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Effect of Mobile Phone Position on the Visual and Driving Behaviour – A Lane Change Test-Based Study

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ABSTRACT

This study aims to investigate the effect of the position of mobile phones used for navigation purposes on the driving performance and visual behaviour of drivers. With the advancement of technology in recent times, drivers use mobile phone applications for navigation. Previous studies showed that drivers place their in-vehicle mobile phones at various locations. This behaviour could severely affect their driving performance and visual behaviour. Thirty drivers performed visual-manual tasks on mobile phones located at different positions (left, right, front and middle of the steering wheel) around the dashboard while driving in a simulated driving environment. The lane change test (LCT) assessed the driving behaviour, and the eye-tracker measured the visual behaviour. The outcome of LCT revealed that the best driving performance was achieved for mobile phones at the front of the steering wheel. The subjective workload rating score was the highest, and driving performance was worst for the middle mobile phone position. The findings of this study show that the in-vehicle mobile phone position has a significant effect on the driving performance and visual behaviour of the drivers. Insights drawn could be useful in drafting standard operating procedures for professional drivers and others in general.

KEYWORDS

driver distraction; lane change test (LCT); visual behaviour; driving activity load index (DALI); glance duration; eye-tracking.

1. INTRODUCTION

Globally, road traffic accidents are the 8th leading cause of fatalities and injury. An estimated 1.35 million people die due to road traffic accidents annually [1]. Deviation of attention to non-driving-related activity is a causal factor of road accidents. Using mobile phones while driving is one activity that deviates the attention of drivers from driving leading to accidents and near-crash involvement [2]. Mobile phone use in our daily lives has also increased. According to "Ericsson's Mobility Report", the total number of mobile subscriptions worldwide was around 7.9 billion in Q3 of 2018; it also estimated 8.9 billion subscribers by 2024 [3]. Advancements in communication and information technologies have led to mobile phone use as an in-vehicle information system (IVIS) [4]. These mobile phones, used as IVIS, provide drivers with more information about driving and non-driving tasks (navigation, vehicle status, weather and entertainment) [5]. It is frequently discovered that drivers place mobile phones inside the vehicle at various locations (on the dashboard/windshield close to the central console, close to the base of the A-pillar) [6]. The use of mobile-phone-based IVIS is often associated with inattention to driving, causing driver distraction, thereby impairing road safety [7]. According to Ranney et al. [8], driver distraction is "any activity that takes a driver's attention away from the task of driving" [8]. Any distraction from rolling down a window, over-adjusting a mirror or tuning a radio to using a cell phone can contribute to a crash. It is worthwhile to point out that De Lumen et al. (2019), in their study, found that drivers have no idea about the safe and efficient location to mount their navigation devices [9].

1.1 In-vehicle display position in the driving context

Previous research has evaluated the effect of in-vehicle display positions on various aspects of driving [6, 9–14]. Studies have focused on positioning the infotainment screen inside the vehicle for a better visual experience, emphasis was given to parameters like vision angle, avoiding any obscuration due to vehicle components, avoiding in-vehicle reflections and avoiding ambient reflections [12, 15], and cluster packaging process flow for in-vehicle visual hindrance free instrument cluster position [11]. Some other researchers have conducted empirical studies to determine the optimal location of in-vehicle displays. In their study, De Lumen et al. (2019) [9] measured the driver's visual distraction level by conducting a peripheral detection test on three locations around the steering wheel to determine the ideal location for placing a mobile navigation device. Further, researchers have also used digital human modelling to identify a suitable location for mobile navigation devices. Verma and Karmakar (2020) [6], measured head rotation and flexion/extension of the manikins (5th, 50th and 95th percentile), when mobile phones are placed at nine different locations around the steering wheel. It is evident that there is a lack of rules or guidelines for the optimal position of mobile phone-based IVIS. Further, formulating driver distraction policy is an incremental process as bringing the empirical and theoretical knowledge is a complex process [16]. However, some countries have enacted laws to prevent distracted driving. One such country is the Philippines, which has implemented the Anti-Distracted Driving Act (ADDA, RA 10913). It proposes a safe zone for the placement of mobile phone-based IVIS [17]. Further, the research conducted by Wittmann et al. [13], hypothesised that with an increase in the eccentricity of the display position and workload of the secondary task, the primary task of driving would degrade. They reported an exponential decrease in driver's performance as a function of the distance between the line of sight and on-board display position. Also, the empirical study of Zheng et al. [14] evaluated the suitability of display positions based on eye-gaze tracking of drivers, when navigation systems were placed at different locations around the dashboard. The findings suggest that in-vehicle display positions with small visual angles have significantly shorter glance times compared to displays with larger visual angles. A few researchers have conducted studies to investigate the positioning of mobile data terminals (MDT) used by the police force for assistance during patrolling duties [18, 19] as an influencing factor for distraction. Hampton and Langham [18] have investigated the requirements of MDT installed inside the police vehicle in terms of safety and the requirements of systems design. McKinnon et al. [19] conducted studies on five MDT locations and two types of seats (standard and modified) to find the best possible MDT locations in terms of reduced physical discomfort. Results reveal that self-selected MDT locations, along with modified driver seats, reduced physical discomfort compared to the traditional arrangement. Some researchers have also studied the effect of display positions on driving performance when camera monitor systems (CMS) replaced side-view mirrors [10, 20, 21]. Studies conducted by Large et al. [21] also evaluated five types of layouts for three in-vehicle displays (two side-view and one rear-view), in comparison to the existing mirror system. Results revealed that layouts that were similar to the existing mirror locations were subjectively preferred. Further, the empirical study conducted by Beck et al. [20] compared three CMS layouts to the traditional side-view mirror system. It was concluded that the CMS display position that was closer on either side of the steering wheel was relatively better in terms of reduced mean eye-off-road time, higher preference, and perceived safety. The results of the study conducted by Doi et al. [10] were in agreement with the previous results, with accurate and faster reactions to rearward situations when CMS displays were located at a smaller view angle.

