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Effects of E-Mirror Location and Size and Lane Change Direction on Lane Change Time, Eye-Off-Road Time, Mental Workload, and Preference

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ABSTRACT Electronic mirrors (E-mirrors) are camera-based mirrorless systems that have been considered as an alternative to conventional automotive rear-view mirrors. E-mirror location and size need to be carefully determined to provide safe and preferred driving conditions. This study examined the effects of E-mirror location, E-mirror size, and lane-change direction on lane change time, eye-off-road (EOR) time, mental workload, and preference. In a fixed-base driving simulator, a total of 20 individuals (mean (SD) age = 24.7 (2.2) years) performed lane-change maneuvers under 12 different E-mirror configurations, comprising 4 E-mirror locations × 3 screen heights (6, 8, and 9.7 cm; width-to-height aspect ratios = 16:9). E-mirror location significantly affected EOR time, mental workload, and preference, whereas E-mirror size significantly affected preference only. Lane-change direction significantly affected lane change time, EOR time, and mental workload, with right lane change maneuvers demanding more time and mental workload. Considering the EOR time, mental workload, and preference, E-mirrors 8 cm high or higher should be positioned near the sides of the steering wheel or the bottom of the front inner pillars. The relevance of these findings to ergonomic design guidelines is discussed.

INDEX TERMS Ergonomics, human–computer interaction, human factors, product design.

I. INTRODUCTION

Drivers' accurate and rapid perception of their side and rear traffic situations through automotive outside and inside rear-view mirrors is essential for lane changing, merging, and passing [1]. According to Traffic Safety Facts by National Highway Traffic Safety Administration (NHTSA) [2], 6.1% of all crashes, 3.4% of the fatal crashes, and 3.8% of injury-involved crashes in the USA in 2018 resulted from lane changing, merging, or passing another vehicle. Thus, drivers could benefit from enhanced awareness of their side and rear traffic situations. For this purpose, improving current automotive mirrors or replacing them with new systems should be considered.

Although planar and nonplanar (convex and aspherical) mirrors are used for outside mirrors [3], all these reflection-based optical outside mirrors suffer limitations. Compared to nonplanar mirrors, planar mirrors provide a relatively large mirror image (closer to the actual size of the object), help accurately estimate inter-vehicular distance and speed, and provide a less distorted mirror image, but provide a narrower field of view and larger blind spots [3], [4]. Furthermore, being located outside of the vehicle, current outside mirrors, regardless of whether they are planar or nonplanar, have common problems such as night glare [5], poor visibility in bad weather [6], and increased air resistance [5]. Moreover,

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the locations of current outside mirrors inevitably require excessive neck rotation and eye gaze behavior [7], and are not free from blind spots [8], potentially leading to unsafe driving conditions (e.g., missing critical events). Compared to the driver-side outside mirror, the passenger-side outside mirror provides poor visibility and distance perception [9], and is thus less likely to be useful during lane changes. Indeed, drivers more heavily rely on the inside rear-view mirror than the passenger-side outside mirror, according to Robinson, Erickson, Thurston, and Clark [10] as cited in Finnegan and Green [11] (i.e., looking at the inside rear-view mirror 16.3 times more than the passenger-side outside mirror during a right lane-change in the USA.; 49% vs. 3%).

To overcome the above drawbacks of current outside mirrors, a new system called the camera monitor system (CMS), camera-monitor combination [12], or E-mirror [13] has been proposed to remove optical mirrors and instead provide camera-acquired images on in-vehicle displays. In-vehicle E-mirror displays are less susceptible to inclement weather conditions [14], reduce the required neck rotation range [7], and decrease eye-off-road time [15], air resistance, and glare at night [5]. Some concept cars and commercial vehicles have installed E-mirrors at different locations – on top of the center stack, above the front door armrests (Audi E-Tron, Volkswagen XL1, Hyundai Ioniq5), at the locations of conventional inside rear-view mirrors (BMW i8), and at the side ends of the dashboard top (Honda E). Compared to other positions, E-mirrors located on top of the center stack are easier to view because their locations are closer to the driver's normal line of sight when looking at the road ahead, but at the same time this area becomes visually cluttered, increasing driver workload and generating more mirror-to-mirror transitions [14]. When integrated into the front door or located on the side ends of the dashboard, E-mirrors are positioned closer to the conventional outside mirrors, likely facilitating a positive transfer of learning and a natural spatial mapping between the actual traffic and the E-mirror-provided traffic image. Furthermore, positioning E-mirrors in these locations makes the driver's forward field of view less cluttered.

