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In-vehicle visuo-spatial distraction and expertise in gaze behavior

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Abstract

Driving related information is predominantly visuospatial in nature. Scientific evidence from neuropsychological and developmental studies support the hypothesis that visuospatial information is processed by different areas of brain (Courtney, Ungerleider, Keil, & Haxby, 1996) and by different cognitive processes (Hecker & Mapperson, 1997). Visuospatial Working Memory is comprised of Visual Cache (stores information about object appearance) and Inner Scribe (stores information about location of the object) (Logie & Pearson, 1997). The current study investigated whether it is the object or the spatial distraction that has more detrimental effect on the gaze behaviour of novice and experienced drivers. In this regard an experimental paradigm named as Direction Following in Distracted Driving – Object and Spatial (D3OS) was developed. 40 drivers drove an instrumented vehicle on a two lane track and were required to follow certain directions shown on direction signboards installed along the track. During driving they were also required to attend the in-vehicle object and spatial distractions displayed on a monitor attached to the dashboard. The results demonstrated that compared to spatial distraction, object distraction has more detrimental effect on gaze behaviour of drivers. This study signifies the compromises in gaze behaviour when the driver operates in-vehicle interactive devices.

Keywords: Fixation counts; object and spatial distraction; working memory; distracted driving;

1. Introduction

Use of in-vehicle technologies during driving have a high potential of distraction as they take the eyes and mind off the road and hands off the steering wheel (Lee, & Strayer, 2004). As more interactive systems (whether portable

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devices or an embedded device) finds way into the vehicle the number of crashes or near crashes is expected to increase (Stutts, Reinfurt, Staplin, & Rodgman, 2001). In distracted driving, the driver's attention is diverted away from the activities critical for safe driving towards some competing activity (Regan, Lee, & Young, 2009). From the last decade, number of deaths on Indian roads show an upward trend. During 2016, 1,50,785 persons died on Indian roads whereas in 2015 the total number of deaths resulting from traffic accidents was 1,46,133 (an increase of 3.2 per cent over the previous year) (Bureau, 2017). Distraction due to interaction with the in-vehicle devices is one of the reasons behind the increased number of crashes (Bureau, 2017).

Information related to driving task is visuospatial in nature. Baddeley and Hitch's (1974) Working Memory (WM) model thoroughly explains the processing of visuospatial information. WM temporarily stores information and at the same time manipulates it so that the task is executed properly (Baddeley, 2007). WM consists of a central executive and two subsystems: a visuospatial sketchpad and a phonological loop. Central executive, also known as the real brain of working memory, controls attention and allocates resources to the two subsystems. The primary responsibility of central executive is to select information from the environment and retrieve knowledge from long term memory (Baddeley, 1992). Visuospatial sketchpad holds visual and spatial information that is received through senses or retrieved from long term memory. The phonological loop, temporarily stores information related to sounds and rehearses it through Articulatory Rehearsal Mechanism. Logie and Pearson (1997) distinguished between a visual store (visual cache) which temporarily stores object information (e.g., shapes, textures and color) and inner scribe that stores information about sequences of spatial information. This dissociation between visual (also known as object memory) and spatial memory has been supported from different fields e.g., on the basis of selective interference paradigm (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999), neuropsychological evidence (Carlesimo, Perri, Turriziani, Tomaiuolo, & Caltagirone, 2001), and on developmental data (Hamilton, Coates, & Heffernan, 2003; Pickering, Gathercole, & Peaker, 1998). There is scientific evidence that support the hypothesis that object and spatial information is processed by different cognitive systems (Della Sala et al., 1999; Hecker & Mapperson, 1997), and by different areas of the brain, e.g., 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 (Munk et al., 2002; Nelson et al., 2000). Object memory deals with information related to object appearance (color, shape, contrast, size, and visual texture) whereas the spatial domain of the visuospatial sketchpad 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 pathways or sequences of movements from one location to another in the scene) (Della Sala, & Logie, 2002). The current study investigates whether it is the object distraction or the spatial distraction that has more detrimental effect on gaze behaviour and whether novice and experienced drivers are differentially affected by object and spatial distractions. It would also examine which of the two processes (object or spatial) consumes more cognitive resources.

