts are significantly reduced during spatial-simultaneous distractions. This indicates that compared to spatial-sequential processes there is more demand of cognitive resources during spatial-simultaneous processing of information.
- More number of slips, lapses, and overall driving error during spatial-simultaneous distraction implies that distractions while processing spatial-simultaneous information are more detrimental.
- In comparison with spatial-sequential distraction, overall driving error, slips, and lapses occurred significantly more during spatial-simultaneous distraction. Performance compromise during spatial-simultaneous distraction is substantiated by the fact that the drivers had to attend the stimuli from multiple locations simultaneously which compared to spatial-sequential distraction consumed more cognitive resources.

7.2. Limitations and implications of the Study

The thesis besides being an addition to the existing literature on the phenomenon of distracted driving, however, has some limitations that could be overcome in future researches.

- All the three experiments mentioned in this dissertation were conducted in a safe driving environment where the movement of any other road user was totally controlled. There could be some variation in the driving behavior if the same studies were conducted in an environment which is similar to that of traffic situations drivers face on a daily basis. But it is worth to mention that executing such studies where the driver is involved in a distracted driving in presence of other road users is not ethically permissible because doing so pose a threat not to the participating driver only but to the other road users also.
- Majority of the participants who voluntarily participated in this research are professional bus drivers belonging to either researcher's educational institute or nearby educational institutes. It is expected that the 'behind the wheel behavior' of professional bus drivers would be different (as they would be complying relatively more with the traffic rules and regulations) than the rest of the drivers driving on the road. The results presented here could have been different if participants were randomly recruited from the general pool of drivers. Moreover, the driving behavior varies across type of vehicles, for example, driving behavior of small vehicle drivers is different from that of truck and bus drivers (Janz, 2000), and the results might have been affected as the recruited participants were mostly professional bus drivers. Another concern with respect to participant characteristics is that most of them were working in the same campuses, even though they were instructed not to discuss the experimental procedure with their colleagues, there are possibilities that they might have discussed about it among themselves, which possibly might have affected the results.

- In terms of collecting gaze behavior data, the instrument used in this research collected data at the rate of 30 samples per second, which is considered a poor sampling rate. There are high chances that some significant amount of crucial gaze behavior data might not have been captured by the eye tracking instrument. Moreover, due to technical limitations of the eye tracking instrument and glare of the in-vehicle display system, the gaze data of participants looking at the display system could not be collected. The changes in gaze patterns while processing object and spatial information would have been more insightful and thought provoking.
- With respect to the implication of this research, the D3 experimental paradigm could be used by automotive human factors researchers for investigating issues related to distracted driving. Furthermore, with respect to Indian traffic rules, the results of this research signify the importance of strict enforcement of traffic regulations related to distracted driving, more stringently in the case of novice drivers. In addition to this, the findings of the current research provide further behavioral evidence in support of the dissociation between object and spatial working memory.

7.3. Scope for future research

From the perspective of distracted driving research, there are certain areas that demand the attention of contemporary automotive human factors researchers and practitioners.

In the domain of automotive human factors, driving errors resulting from interaction with the in-vehicle interface can jeopardize vehicle control and even lead to fatal crashes. Thus, it is wise to take driving errors into account when designing the structure and elements of interaction. When it comes to the interaction with in-vehicle displays, human errors have been largely ignored (Lee, Gibson, & Lee, 2016). For instance, the National Highway Traffic Safety Administration (NHTSA) provides guidelines on visual manual interaction and recommends removing tasks that cause errors during more than 50 percent of test trials (NHTSA, 2013). Nevertheless, errors can affect how well drivers interleave secondary tasks with driving tasks, jeopardizing driving performance (Brumby, Salvucci, & Howes, 2007). To understand how secondary task errors affect driving, we need to study the reaction of drivers to the errors. Compared to error prevention, how people react to or recover from errors has received relatively little attention. Furthermore, designing effective countermeasures for mitigating its effect will be important avenue of research endeavor. The researchers need to understand whether the error recovery strategies of the driver also get affected by distraction, if yes, how? It is relevant to explore the relationship between distracted driving and error recovery of the driver which might include detecting error, choosing and implementing a response for recovering from the error.