Previous studies of E-mirror location reported the beneficial effects of E-mirrors on decision-making time, eye-off-road (EOR) time, workload, preference, and perceived safety, yet their recommended E-mirror locations studies are inconsistent. Ali and Bazilah [7] reworked an actual car and installed E-mirrors at the side ends of the dashboard. Compared to conventional side mirrors, their E-mirrors improved the field of view, distance estimation, and visibility at night. A driving simulator study by Large *et al.* [14] evaluated five E-mirror locations. Decision time and EOR time were reduced with E-mirrors installed on the center console or at conventional locations, and E-mirrors installed at conventional locations were most preferred. Beck *et al.* [15] conducted a driving simulator study to evaluate three different E-mirror locations. The E-mirrors positioned at the dashboard top areas next to the sides of the steering wheel were best in terms of EOR time, response time, workload, preference, and perceived safety. However, in the studies by Large *et al.* [14] and Beck *et al.* [15], the E-mirror images were augmented directly on the forward driving scene image. In this condition, the forward road scene and the scene in the E-mirror require almost identical visual depth, thus potentially reducing otherwise longer ocular accommodation and vergence times between the images. This condition would consequently shorten visual information processing time and response time, potentially leading to inaccurate driving-related performance measures. Thus, inconsistency of the recommended E-mirror locations and involvement of inaccurate visual depth settings in previous studies necessitate an additional investigation of E-mirror location.

Compared to E-mirror location, much less attention has been paid to E-mirror size, even though the field of view in the E-mirror is mostly determined by E-mirror size. Indeed, the above three E-mirror studies [7], [14], [15] considered a single fixed E-mirror size, and did not examine the potential effects of E-mirror size on driver performance, safety, and preference. An exception is a driving simulator-based study by Murata and Kohno [16] that evaluated three E-mirror locations (in front of the steering wheel, around the steering wheel, and at the side mirrors) and two display sizes (6 and 8 inches). In their study, driving and detecting pre-specified vehicles were used as primary and secondary tasks. The beneficial effect of increasing E-mirror size was more evident when E-mirrors were more distant from the driver. Reaction time was reduced with 8-inch E-mirrors located in front of the steering wheel. Although their study considered both E-mirror location and size, locating E-mirrors in front of the steering wheel is not practically feasible as E-mirrors can be partially obscured by the steering wheel, and the front road scene can be partially obscured by the E-mirrors. In addition, the secondary task of detecting pre-specified vehicles (a color matching task between a following car and the reference color) did not require driving-related motor skills (e.g., steering and using pedals). It thus remains necessary to examine the effects of E-mirror location and size simultaneously while considering practically feasible E-mirror locations and sizes as well as representative driving tasks.

The objective of this study is to examine the effects of E-mirror configuration (location and size) and lane-change direction on lane change time, EOR time, mental workload, and preference. Specific hypotheses were that E-mirror configuration and lane-change direction independently or interactively affect lane change time, EOR time, and mental workload, and that E-mirror configuration affects preference.