Even though previously mentioned studies have evaluated and provided insight into the in-vehicle display positions, they have some limitations. These studies have mainly considered the position of the rear-view or side-view mirrors, which were replaced by CMS. The drivers did not perform any visual-manual task (dual-task scenario) on these displays. Although a few researchers have studied the interaction of IVIS at different locations, these results cannot be generalised for smaller (in-vehicle mobile phone displays). Even the studies conducted on MDTs did not consider eye movement while performing tasks on MDTs at different locations. Since more than 90% of the information to the drivers is gathered from the visual senses, evaluation of eye movement becomes an important agenda in driver behaviour studies. Also, the tasks performed on MDTs are different from those on mobile phones. Moreover, these studies did not consider the drivers' visual behaviour in a dual-task driving scenario. Hence, we conducted the present study to evaluate the driving performance and the drivers' visual behaviour when in-vehicle mobile phones are placed at different positions in a dual-task simulated driving condition.

1.2 Research objective

The objective of the current study was to evaluate the effect of mobile phone position on driving performance (measured by lane change test), visual behaviour (measured by eye-tracking) and the perceived driving workload. We expected that as the eccentricity of the mobile phone position increases from the normal line of sight, there would be difficulty in maintaining the lane (higher mean deviation) and thus would also influence the visual behaviour. It was hypothesised that better lane-keeping would result in lower driving workload scores by the participants.

2. METHODS AND MATERIALS

2.1 Participants

Thirty participants took part in the study. The participants' age was 21 to 45 years (M = 27.67 years, SD = 5.03), having a mean driving experience of 6.93 years (SD = 3.94). All of them declared they had a valid Indian driving licence and had prior experience interacting with the mobile phone while driving. They were healthy and were not suffering from any musculoskeletal disorders. The participants were informed that they could choose to leave (without any consequences) at any stage if they felt uncomfortable during the experiment. The study objective and the experimental procedure were clearly explained to the participants. Written informed consent was obtained from each participant before starting the study. The entire data collection was performed following the declaration of Helsinki [22]. Since most of the subjects were not well-versed in English, they were explained the questions in their vernacular language and data were filled in by the interviewer. The inclusion criterion for participating in the study was: good general health, regularly driving with a valid driver's licence, and having experience of using a mobile phone while driving. Each of them had normal or corrected to normal vision, and those having glasses were not included in the study.

2.2 Apparatus

We used a low-fidelity driving simulator for the experiment. It comprised a separate 42-inch display screen, resolution: 1024×768 pixels and a Logitech G29, racing wheelset (a force-feedback steering wheel, brake pedal and accelerator), shown in *Figure 1*. The viewing distance between the LCD monitor and the participant was kept at 70–75 cm depending upon the participant's stature. The participants could adjust the position and degree of the seat backrest as per their comfort. It is essential to note that the simulator set-up was for the right-handed driving vehicle. Simulated driving was performed using the lane-change test (LCT) software [7] installed on the computer system.

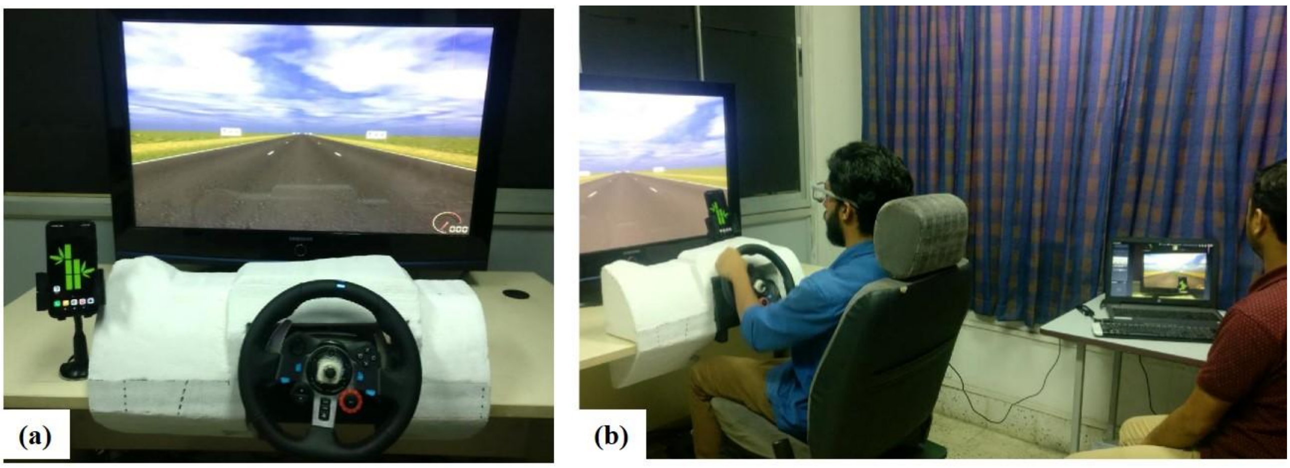

Figure 1 – Experimental setting: a) Driving simulator (front-view); b) Experimenter monitoring the participant

A binocular eye-tracker glass by SensoMotric Instrument (SMI) was used to acquire and analyse eye-movement data on a separate computer system. The eye-tracking device was calibrated using a one-point calibration technique, per participant [23]. A 6.3-inch touch screen mobile phone was used to perform the secondary task in a dual-task scenario. This mobile phone was mounted at different positions using a mobile holder. Comfortable room temperature and ideal ambient illumination of about 24° C (75° F) and 500 lux, respectively, were maintained during the experiment [24].

2.3 Experiment design

The study used a within-subject design to measure the driving performance: one baseline driving (only lane change test), and four dual-task driving (lane change + secondary task, when a mobile phone is at left, right, front and middle of the steering wheel). Every participant was subjected to all five driving conditions. During each of the five simulated driving sessions, the participants were instructed to perform the lane change deliberately as soon as they saw the lane change signboard. The participants had to maintain the vehicle's speed to 60 km/hr. The participants had to perform the secondary task on the mobile phone without removing it from the mobile holder. A visual representation of the experimental design is shown in *Figure 2*. The rest period between the driving session is represented by 'R'; it was approximately 5 min and used to collect driving activity load index (DALI) subjective rating data. Baseline and dual-task driving sessions took 3 min each.