Challenging driving scenarios, e.g., entering narrower routes and the acts of overtaking significantly reduces fixation durations (Miura, 1979). Driving instructors have an increased sampling rate, shorter processing time and broader scanning of the road than drivers at the learning stage (Konstantopoulos, Chapman, & Crundall, 2010). Konstantopoulos, Chapman, and Crundall (2010) justify that the results could be because of the mirror inspection pattern of the driving instructors which was lacking in learner drivers. As the situation becomes too demanding for the driver, fixation duration 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 key predictor of crash rates is driving experience (Gregersen & Bjurulf, 1996), with higher crash rates among young novice drivers (Clarke, Ward, Bartle, & Truman, 2006). Young novice drivers are susceptible to crashes three times more during nights than daytime (Williams, 2003). The reason of higher crashes among novice drivers is their inefficiency in deploying visual attention (both foveal and peripheral attention) which increases as the person gains more experience. Underwood (2007) also suggests that visual search strategy is one of the basic skills that marks the transition from novice to experienced driver. This paper investigates the effect of object and spatial distraction on gaze behaviour and whether they have differential effects on novice and experienced drivers. If novice and experienced drivers are placed under same task situations, it is expected that novices — due to lack of automatized procedures of performing the task, or the absence of relevant schemas — would experience higher demand on their cognitive resources and it would be reflected in their gaze behaviour.

2. Methods and materials

An experimental paradigm named as Direction Following in Distracted Driving – Object and Spatial (D3OS) was developed for the purpose of the current study. This paradigm is characterized by – vehicular platform, lane setting, direction input, distance, speed-range, and distraction inducement. On a two-lane track, an instrumented vehicle (vehicular platform) was driven by drivers within the speed range of 25-35 km/h (speed range). The two lanes of the experimental track were separated by permanent markers (lane setting) and the drivers were required to drive according to the directions shown on the direction signboards (direction input). Each direction signboard consisted of two signs "↑" and "X". "↑" sign indicates the corresponding lane where the driver has to drive, and the other side of the direction signboard is marked by a "X" sign which indicates that the driver has to avoid driving in the corresponding lane. The length of the experimental track was 1 km and the gap between any two direction signboards was 250 meters (distance). The drivers were distracted by means of distracting stimuli run by a computer program named as "Distracting Stimuli Regulator (DSR)". DSR was developed on MATLAB platform and run on DELL Inspiron 11.6 inch HD display laptop which was attached to the dashboard with the help of a monitor holder. The program is characterized by two conditions: (a) stimulus condition, and (b) probing condition. In stimulus condition, the letter 'P' appears accompanied by a male voice saying "1", and in the probing condition the letter 'P' appears accompanied by a male voice saying "2". Depending on the distracting condition (object or spatial), 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 colour) of the letter 'P'. After a delay time of 3 seconds the letter 'P' would reappear accompanied by male voice saying "2". This time the participant is required to look at the monitor and judge whether the previous 'P' (which appeared in stimulus condition) matches with the current 'P' or not, if it matches, he/she has to verbally say "yes", otherwise he/she has to say "no". 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 of the letter 'P' (each time the letter 'P' randomly appears in one of the 30 squares). After a delay time of 3 seconds the letter 'P' would reappear accompanied by male 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 (i.e., the time period between the appearance and disappearance of letter 'P') was 4 seconds and the delay time (i.e., the time period 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 basis of the feedback received from the participants during initial test trials.

2.1. Design

This experiment use a 2 (in-vehicle distraction: object vs spatial) × 2 (expertise: novice and experienced) between-groups design. A participant was treated as novice on the basis of 3 parameters: (a) if the license was not older than three years, (b) after fulfilling parameter (a) researchers would ask him/her if he/she considers him/herself as novice or expert driver, and (c) if both (a) and (b) parameters are fulfilled then the researchers would take the participant for a test drive and observe his/her driving. Novice drivers usually drove in a single gear irrespective of the speed, forgot to use indicators and did not check side mirrors.

Gaze behaviour data of the drivers was collected by Tobii glasses 1 eye tracker (collects data at the rate of 30 Hz). 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. Gaze behaviour was analysed in terms of fixation counts on the Areas of Interests (AOIs) i.e., signboards for direction input. Fixation counts is the number of times the participant fixates on an AOI (Tobii, 2012). 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.

2.2. Participants

40 novice and experienced drivers (20 in each group) participated in this naturalistic distracted driving study. Novice drivers ranged between the age group 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. The age range of experienced drivers was 23 and 48 years (*M* = 33.45; *SD* = 7.74) and a mean of 12.10 years' driving experience. Each driver's voluntary participation was compensated by paying 250 INR.