II. METHODS

A. PARTICIPANTS

Twenty (19 males and 1 female) young individuals with a mean (standard deviation, SD) age of 24.7 (2.2) years participated in this study. This study did not aim to recruit

FIGURE 1. **Experiment environment with E-mirrors positioned near the sides of the steering wheel (ML_2) (top panel) and driving scene taken by the eye-tracking device (orange circle indicates the gaze fixation of a driver; bottom panel).**

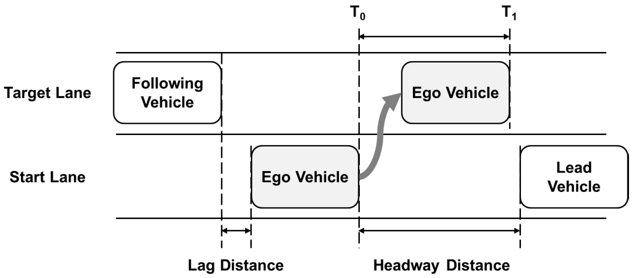


FIGURE 2. **Lane change scenario (T_0: start, T_1: end).**

a gender-balanced group, although each gender was given an equal chance to participate in this study. All participants were recruited from a university population and reported no musculoskeletal diseases. They all had a valid driver license and over 2 years driving experience with a mean (SD) experience of 4.6 (2.0) yrs. Glasses wearers were excluded to measure EOR time using a glasses-type eye-tracking device. This study was approved by a local institutional review board. All of the participants provided written informed consent and were compensated for their time.

B. EXPERIMENT SETTING

A driving simulator (SCANeR^{TM} v1.1, OKTAL, France) was used for the study (Fig. 1). Planned lane changes were considered to be driving tasks ([17]; Fig. 2). The speeds of the ego vehicle and lead vehicle were 70 km/h, and the initial distance headway was 80 m, which was considered as a safe margin for a speed of 80 km/h [18]. The speed of the following vehicle in the target lane was 80 km/h. The initial time-to-collision (TTC) of this car with the ego vehicle was 5.5 s [19], and the TTC time was further programmed to maintain $\geq$2.0 s.

Four dependent variables were considered in this study – lane change time, EOR time, mental workload, and preference. When the distance headway to the lead vehicle was at least 80 m on a straight road, a beep sound signaled the initiation of a lane change (T_0), and a lane change was finished when the ego vehicle moved to the target lane and stayed there for 1 s (T_1). Lane change time (s) was defined as $T_1 - T_0$ (Fig. 2). Eye movement was measured at a sampling rate of 60Hz using a glasses-type eye-tracking device (SMI mobile eye tracking glasses, SensorMotoric Instrument, Germany). EOR time was the time spent not looking at the road ahead during the lane change. The NASA-TLX questionnaire with six items (mental demand, physical demand, temporal demand, performance, effort, and frustration; [20]) was used to assess drivers' mental workload on the original 21-pt (0-100) scales for each lane change trial. Driver preference for each E-mirror configuration was verbally rated on a 5-point scale for the question of "How much do you prefer to use this E-mirror configuration (location and size) over the conventional outside mirrors?" (1: do not prefer this configuration at all, 3: do not prefer this configuration, 5: neutral, 7: prefer this configuration, 9: prefer this configuration the most).

C. EXPERIMENT DESIGN

This study used a 3-way (4 (E-mirror location, ML) ×3 (E-mirror size, MS) × 2 (lane change direction, LD)) factorial design. ML considered the conventional outside mirror locations (as a control condition, ML_1), two E-mirror locations recommended by Beck *et al.* [15] and Large *et al.* [14] (near the sides of the steering wheel (ML_2) and near the bottoms of the front pillars (ML_3)), and the result of a focus group interview (FGI) conducted by the current author that involved 16 drivers (near the tops of the front pillars, ML_4; Table 1). Two 8-inch tablet PCs (Galaxy Tab A 8.0, Samsung Electronics, South Korea) with a 16:9 aspect ratio and 130-nit screen were used for E-mirror displays. MS included 6H (6 cm high; reflecting the mean (SD) height of inside rear-view mirrors (room mirrors) of 5.7 (1.1) cm with the 10th-90th percentiles of 5.1-6.1 cm; [21]), 8H (8 cm; reflecting the mean preferred mirror size (8.5 cm) from the FGI), and 9.7H (9.7 cm; reflecting the 10th-90th percentiles of outside rear-view mirror sizes (10.9-14.9 cm with the mean (SD) of 12.5 (1.5) cm; [21]) as well as considering acceptable forward vision occlusion by E-mirrors (10 cm; the FGI result)). The screen images of 9.7H were truncated for 6H and 8H MSs (i.e., the sizes of the ego-vehicle image were identical across three MSs). Both left (L) and right (R) lane changes were considered for LD.