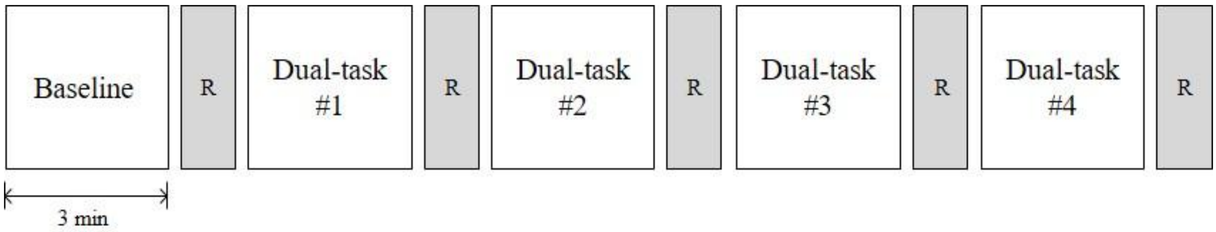

Figure 2 – Visual representation of experimental design

2.4 Secondary task

During each of the four dual-task driving sessions, the participants performed four (4) secondary tasks (description in *Table 1*). Participants performed these tasks after the experimenter gave a clap signal to start the secondary task. The sequence of these tasks was counterbalanced for each dual-task driving session to reduce the learning effect. The tasks chosen to perform during the experiment resemble the typical tasks that are being performed by the drivers during their day-to-day activities.

Table 1 – Descriptions of the secondary task

Task	Category	Description
1	Dialling	Call a pre-saved number by the name Demo '1'
2	Dialling	Call a pre-saved number by the name Demo '2'
3	POI Address	Open Google Maps and find a POI (point of interest) address (for ATM, petrol pump, restaurant) and start navigation
4	Dialling	Open the telephone dialler and dial your own phone number (ten-digit number)

2.5 Position of the mobile phone

Since the simulator setup was for a right-handed driving vehicle, all the mobile phone positions were accordingly demarcated. The mobile phone was placed at each of the four positions: left, right, front and middle of the steering wheel. The position of the mobile phone with respect to the steering wheel is shown in *Figure 3*. The dashboard shown represents half of the car's actual dashboard, and the left position of the mobile phone is at the centre of the actual dashboard. Dots represent the centre of the mobile phones in the illustrated image. The relative positions (see *Table 2*) of the mobile phones are calculated with respect to the centre of the middle position.

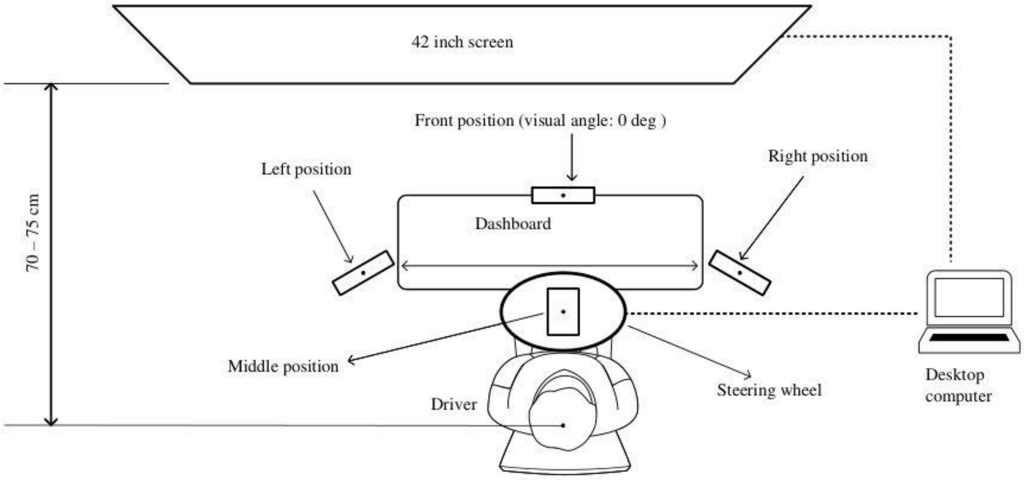

Figure 3 – Diagram showing different positions of the mobile phone in relation to the driver

Table 2 – Descriptions of mobile phone positions

Position	**Description**	
	Distance w.r.t middle (mm)	Horizontal visual angle (°)
Left	410	58
Right	310	50
Front	260	0
Middle	0	0

2.6 Experimental procedure

The experiment was divided into three sessions: screening and briefing, practice and experimental session. Upon arrival of the participants in the experiment area, they were allowed to rest for 5 min. Then they were screened and tested for fitness (for physical pain or discomfort), visual acuity (using the Snellen chart) [25], and colour blindness (using the Ishihara colour-blindness type test) [26]. Subsequently, they were given a brief introduction to the study and informed about the experimental protocol. Before starting the session, all participants answered demographic questions regarding their age, gender, driving experience, licence and visual status. Each of them signed a consent form to participate in the experiment. After the screening and briefing session, the participants practised the driving simulator with single and dual-task driving. The practice session ended once the participants were comfortable with the simulated driving environment and completely understood the task to be performed. In the experimental session, the participant's driving performance and eye movement data were recorded. The participants drove as per the experiment design (mentioned in 2.3). After each driving session, the participants rested for 5 minutes and filled out a subjective rating questionnaire using the DALI. The entire session took approximately 60 minutes. A flowchart showing the procedure adopted for the study is given in *Figure 4*. Upon completion of the experiment, participants were given refreshments and a remuneration amount of ₹200 to compensate for the time and effort required for taking part in the experiment.