In the light of the current study, use of in-vehicle interactive systems behind the wheel throws further insights and challenges for investigators related to distracted driving. Future research could focus on issues related to distractions and spatial anticipatory mechanism of the driver. Spatial anticipatory mechanism is the ability of the driver to direct his/her visuospatial attention to an upcoming (anticipatory) stimulus location. The anticipation could be in terms of hazard anticipation, other road users appearing from blind spots, or upcoming changes in the traffic flow, etc. In unfamiliar situations, drivers tend to react to events, while upon encountering familiar situations, they tend to anticipate what is about to happen (Tanida & Poeppel, 2006). Being in a reactionary mode requires a given event to have occurred, thereby limiting the time a driver has to deal with the event. In contrast, anticipation of the event allows for additional space and time to reduce disruptions and avoid potential conflicts. The importance of anticipation arises frequently in driving research. “The inability to predict ahead of time the risks that will appear in the roadway” is a primary cause of fatalities for novice drivers (Pollatsek, Narayanaan, Pradhan, & Fisher, 2006). Future research should identify ways to facilitate anticipation of drivers. An interface could be developed that helps drivers identify and interpret important pre-event cues. For experienced drivers with an already high potential for anticipatory competence, such an interface should focus on augmenting cues to activate skill-based behavior, while novice drivers would likely profit from a rule-based approach that also aids in the interpretation of those cues (Stahl, Donmez, & Jamieson, 2013). Facilitating anticipation may also prove important in automation design. For example, there will most likely be a phase when autonomous vehicles will share the road with human drivers. Understanding how competent human drivers are able to interpret traffic situations and anticipate other drivers' behavior can help designers train automation to do the same.

While driving, visual perception is the main source of information, and attention is crucial to visual perception. Information located in unattended places is scarcely processed or not processed at all (Theeuwes, 1995), and attention plays an essential role in visual inspection strategy, especially in planning eye movements (Henderson, 1993) either toward locations preselected by expectations or toward objects that automatically attract attention because of conspicuous or contrasting attributes (Theeuwes, 1995). It is clearly established that mental image processing and visual perception share the same brain structures to a high degree (Posner & Raichle, 1997). In addition to neurological structures, other processes are also involved, for e.g., ocular fixation patterns are involved in mental imagery rotation tasks, even when perceptual representations are recalled from memory (Liman & Zangemeister, 2012). Therefore, if ocular inspection is required for visual information processing, then eye performance is expected to be more affected by concurrent mental spatial-imagery tasks. Future research could focus on investigating the patterns of gaze behavior when the drivers are distracted by mental spatial-imagery tasks and how does it affect ordinary visual search behavior of drivers.

Within the realm of distracted driving, future systematic investigations will benefit from investigating mediating factors (e.g., driving environment, age, and experience) that have the potential of affecting driving performance and gaze behavior. This systematic examination can distinguish between different degrees of distraction associated with the location of off-road glances indicating that some of them could be more dangerous than others.

Appendices

Informed consent form

I acknowledge that I am going to participate in a research study which is trying to investigate the effect of Suppression of Articulatory Rehearsal Mechanism on driving performance. The research requires me to drive a vehicle on a track and data will be collected through video cameras, eye tracker, and through probing questions. I agree to provide my personal and professional details. I acknowledge that the risks associated with participation in this research study are not greater than those associated with driving a car in a safe environment. I will drive a vehicle on the track just as I usually drive my vehicle on the road, for a period of approximately 5 minutes.

I am participating in this study on the condition that my name will not be revealed when the data is presented or reported and that I will be compensated monetarily for the time and effort that I put by participating in the study.

I understand that I will not claim any share or right in terms of acknowledgement or authorship of the research paper(s) published on the basis of the data collected in this study and that all data will be the property of HFAC Lab IIT Indore. If I have any questions about the research, I can call the researcher on 9993614889 or drop a mail at sajadnimh123@gmail.com. I also understand that I am free to withdraw from the study at any time and at any phase of the data collection.

Name: ____

Date: ________________________

Signature: ______________________

Participant ID: _______________________

Non-suppression of ARM

You are welcome to our driving study. You are required to drive as normally as you would usually do and at the speed you feel comfortable with. While you are driving you will be involved in two tasks.

Signboards are placed along the road in pairs (having same signs). Whenever you see a pair of signboards, you are required to understand what is being indicated by the signs and execute your driving task accordingly.

- Each sign board has two parts representing a road with two lanes (e.g., the left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each sign board, "↑" (indicating the lane to drive in) and "X" (indicating the lane to avoid). You have to drive in the lane corresponding to the "↑" sign and avoid driving in the lane which corresponds to the "X" sign.
- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the sign board indicates to change the lane, try to change it when you pass the sign boards.