TABLE 1. E-mirror location (ML) and size (MS; height (H) × width (W); mm) (ML_1: control condition, ML_2: near the sides of the steering wheel (recommended by Beck *et al.* [15], ML_3: near the bottoms of front inner pillars (recommended by Large *et al.* [14], ML_4: near the tops of front inner pillars).

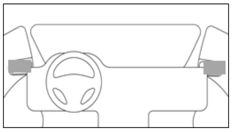
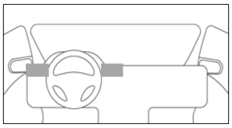
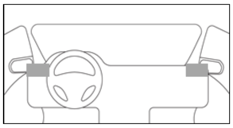
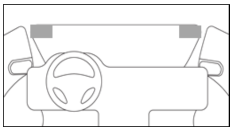
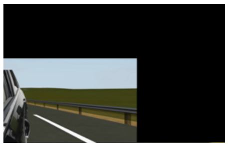
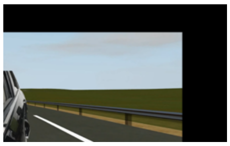
IVs	Level 1	Level 2	Level 3	Level 4
E-mirror Location (ML)	 ML_1	 ML_2	 ML_3	 ML_4
E-mirror Size (MS)	 6H (6H×9.6W)	 8H (8H×12.8W)	 9.7H (9.7H×17.3W)	

TABLE 2. p-values for E-mirror location, size, and lane change direction effects on EOR, mental workload, and preference ($p < 0.05$ underlined).

Treatments		E-mirror Location (ML)	E-mirror Size (MS)	Lane Change Direction (LD)	ML×MS	ML×LD	MS×LD	ML×MS×LD
Lane Change Time	p-value	0.95	0.79	**<.0001**	0.71	0.62	0.19	0.96
	partial η^2	0.001	0.001	0.156	0.009	0.004	0.008	0.004
	F ratio	$F_{3,428}=0.111$	$F_{2,429}=0.236$	$F_{1,430}=79.510$	$F_{6,420}=0.625$	$F_{3,424}=0.587$	$F_{2,426}=1.673$	$F_{6,404}=0.239$
EOR	p-value	**<0.0001**	0.48	**<0.0001**	0.74	0.81	0.66	0.59
	partial η^2	0.037	0.002	0.005	0.036	0.001	0.001	0.006
	F ratio	$F_{3,428}=5.580$	$F_{2,429}=0.438$	$F_{1,430}=0.348$	$F_{6,420}=16.083$	$F_{3,424}=0.189$	$F_{2,426}=0.246$	$F_{6,404}=0.461$
Mental Workload	p-value	**0.001**	0.35	**0.032**	0.22	**0.017**	0.95	0.99
	partial η^2	0.019	0.003	0.01	0.005	0.012	0.0001	0.001
	F ratio	$F_{3,428}=2.825$	$F_{2,429}=0.543$	$F_{1,430}=0.711$	$F_{6,420}=2.369$	$F_{3,424}=1.778$	$F_{2,426}=0.028$	$F_{6,404}=0.086$
Preference	p-value	**<0.0001**	**0.004**	-	0.85	-	-	-
	partial η^2	0.073	0.034	-	0.008	-	-	-
	F ratio	$F_{3,212}=5.996$	$F_{2,213}=4.045$	-	$F_{6,204}=0.320$	-	-	-

D. EXPERIMENTAL PROCEDURE

After being informed of the E-mirror concept, participants practiced simulated driving until they were familiar with all 12 E-mirror configurations (treatments). For each configuration, each participant made left and right lane changes while their eye movement was recorded. Mental workload was rated for each lane change trial, whereas preference was rated for each configuration considering both left and right lane change tasks. The total number of lane change maneuvers was thus 24 per participant, which took approximately 1.5 h per participant.