2.7 Experiment variables

In this study, the independent variable was the position (spatial arrangement of the mobile phone around the steering wheel), which had five levels: baseline (no mobile phone), and mobile phone at left, right, front and middle of the steering wheel. The dependent variables were: mean deviation (M.Dev), lane-change error, fixation (duration and count), glance (duration and count), total eye-off road time (TEORT) and DALI subjective workload ratings. The mean deviation (M.Dev) is defined as the mean deviation between the actual driving course and the position of the normative model. It has been used by many researchers to evaluate driving performance [27–30]. Lane excursion is the errors performed during the lane change. It was measured using the LCT simulation software. Glance duration refers to the time duration for which the drivers looked at a particular area of interest (AOI), and the number of glances to a particular AOI is defined as glance count [31,32]. Fixation duration is the time duration for which fixation occurs at a particular area of interest (AOI); the number of fixations occurring at a particular AOI is defined as fixation count [23,33]. Total eye-off-road time is defined as the total time when the driver is not looking towards the road or time spent looking away from the road [20,34]. DALI subjective workload scale is a modified version of the NASA-TLX – task load index scale measuring the workload during the driving task [35]. It has six sub-scales; attention, visual, temporal demand, stress and interference [36].

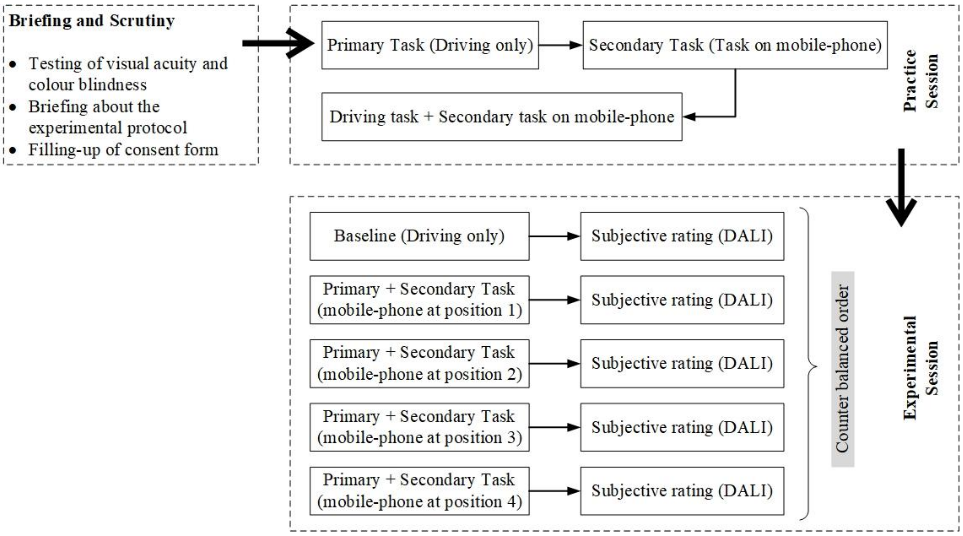

Figure 4 – Flowchart of the experimental procedure

2.8 Statistical analysis

A Shapiro-Wilk's test ($p > 0.05$) [37,38] and visual inspection of the histogram, normal Q-Q plot and box plots were used to check the normality of the individual groups of each variable. A one-way repeated measures ANOVA (analysis of variance) was used to test statistical significance (if any) by comparing the means of each group in a within-subjects design [39]. The statistical analysis was performed using IBM SPSS 25.0, software at a significance level of $p = 0.05$. The calculated effect sizes were reported as being large ($0.14 \geq \eta^2$), medium ($0.06 \leq \eta^2 < 0.14$) and small ($\eta^2 < 0.06$) [40].

3. RESULTS

The mean and SD of the dependent variables are given in *Table 3*.

Table 3 – Descriptive of the dependent variables for different test conditions

Measure	Test Conditions				
	Baseline	Left	Right	Front	Middle
M.Dev (m)	0.51 (0.26)	0.81 (0.38)	0.76 (0.30)	0.68 (0.30)	0.83 (0.44)
LC error (n)	2.53 (2.37)	4.10 (3.02)	3.83 (2.57)	3.50 (3.10)	4.10 (3.18)
Fixation duration (s)	N.A.	19.20 (8.42)	18 (6.13)	24.64 (5.40)	17.32 (6.82)
Fixation count (n)	N.A.	73.23 (29.55)	71.93 (23.15)	90.26 (22.20)	72.97 (26.23)
Glance duration (s)	N.A.	24.67 (10.55)	23.57 (7.89)	31.06 (6.60)	23.47 (9.20)
Glance count (n)	N.A.	23.10 (7.88)	24.50 (7.10)	32.70 (8.90)	22.10 (6.53)
TEORT (s)	N.A.	27.93 (11.62)	26.86 (8.42)	33.93 (7.09)	25.78 (9.53)
DALI (0 – 100)	23.33 (5.04)	39.24 (7.42)	36.73 (5.69)	30.35 (5.47)	40.97 (4.97)

Mean (SD); M.Dev – mean deviation, LC – lane change, TEORT – total eye-off road time, DALI – driving activity load index, N.A. – not applicable.

3.1 Driving performance

The mean deviation (M.Dev) of lane change from the normative path (in meters) and the number of lane change errors was used as a measure of driving performance. The value of M.Dev was lowest at 0.51 for the baseline and highest at 0.83 for the middle position of the mobile phone. A repeated measures ANOVA showed that there was a significant effect of driving condition ($F(4, 116) = 36.80$, $p < 0.05$, $\eta^2 = 0.559$, large effect size) on M.Dev values. A post hoc test using the Bonferroni correction revealed that there was a significant difference between the M.Dev values of baseline and all the dual-task driving scenarios at $p < 0.05$. Also, a significant difference in M.Dev values was observed for driving conditions when a mobile phone was placed at the front and middle of the steering wheel ($p < 0.05$). However, no significant difference ($p > 0.05$) was observed in M.Dev values for; left vs right, left vs front, left vs middle, right vs front and right vs middle position of steering wheel.