(*Note*: Experimenter demonstrates using sample of direction signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.
- Left Indication: For changing lane from right to the left lane or for taking left turn.

Another important aspect of your task is that you are required to maintain the driving speed within the limits of 20 – 45 km/h. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'.

Simple suppression of ARM

You are welcome to our driving study. You are required to drive as normally as you would usually do and at the speed you feel comfortable with. While you are driving you will be involved in two tasks.

Signboards are placed along the road in pairs (having same signs). Whenever you see a pair of signboards, you are required to understand what is being indicated by the signs and say ‘Yes Seen’ followed by ‘Counting Aloud’ from 1 to 30.

- Each sign board has two parts representing a road with two lanes (e.g., The left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each sign board, “↑” (indicating the lane to drive in) and “X” (indicating the lane to avoid). You have to drive in the lane corresponding to the “↑” sign and avoid driving in the lane which corresponds to the “X” sign.
- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the sign board indicates to change the lane, try to change it when you pass the sign boards.

(*Note*: Experimenter demonstrates using sample of direction signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.
- Left Indication: For changing lane from right to the left lane or for taking left turn.

Another important aspect of your task is that you are required to maintain the driving speed within the limits of 20 – 45 km/h. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'.

Complex suppression of ARM

You are welcome to our driving study. You are required to drive as normally as you would usually do. While you are driving you will be involved in two tasks.

Signboards are placed along the road in pairs (having same signs). Whenever you see a pair of signboards, you are required to understand what is being indicated by the signs and say 'Yes Seen' followed by 'Counting Down Aloud' from 50.

- Each sign board has two parts representing a road with two lanes (e.g., The left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each sign board, "↑" (indicating the lane to drive in) and "X" (indicating the lane to avoid). You have to drive in the lane corresponding to the "↑" sign and avoid driving in the lane which corresponds to the "X" sign.
- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the sign board indicates to change the lane, try to change it when you pass the sign boards.

(*Note*: Experimenter demonstrates using sample of direction signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.

- Left Indication: For changing lane from right to the left lane or for taking left turn.

Another important aspect of your task is that you are required to maintain the driving speed within the limits of 20 – 45 km/h. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'.

In-vehicle object distraction

"Welcome to the study on distracted driving. It is a pleasure to have you with us. Our interest is to study your ability to perform multiple tasks at the same time. You have to drive a car as normally as you would do. While driving you have to look at the monitor (which is attached to the dashboard on your left side) whenever you hear a male voice saying "1" or "2". Once you hear the male voice saying "1" you have to look at the display monitor and concentrate and remember the appearance of letter P, while ignoring the location of it. After some time you will hear the male voice saying "2". This time you have to match the appearance of letter P with the one shown in condition 1, if it matches, you have to respond verbally by saying "yes" otherwise you have to say "no".

Signboards are placed along the road. Whenever you see a signboard, you are required to understand what is being indicated by the signs and execute the direction accordingly.

- Each signboard has two parts representing a road with two lanes (e.g., the left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each sign board, "↑" (indicating the lane to drive in) and "X" (indicating the lane to avoid). You have to drive in the lane corresponding to the "↑" sign and avoid driving in the lane which corresponds to the "X" sign.
- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the sign board indicates to change the lane, try to change it when you pass the signboards.

(*Note*: Experimenter demonstrates using sample of direction signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.
- Left Indication: For changing lane from right to the left lane or for taking left turn.

You are required to drive within the speed limits of 25-35 kmph. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses during driving.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'.

In-vehicle spatial distraction

"Welcome to the study on distracted driving. It is a pleasure to have you with us. Our interest is to study your ability to perform multiple tasks at the same time. You have to drive a car as normally as you would do. While driving you have to look at the monitor (which is attached to the dashboard on your left side) whenever you hear a male voice saying "1" or "2". Once you hear the male voice saying "1" you have to look at the display monitor and concentrate and remember the location of letter P, while ignoring the appearance of it. After some time you will hear the male voice saying "2". This time you have to match the location of letter P with the one shown in condition 1, if it matches, you have to respond by verbally saying "yes" otherwise you have to say "no".

Signboards are placed along the road. Whenever you see a signboard, you are required to understand what is being indicated by the signs and execute the direction accordingly.