E. DATA ANALYSIS

Three-way analysis of variance (ANOVA) was used to analyze the main and interaction effect of ML, MS, and LD on lane change time, EOR, and mental workload, and two-way ANOVA was used to analyze the main and interaction effect of ML and MS on preference. When a main or interaction effect was significant, Tukey's honestly significant difference (HSD) test was used for post hoc pairwise comparison. Effect sizes were categorized as low, medium, and high when the partial eta squared was ≥ 0.01, 0.06, and 0.14, respectively [31], [32]. JMP^{TM} (v14, SAS Institute Inc., NC, USA) was used for all statistical analyses and significance was concluded when $p < 0.05$.

III. RESULTS

This section describes the results of three-way ANOVA for the main and interaction effects of ML, MS, and LD on lane change time, EOR, and mental workload, and two-way ANOVA for the main and interaction effects of ML and MS on preference (Table 2).

A. ML × LD INTERACTION EFFECTS

The interaction effect of ML × LD on mental workload was significant (p-value = 0.017; Table 2). A post-hoc test showed that the eight ML × LD treatments were split into two groups (Fig. 3). The mean mental workload (SE; Standard Error) was lowest for $ML_3 \times LD_L$ (34.7 (0.55)) and highest for $ML_4 \times LD_R$ (46.9 (0.39)) (Fig. 3).

B. ML EFFECTS

The effect of ML on EOR was significant (p-value < 0.0001; Table 2). The ML levels were split into two

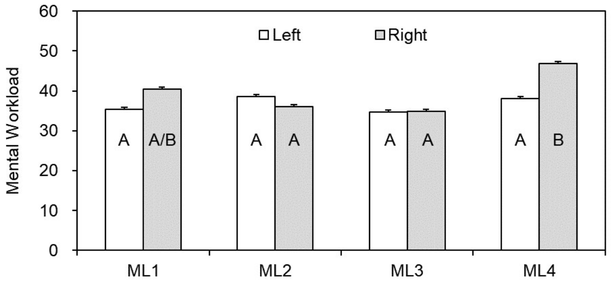


FIGURE 3. Effects of E-mirror location (ML) × lane change direction (L/R) on mental workload; A-B inside bars denote HSD grouping; error bars indicate SEs; SE range = 0.45-0.59.

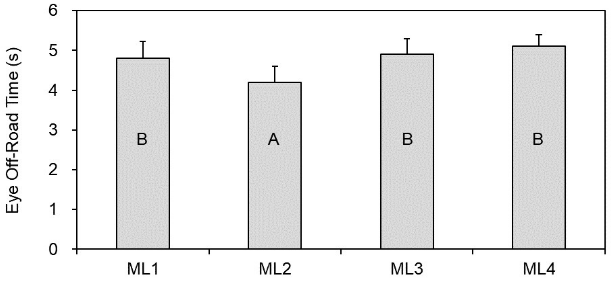


FIGURE 4. Effects of E-mirror location (ML) on eye off-road time; A-B inside bars denote HSD grouping; error bars indicate SEs; SE range = 0.31-0.42.