The errors performed during lane change were minimum for baseline (M=2.53) and maximum for the left and middle (M=4.10) positions of the mobile phone. A Friedman test revealed that there was a significant main effect of driving condition ($\chi^2(4) = 14.09$, $p < 0.05$) on lane change errors. A post hoc analysis with the Wilcoxon signed-rank test was conducted with Bonferroni correction applied, resulting in a significance level set at $p < 0.005$. The result revealed that a significant difference exists in lane-change error for mobile phones at middle vs baseline driving ($Z = -3.212$, $p = 0.001$). Median (inter-quartile range) error in lane change for baseline, left, right, front and middle of the steering wheel are shown in *Table 4*. The M.Dev and error in lane change values for different driving conditions is shown in *Figure 5*.

Table 4 – Descriptive of error in lane change at different conditions

Condition	Mean (SD)	Percentile		
		25th	50th (median)	75th
Baseline	2.53 (2.41)	1	2	4
Left	4.1 (3.07)	2	3	6
Right	3.83 (2.61)	1.75	4	5.25
Front	3.5 (3.16)	1	3.5	5.25
Middle	4.1 (3.23)	1.75	3	5.25

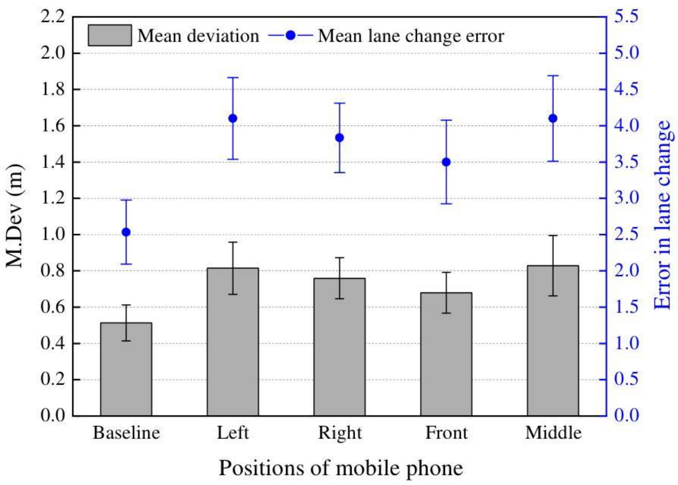

Figure 5 – Mean deviation of lane change at different positions

3.2 Visual behaviours

Glance (duration and count), fixation (duration and count), total eye-off road time (TEORT) and mean eye-off road time was used as a measure of visual behaviour.

Glance duration and count

The longest glance duration value was observed for the front mobile phone position (M = 31.06, SD = 6.60). A repeated measures ANOVA with Greenhouse-Geisser correction revealed that the difference in glance duration values between the different positions of the mobile phone was statistically significant (F (2.528, 73.304) = 10.339, $p < 0.05$, $\eta^2 = 0.263$ large effect size). Post hoc test with Bonferroni correction determined significantly higher total glance duration for mobile phones at the front position than left ($p = 0.01$), right and middle ($p < 0.05$).

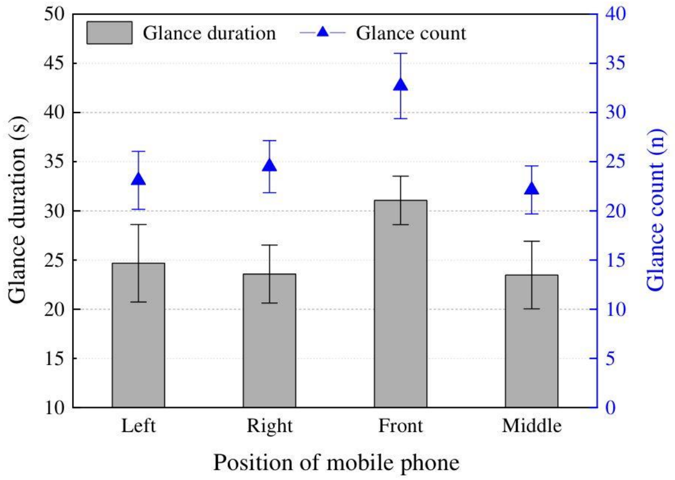

Figure 6 – Glance duration and glance count at different mobile phone positions

The glance count values were minimal for the middle mobile phone position (M = 22.13, SD = 6.53). A repeated measures ANOVA revealed that the total glance count was significantly different for mobile phone position (F (3, 87) = 23.078, $p < 0.05$, $\eta^2 = 0.443$). Post hoc test with Bonferroni correction revealed that the total glance count was significantly higher for the front position ($p < 0.05$) as compared to the left, right and middle positions. The total glance duration and count for different mobile phone positions are shown in *Figure 6*.

Fixation duration and count

The minimum values for fixation duration values were observed for the middle mobile phone position (M = 17.32, SD = 6.82). A repeated measures ANOVA of different positions revealed that total fixation duration differed significantly between the positions of mobile phones (F (3, 87) = 16.122, $p < 0.05$, $\eta^2 = 0.357$, large effect size). Post hoc test with Bonferroni correction determined that the total fixation duration was significantly higher for mobile phones placed at the front as compared with left ($p = 0.005$), right ($p < 0.01$) and middle ($p < 0.01$).