2.3. 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 DSR 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 acquainted 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 Video Velocity Box (V V Box), started – the eye tracking glasses, the DSR, and screen recording of DSR (for analyzing the responses of the participants). The male voice feature of the DSR (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.

3. Results

In this study fixation counts were measured as the number of times (counts) the participant fixates on AOIs (i.e., for all the direction signboards). As shown in Fig. 1, statistical analysis showed a significant main effect of in-vehicle distraction. Object and spatial distraction had mean fixation counts of 33.050 and 64.850, respectively, $F(1,36) = 4.400$, $p = 0.043$, $\eta_p 2 = 0.109$. There was no main effect of expertise (novices, *M* = 42.200, experts, *M* = 55.700, see Fig. 1), $F(1,36) = 0.793$, $p = 0.379$, $\eta_p 2 = 0.022$.

As shown in Fig. 2, there was no significant interaction between information processing and expertise with respect to fixation counts on AOIs, $F(1,36) = 0.109$, $p = 0.743$, $\eta_p 2 = 0.003$.

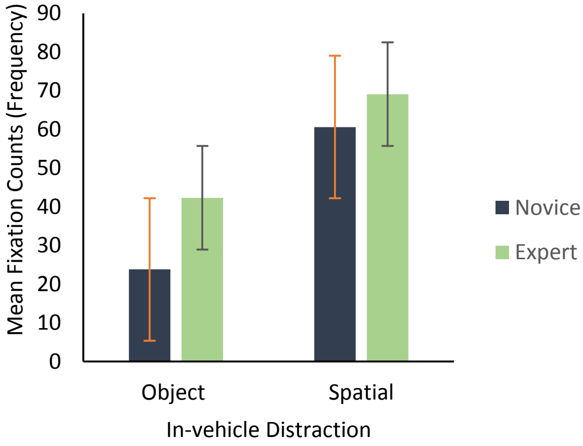

Fig. 1. Fixation counts as a function of in-vehicle distraction and expertise.

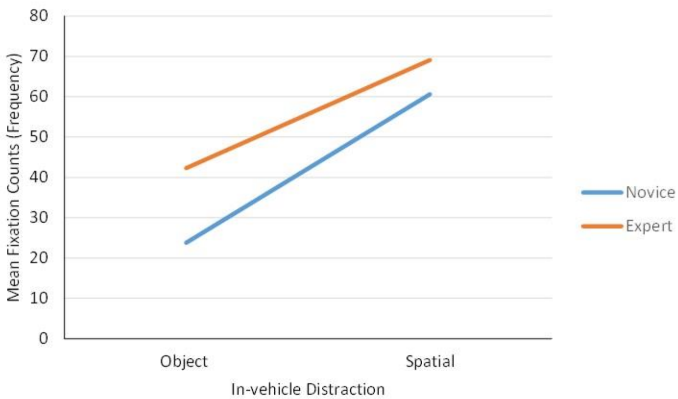

Fig. 2. Fixation counts as a function of interaction between in-vehicle distraction and expertise.

4. Discussion and conclusion

The study investigated the effect of in-vehicle distraction (object and spatial) and driving expertise (novice and experts) on drivers' gaze behaviour with respect to fixation counts on the AOIs, i.e., direction signboards. The results show that object distraction significantly reduces fixation counts on the AOIs. In other words, in comparison to spatial distraction, it is the object distraction that has more detrimental effect on the gaze behaviour of drivers. This indicates that object processing of visuospatial information demands more cognitive resources and that very less resources are residual during this processing, so if a driver gets distracted during object processing of the driving related information, the driver faces difficulties in processing driving related visual information. There was no significant interaction between information processing and expertise with respect to fixation counts on AOIs, but the trend line shows that during object distraction novice drivers had lesser fixation counts on AOIs in comparison with novice drivers in the spatial distraction group. The justification for greater demand of cognitive resources for processing object related information is that the representations of objects in WM depends on a semantic verbal code, and this semantic verbal code is rehearsed in order for it to stay longer in the memory, whereas the representation of the location of objects does not (Postle, D'Esposito, & Corkin, 2005; Simons, 1996). In the current study, driving experience did not show any significant difference with respect to fixation counts on AOIs. Further analysis of the data revealed that novice drivers 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 AOIs 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.

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