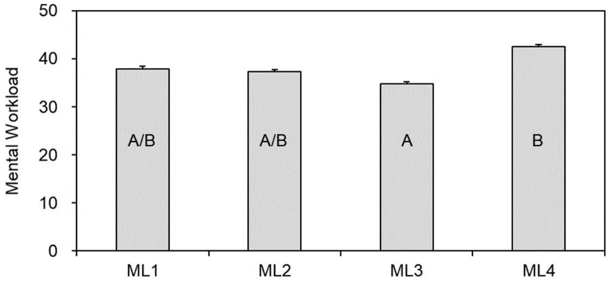


FIGURE 5. Effects of E-mirror location (ML) on mental workload; A-B inside bars denote HSD grouping; error bars indicate SEs; SE range = 0.52-0.55.

groups (ML_2 and ML_1-ML_3-ML_4; Fig. 4). The mean EOR time (SE) was shortest for ML_2 (4.2 (0.36) s) and longest for ML_4 (5.1 (0.31) s).

The effect of ML on mental workload was significant (p-value = 0.001; Table 2). The ML levels were split into two groups (ML_3-ML_2-ML_1 and ML_2-ML_1-ML_4; Fig. 5). The mean workload (SE) was lowest for ML_3 (34.8 (0.52)) and highest for ML_4 (42.5 (0.52)).

The effect of ML on preference was significant (p-value < 0.0001; Table 2). The ML levels were split into two groups (ML_2-ML_3-ML_1 and ML_4; Fig. 6). The mean preference (SE) was highest for ML_2 (6.1 (0.30)) and lowest for ML_4 (4.6 (0.46)).

C. MS EFFECTS

The effect of MS on preference was significant (p-value = 0.004; Table 2). The MS levels were split into two groups

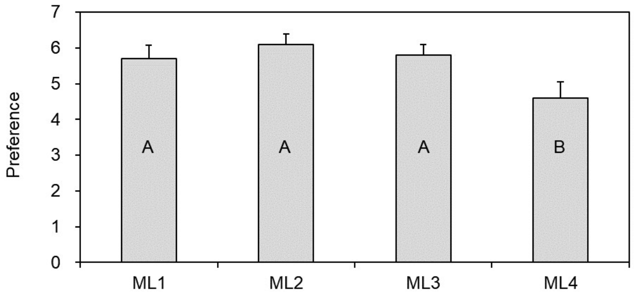


FIGURE 6. Effects of E-mirror location (ML) on preference; A-B inside bars denote HSD grouping; error bars indicate SEs; SE range = 0.29-0.46.

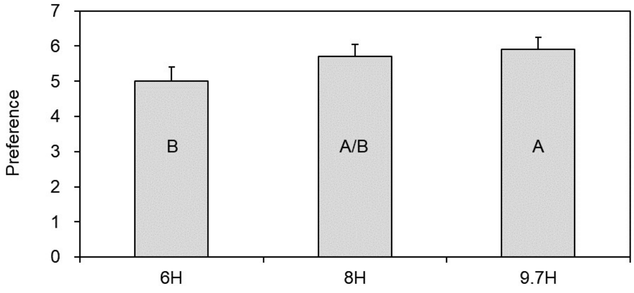


FIGURE 7. Effects of E-mirror size (MS) on preference; A-B inside bars denote HSD grouping; error bars indicate SEs; SE range = 0.35-0.40.

(9.7H-8H and 8H-6H; Fig. 7). The mean preference (SE) was highest for 9.7H (5.9 (0.36)) and lowest for 6H (5.0 (0.40)).

D. LD EFFECTS

The effect of LD was significant for lane change time (p-value < 0.0001; Table 2). The mean lane change time (SE) was shorter for LD_L (7.3 (0.10)) than for LD_R (8.5 (0.09)). The effect of LD on EOR was significant (p-value < 0.0001; Table 2). The mean EOR time (SE) was shorter for LD_L (4.4 (0.36) s) than for LD_R (5.1 (0.33) s). The effect of LD was significant for mental workload (p-value = 0.032; Table 2). The mean workload (SE) was lower for LD_L (36.6 (0.56)) than for LD_R (39.6 (0.52)).