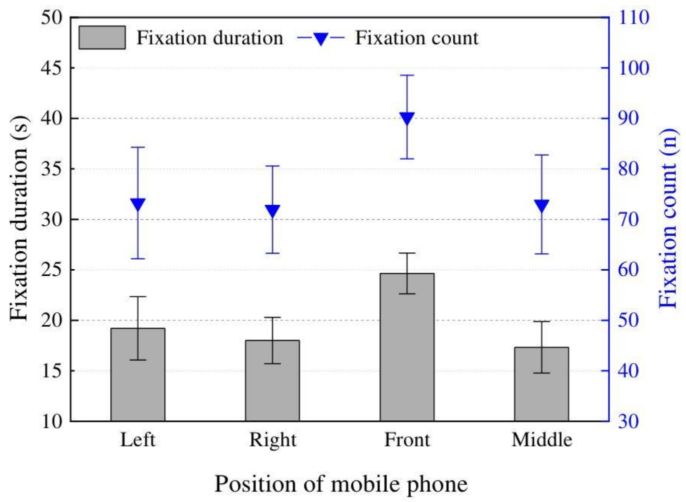

Figure 7 – Fixation duration and count at different mobile phone positions

The least fixation count was recorded for the right mobile phone position (M = 71.93, SD = 23.15). A repeated measures ANOVA with Greenhouse-Geisser correction revealed that the position of the mobile phone had a significant main effect on fixation count (F (2.503, 72.594) = 7.287, $p < 0.05$, $\eta^2 = 0.201$, large effect size), while post hoc test with Bonferroni correction showed that the fixation counts for the front position of mobile phone are significantly higher than left (p = 0.019), right ($p < 0.01$) and middle (p = 0.008) positions of mobile phone. Fixation duration and count for different mobile phone positions are shown in *Figure 7*.

Total eye-off-road time (TEORT)

The middle mobile phone position recorded the minimum value of TEORT (M = 25.78 s). A repeated measures ANOVA with Greenhouse-Geisser correction revealed that mobile phone position had a statistically significant effect on TEORT (F (2.508, 72.73) = 8.935, $p < 0.05$, $\eta^2 = 0.236$, large effect size). A post hoc test with Bonferroni correction revealed that TEORT was significantly higher for front than left, right and middle ($p < 0.05$) positions of mobile phones. The graph showing total eye-off-road time (TEORT) is shown in *Figure 8*. For mean eye-off-road-time, a log transformation was performed on the data set to make them normal. A repeated measured ANOVA revealed that mobile phone position did not have a statistically significant effect on the mean eye-off road time (F (3, 87) = 1.974, p = 0.124, $\eta^2 = 0.064$, low effect size).

3.3 Subjective workload assessment

The subjective workload measured using DALI was minimum for the baseline task (M = 23.33), and maximum for the middle mobile phone position (M = 40.97). A repeated measures ANOVA revealed that the position of the mobile phone had a statistically significant effect on the subjective workload ratings (F (4, 116) = 61.14, $p < 0.05$, $\eta^2 = 0.678$, large effect size). A post hoc test revealed that the baseline driving condition was significantly different from left, right, front and middle ($p < 0.05$). In addition, the front position was found to be significantly different from baseline, left, right and middle ($p < 0.05$).

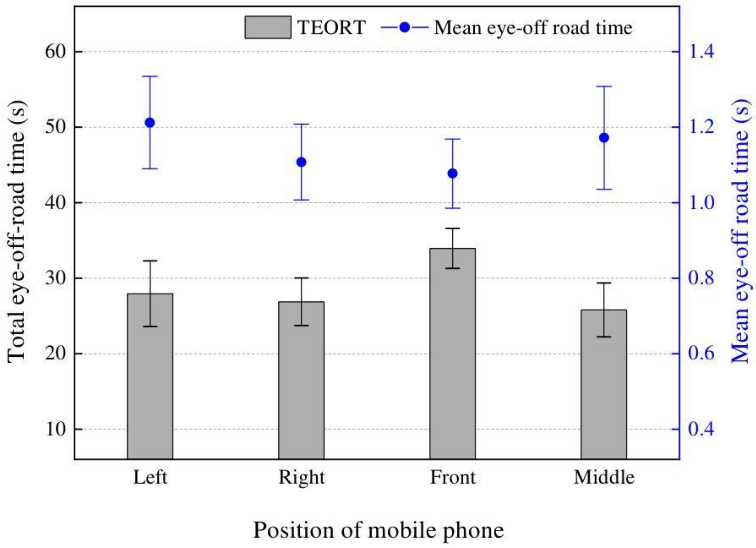

Figure 8 – Total and mean eye-off-road time at different mobile phone positions

The graph showing the DALI subjective assessment is shown in *Figure 9*. The individual sub-scales of DALI for different test conditions are shown in *Figure 10*. The mean values of the DALI sub-scale for different driving conditions are given in *Table 5*.

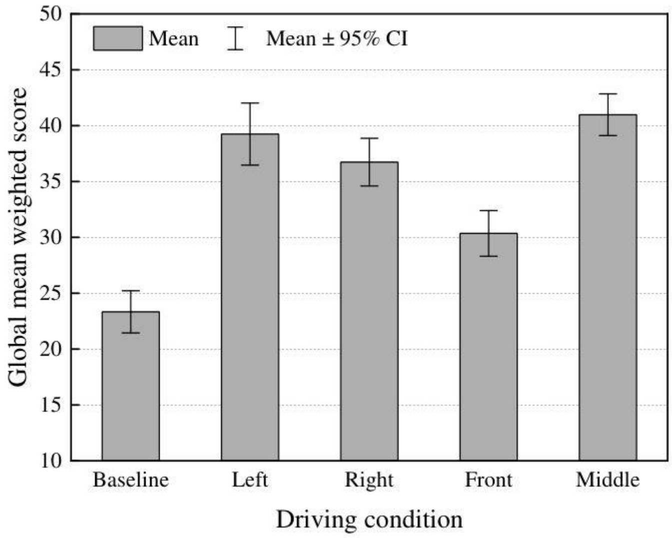

Figure 9 – DALI subjective assessment scores

Table 5 – Mean DALI scores for each task condition

Dimensions	**Test conditions**				
	Baseline	**Left**	**Right**	**Front**	**Middle**
Attentional	54.98	70.80	64.53	61.20	67.73
Visual	58.40	55.60	50.40	49.33	57.33
Auditory	04.00	06.93	09.20	01.33	08.67
Stress	11.87	34.40	32.40	21.73	36.53
Temporal	10.00	24.93	19.20	14.93	24.00
Interference	00.80	42.80	44.67	33.60	51.60