- Each sign board has two parts representing a road with two lanes (e.g., the left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each signboard, "↑" (indicating the lane to drive in) and "X" (indicating the lane to avoid). You have to drive in the lane corresponding to the "↑" sign and avoid driving in the lanes which corresponds to the "X" sign.
- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the signboard indicates to change the lane, try to change it when you pass the sign boards.

(*Note*: Experimenter demonstrates using sample of direction signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.
- Left Indication: For changing lane from right to the left lane or for taking left turn.

You are required to drive within the speed limits of 25-35 kmph. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses during driving.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'.

In-vehicle spatial-simultaneous distraction

"Welcome to the study on distracted driving. It is a pleasure to have you with us. Our interest is to study your ability to perform multiple tasks at the same time. You have to drive a car as normally as you would do. While driving you have to look at the monitor (which is attached to the dashboard on your left side) whenever you hear a male voice saying "1" or "2". Once you hear the male voice saying "1" you have to look at the display monitor and concentrate and remember the locations of letter P displayed at three locations simultaneously, while ignoring the appearance of it. After some time you will hear the male voice saying "2". This time you have to match the locations of letter P with the ones shown in condition 1, if all the three locations match, you have to respond verbally by saying "yes" otherwise you have to say "no".

Signboards are placed along the road. Whenever you see a signboard, you are required to understand what is being indicated by the signs and execute the direction accordingly.

- Each signboard has two parts representing a road with two lanes (e.g., the left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each sign board, "↑" (indicating the lane to drive in) and "X" (indicating the lane to avoid). You have to drive in the lane corresponding to the "↑" sign and avoid driving in the lane which corresponds to the "X" sign.
- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the sign board indicates to change the lane, try to change it when you pass the signboards.

(*Note*: Experimenter demonstrates using sample of signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.
- Left Indication: For changing lane from right to the left lane or for taking left turn.

You are required to drive within the speed limits of 25-35 km/h. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses during driving.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'

In-vehicle spatial-sequential distraction

"Welcome to the study on distracted driving. It is a pleasure to have you with us. Our interest is to study your ability to perform multiple tasks at the same time. You have to drive a car as normally as you would do. While driving you have to look at the monitor (which is attached to the dashboard on your left side) whenever you hear a male voice saying "1" or "2". You will hear the male voice saying "1" consecutively three times. Once you hear the male voice saying "1" you have to look at the display monitor and concentrate and remember the locations of letter P shown three times, while ignoring the appearance of it. After some time you will hear the male voice saying "2" consecutively three times. This time you have to match the locations of letter P with the ones shown in condition 1, if it matches, you have to respond verbally by saying "yes" otherwise you have to say "no". You have to match them in such a manner that the first P of condition "1" is matched with first P of condition "2", second P of condition "1" is matched with second P of condition "2" and similarly, third P of condition "1" is matched with the third P of condition "2".

Signboards are placed along the road. Whenever you see a signboard, you are required to understand what is being indicated by the signs and execute the direction accordingly.

- Each signboard has two parts representing a road with two lanes (e.g., the left side of the signboard corresponds to left lane of the road on which you are driving. Similarly, right side of the signboard corresponds to right lane of the road.
- There will be two types of signs on each sign board, "🡡" (indicating the lane to drive in) and "X" (indicating the lane to avoid). You have to drive in the lane corresponding to the "🡡" sign and avoid driving in the lane which corresponds to the "X" sign.

- Therefore, you will be involved in changing the lane (or not) depending upon what is indicated by the signs. In case the sign board indicates to change the lane, try to change it when you pass the signboards.

(*Note*: Experimenter demonstrates using sample of signs)

Please remember that you are required to give indication whenever you have to change the lane or take a turn. You have to give indications in the following manner:

- Right indication: For changing lane from left to the right lane or for taking right turn.
- Left Indication: For changing lane from right to the left lane or for taking left turn.

You are required to drive within the speed limits of 25-35 kmph. Please try not to deviate from the stipulated speed limits.

Throughout the driving task you are required to strictly maintain the following:

- During the driving task you will be wearing a pair of glasses (eye tracking glasses). You have to make adjustment of glasses before you start the driving task in order to avoid making any change(s) to the position of the glasses during driving.
- You have to start and stop driving when you are instructed to do so.

Please feel free to ask your doubts, if you have any. If you have clearly understood the instructions, then please repeat them in your own words. If you are clear about the tasks that you have to perform, then let's proceed to a 'Practice Trial'.

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