IV. DISCUSSION

This section describes the effects of E-mirror location and size and lane change direction on lane change time, EOR time, mental workload, and preference for E-mirror configuration. The results of the current and previous studies are compared and interpreted, followed by the limitations of the current study.

A. OVERALL EFFECTS

The effects of ML on EOR time, mental workload, and preference were all significant, whereas the effect of MS was significant for preference only. The effect of LD was significant for lane change time, EOR time, and mental workload. Moreover, the interaction effect of ML × LD on the mental workload was significant.

B. ML × LD INTERACTION EFFECTS

Mental workload was highest for $ML_4 \times LD_R$ (second highest for $ML_1 \times LD_R$). Murata and Kohno [16] showed that E-mirrors around the steering wheel decreased neck movement and increased the perceived display visibility. The passenger-side E-mirrors of ML_1 and ML_4 were positioned distant from the driver's eyes. Here, although the passenger-side E-mirror of ML_4 was closer than the passenger-side E-mirror of ML_3, $ML_4 \times LD_R$ required a 13.8% higher mental workload than $ML_3 \times LD_R$, which seems to be related to the vertical position of the E-mirror. Indeed, more effort is involved in vertical vs. horizontal eye movement [22] and there is a more detrimental effect in vertical vs. horizontal eccentricity [23]. Similarly, perceptually smaller display size and lower display brightness could explain a higher workload for $ML_1 \times LD_R$ compared with $ML_3 \times LD_R$.

C. ML EFFECTS

ML_2 showed the shortest EOR time and the highest preference. Although ML_2, ML_3, and ML_1 were in the same group, ML_3 required 6.7% lower mental workload compared to ML_2. Spatial mapping appears to be more natural with ML_3 because the right E-mirror of ML_3 (vs. ML_2) is closer to the right lane. However, it does not explain the fact that ML_1 (conventional location) showed a higher mental workload than ML_3, which can again be explained by the smaller apparent size of the passenger-side E-mirror of ML_1 vs. ML_3.

D. MS EFFECTS

The size of the E-mirror significantly affected preference only. Preference increased with screen size. Moreover, although not significant, EOR time decreased as the display size increased (6H: 4.9s, 8H: 4.7s, 9.7H: 4.6s) in the current study. As a 0.1s decrease in EOR time is practically meaningful for driving safety (e.g., more distance headway), larger E-mirror sizes appear to be more desirable and should be adopted whenever possible. Similarly, in a study by Murata and Kohno [16], compared to the 6-in E-mirror, the 8-in display provided a significantly shorter mean reaction time.

E. LD EFFECTS

Changing to the right lane (LD_R) showed a longer lane change time, a longer EOR time, and a higher mental workload compared to changing to the left lane (LD_L). Several factors appear to have contributed to these results. In the case of LD_R, the target lane and passenger-side E-mirror are more distant from the driver, leading to a decrease in the perceived display size (or display field of view) and brightness.

F. OTHER CONSIDERATIONS

Wierwille *et al.* [1] compared three types of outside mirrors (planar, convex, and aspheric) in terms of human factors-related issues (e.g., field of view, blind spot reduction, distance perception, binocular disparity, distortion, gap acceptance, adaptation/acceptance, response time, older and younger driver differences) and identified the merits and demerits of each mirror type. Here, E-mirrors are compared with conventional outside mirrors in terms of the above ergonomic issues. It should be noted that it is necessary to verify the below arguments in future studies.