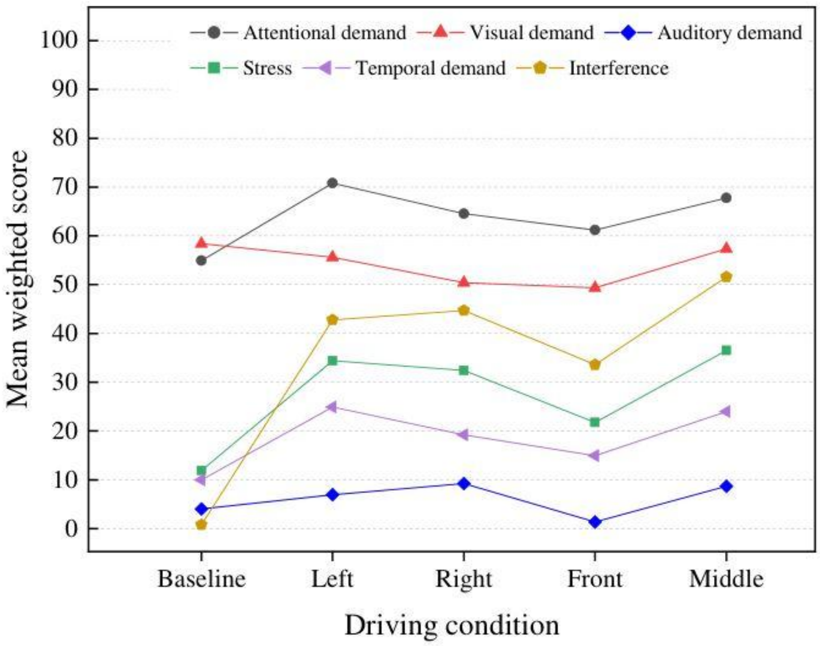

Figure 10 – Sub-scales of DALI for driving conditions

4. DISCUSSION

In the present study, we empirically examined the influence of in-vehicle mobile phone positions on driving performance and the drivers' visual behaviour. The participants performed a visual-manual task on the mobile phone and a driving task in a simulated environment. The driving performance results were interpreted in terms of the mean deviation in lane change (M.Dev) and lane change errors. A smaller value of M.Dev indicates a good lane-keeping (better driving) performance as compared to a larger value, which indicates poor lane-keeping (poor driving) [28, 41]. The best values resulted during the baseline (only driving) session when compared to all the other driving scenarios, whereas the worst values were recorded when the mobile phone was placed in the middle (dual-task) of the steering wheel. When inspecting the dual-task sessions, the values of M.Dev were better for mobile phones placed at the front when compared to other dual-task scenarios. Previous studies conducted by Burns et al. [27]; Harbluk et al. [28]; Young, Lenn´e and Williamson [42] have shown that mean deviation values were smaller for cognitively and visually easier tasks compared to difficult tasks. The lane excursions (lane-change error) for dual-task driving were higher for the middle and left positions, whereas the minimum for the front position, indicating that better driving performance was achieved for the front and worst for the middle mobile phone positions. It is important to note that the mobile phone placed on the left is the farthest from the normal line of sight, and for looking at the middle position, drivers have to shift their attention from the driving scene to the mobile phone. Thus, in terms of driving performance, we can say that the mobile phone positions at the front gave better results than others.

Further, observing the visual behaviour interpreted in terms of the eye-movement measures (fixation, glance and TEORT), we note that eye-movement measures were significantly affected by the in-vehicle mobile phone position.

The glance duration was most prolonged for the front and smallest for the middle position. Apart from the front and middle positions, the left position was the farthest, and the right was the nearest to the normal line of sight horizontally. The hypothesis that the farther the position of the mobile phone away from the normal line of sight the longer is the eye-off-road time holds for left and right positions. Thus, the glance duration values were higher for left than right, but no significant difference was observed. On the contrary, with the mobile phone at the front position, the subjects may still use their peripheral vision to observe the on-road scene. Studies by Summala, Lamble and Laakso [43] show that drivers use peripheral vision for lane and distance-keeping. Thus, using the peripheral vision for on-road monitoring, the drivers tend to spend more time off-road and still maintain better lanes. This argument holds for the front position where we observe a better mean deviation value and a longer glance and eye-off road time. Similar conclusions were also drawn in the studies of Dukic et al. [44], where the button location closer to the normal line of sight resulted in longer eye-off-road time. In the case of a mobile phone in the middle position, the hypothesis mentioned above does not hold since it is farthest from the normal line of sight, located at the centre of the steering wheel, and still has the shortest total eye-off-road time. A potential explanation for this result could be the driver's perception of risk. If the drivers have to look at the middle position at the steering wheel's centre, they have to flex their neck, and they cannot use their peripheral vision to monitor the on-road scenario. This implies that the drivers consider the middle position as dangerous since they cannot look at the on-road situation and are impaired in their motion-detecting capabilities. Hence, they try to keep the visual off-road time to a minimum. Similar arguments were also given in the studies conducted by Dukic et al. [44], for a button located near the gearbox, showing a shorter eye-off-road time.

The fixation duration for the middle mobile phone position was found to be a minimum at 17.32 s, whereas the fixation count was 72.97. The longest fixation duration was recorded for the front mobile phone position. This can be explained because, while looking at the front position, drivers were able to monitor the on-road scenario with their peripheral vision and thus fixated for a longer duration at the front mobile phone position, which was the opposite in the case of the middle position. Similar results were also observed in the studies of Čegovnik et al. [45], where the fixation duration decreased with the presence of increased cognitive load. Similarly, a study conducted by Scialfa et al. [33], which examined the effect of a cellular phone conversation on the search of a traffic sign, also reported a reduction in fixation duration as the complexity/clutter increased.

The DALI subjective workload rating score shows that the baseline task had the lowest workload score compared to the dual-task driving conditions. Among the dual-task driving conditions, the front position had the lowest workload compared to the middle position, which exhibited the highest workload. The above results could be justified because, for performing tasks in the middle mobile phone position, drivers have to continuously shift their attention from the forward on-road view to the mobile phone located at the centre of the steering wheel. Whereas, for the front position, the drivers did not have to move their heads and performed their tasks without the fear of performing any driving error, hence resulting in a lesser workload score.

Studies conducted by Pauzi´e [36], have also shown higher DALI global workload scores for complex guidance systems than the human co-pilot. Similarly, studies by Kim and Wohn [46] also showed higher DALI workload values for an augmented reality navigation system than map navigation. Thus, concluding that a highly demanding session/situation corresponds to a higher value of DALI.

Observing the details of individual DALI factors, it was noticed that a higher value of 'interference' was registered for the middle position compared to other dual-task conditions since the mobile phone interfered in the unobstructed functioning of the steering wheel. 'Stress' was also rated high for middle positions as compared to other dual-task driving conditions. If we arrange the sub-scales according to their impact on dual-task driving, it was observed that attention and visual demands were highly rated. In contrast, temporal and auditory demands were rated low for each of the dual-task conditions. Thus, according to the results of the present study, the in-vehicle mobile phone position at the front seems to be the most suitable in terms of better driving performance and a lesser amount of driving workload as compared to other dual-task conditions in the study.

4.1 Limitations

The present study has the following limitations:

- The experiment was conducted on a fixed-base driving simulator in a simulated laboratory environment. The drivers are less critical about their driving since an error/fault will not lead to an accident. A study conducted in an instrumented vehicle may have produced different outcomes.
- The empirical study did not consider drivers' characteristics (age, gender, comfort and skill of driving the simulator, driving experience), environmental characteristics (road condition (rural/urban), traffic (high/low)) and vehicle characteristics (right/left-hand drive, type of vehicle).
- Although the researchers have taken the utmost care to match the experimental conditions (position of the mobile phone) with the real-world scenario, an accurate resemblance may not have been achieved.
- In the present study, DALI was used to measure workload, however, in the real environment, the driver's workload may also be affected by psycho-social and organisational factors/policies (e.g. targets, incentives).

5. CONCLUSION

In this study, we conducted a driving simulator-based experiment to examine the effect of in-vehicle mobile phone position on driving performance and the visual behaviour of the drivers. Results showed that the in-vehicle mobile phone position had a statistically significant effect on drivers' driving performance and visual behaviour. Placing mobile phones at a smaller visual angle from the normal line-of-sight resulted in better driving performance and lesser driving workload scores. However, the drivers' glance and fixation duration increased, and they spent more time performing tasks on mobile phones because they felt safer compared to other in-vehicle mobile phone positions. Hence, it is concluded that by keeping the in-vehicle mobile phone at the front position, the drivers were able to perform secondary tasks on the mobile phone (when required) along with the primary task (driving), without degrading their driving performance.

This study's observations can be utilised by policy-makers and taxi rental companies to formulate guidelines for better and safer use of in-vehicle mobile phones. The knowledge gained from the study about visual and driving behaviour could be used by the designers and the ergonomics team to develop safer and user-friendly in-vehicle displays. Additionally, the industrial designers can also use the knowledge to design mobile holders/spaces integrated with the dashboard, keeping in mind smaller visual angles for safety and usability (to guide the driver to place the mobile device in the correct position).

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इंद्रेश कुमार वर्मा, बिघना कल्याण नायक, सौगता कर्माकर

मोबाइल फोन की स्थिति का दृश्य और ड्राइविंग व्यवहार पर प्रभाव: लेन परिवर्तन परीक्षण आधारित अध्ययन

अमूर्त
इस अध्ययन का उद्देश्य ड्राइवरों के ड्राइविंग प्रदर्शन और दृश्य व्यवहार पर नेविगेशन उद्देश्य के लिए उपयोग किए जाने वाले मोबाइल फोन की स्थिति के प्रभाव की जांच करना है। हाल के दिनों में प्रौद्योगिकी की प्रगति के साथ, ड्राइवर नेविगेशन के लिए मोबाइल-फोन एप्लिकेशन का उपयोग करते हैं। पिछले अध्ययनों से पता चला है कि ड्राइवर वाहन में मोबाइल फोन को अपनी पसंद के अनुसार विभिन्न स्थानों पर रखते हैं। यह व्यवहार उनके ड्राइविंग प्रदर्शन और दृश्य व्यवहार को गंभीर रूप से प्रभावित कर सकता है। सिम्युलेटेड ड्राइविंग वातावरण में ड्राइविंग करते समय तीस ड्राइवरों ने डैशबोर्ड के चारों ओर विभिन्न स्थानों (बाएं, दाएं, सामने और स्टीयरिंग व्हील के मध्य) पर स्थित मोबाइल-फोन पर दृश्य-मैनुअल कार्य किए। लेन चेंज टेस्ट (एलसीटी) ने ड्राइविंग व्यवहार का आकलन किया,

और आई-ट्रैकर ने दृश्य व्यवहार को मापा। एलसीटी के नतीजे से पता चला कि स्टीयरिंग व्हील के सामने स्थित मोबाइल फोन के लिए सबसे अच्छा ड्राइविंग प्रदर्शन हासिल किया गया था। व्यक्तिपरक कार्यभार रेटिंग स्कोर उच्चतम था, और मध्य मोबाइल फोन की स्थिति के लिए ड्राइविंग प्रदर्शन सबसे खराब था। इस अध्ययन के निष्कर्षों से पता चलता है कि वाहन में मोबाइल फोन की स्थिति का ड्राइवरों के ड्राइविंग प्रदर्शन और दृश्य व्यवहार पर महत्वपूर्ण प्रभाव पड़ता है। प्राप्त अंतर्दृष्टि विशेष रूप से पेशेवर ड्राइवरों और सामान्य रूप से अन्य लोगों के लिए मानक संचालन प्रक्रिया का मसौदा तैयार करने में उपयोगी हो सकती है।

कीवर्ड

चालक का ध्यान भटकाना; लेन चेंज टेस्ट (एलसीटी); दृश्य व्यवहार; ड्राइविंग गतिविधि लोड इंडेक्स (DALI); नज़र अवधि; आँख ट्रैकिंग