1) Field of view: Compared to conventional outside mirrors, E-mirrors can provide a wider field of view (by using larger displays, shrinking images, processing camera-acquired images to make the images similar to those in convex or aspheric mirrors, or combining all or some of these).
2) Blind spot reduction: Compared to conventional outside mirrors, E-mirrors can reduce blind spots (by using larger displays, shrinking images, processing camera-taken images to make the images similar to those in convex or aspheric mirrors, or combining all or some of these).
3) Distance perception, binocular disparity, distortion, and gap acceptance: E-mirrors can be made comparable to conventional planar mirrors in terms of distance perception, binocular disparity, image distortion, and gap acceptance by processing camera-acquired images.
4) Adaptation/acceptance: Drivers are expected to easily adapt to E-mirrors and accept E-mirrors, especially when the E-mirror configuration is spatially compatible (e.g., ML_2 and ML_3).
5) Response time: E-mirrors can provide faster response time than conventional outside mirrors by providing larger images and/or being positioned closer to the driver's forward line of sight.
6) Older and younger driver differences: As older drivers made fewer detection mistakes with planar mirrors than with convex mirrors (the opposite was true for younger drivers; [1]), it may be beneficial to provide differently processed E-mirror images according to driver age (planar images for older drivers and convex images for younger drivers).

G. LIMITATIONS & FUTURE STUDIES

This study encountered some limitations that should be addressed in future studies. First, only younger drivers (20-39 years old) were considered. Older drivers are more likely to suffer from musculoskeletal disorders [24], [25], and have a reduced capacity on average for movement and color recognition [26], [27]. These age-related changes can affect E-mirror configuration-related performance and preference. However, it would be very challenging to use the elderly as subjects for driving-simulator studies, e.g., due to age-related adaptation deficits and vulnerability to simulator sickness [33]. Second, this study used a driving simulator. An actual on-road study is thus necessary to validate the findings of this study. Third, this study considered only a typical large sedan interior design. An expanded study is thus necessary that considers different vehicle segments (e.g., sport utility vehicles, vans, sports cars, and trucks), because the typical interior space of each vehicle segment can affect the feasibility of E-mirror locations and sizes considered in this study. Fourth, curved displays can be considered instead of flat displays for E-mirrors as curved displays can provide more uniform horizontal viewing angles and viewing distance across the screen [28], and display curvature can reduce glares [29] and improve visual performance [28], [30]. Fifth, this study used the same display size for driver-side and passenger-side E-mirrors. It is necessary to examine the effects of providing similar display fields of view and display brightness for both E-mirrors by adopting asymmetric E-mirror size and location relative to the driver (especially for the ML_3 case). Sixth, this study considered lane changes as driving tasks. To determine the generalizability of the E-mirror-related findings of this study, it is necessary to consider other driving tasks that involve glancing at the side mirrors such as driving through intersections [33], merging [1], and passing [1]. Seventh, E-mirror display luminance was fixed at 130 nit in this study. A future study on the preferred E-mirror display brightness for diverse luminance environments is necessary.

V. CONCLUSION

This study examined the effects of E-mirror location and size and lane change direction on lane change time, drivers' EOR time, mental workload, and preference to determine ergonomic E-mirror configurations. A carefully determined E-mirror configuration can outperform conventional outside mirrors in terms of EOR time, mental workload, and preference. Specifically, ML_2 is recommended to reduce the EOR time, whereas ML_2, ML_3, and ML_1 are recommended to reduce the mental workload (the mean mental workload was lowest for ML_3). Moreover, ML_2, ML_3, and ML_1 and E-mirrors $\geq$ 8H are recommended for preference (the mean preference was highest for ML_2 and for 9.7H, respectively). Overall, E-mirrors $\geq$ 8H should be placed at ML_2, while ML_3 can be an acceptable alternative location.

LIST OF ABBREVIATIONS

ANOVA:	analysis of variance.
E-mirrors:	electronic mirrors.
EOR time:	eye-off-road time.
FGI:	focus group interview.
H:	height.
HSD:	honestly significant difference.
LD:	lane change direction.
ML:	E-mirror location.
MS:	E-mirror size.
NHTSA:	National Highway Traffic Safety Administration.
SD:	standard deviation.
SE:	Standard Error.
W:	width

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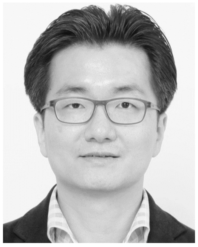

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