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SIMULATOR STUDY ON THE RESPONSE TIME AND DEFENSIVE BEHAVIOR OF DRIVERS IN A CUT-IN SITUATION

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ABSTRACT−The purpose of this study was to record and analyze various reaction times and behaviors of drivers in response to cut-in situations in a driving simulator. A total of 105 male and female volunteers between the age of 20 and 49 participated in an experiment in a driving simulator with an installed eye-tracking system. The participants experienced a scenario in which a vehicle parked on a shoulder unexpectedly cut in while they were driving on a city road. The mean perceived reaction time was 1.05 s with a standard deviation of 0.43 s. The mean brake/steering reaction time after perceiving the danger was 0.59/0.56 s with a standard deviation of 0.40/0.42 s. The influence of age and gender was observed only in the steering reaction time. No interaction effects were found in any reaction times. Approximately half the drivers steered first and then braked to avoid collision. The perceived reaction time in accident cases was longer than in no-accident cases. A rich dataset was established based on the 93 valid participants who completed the experiment, and established database can be used as a look-up table to identify the percentile of a certain cut-in case.

KEY WORDS : Traffic accident, Reaction, Perception, Steering, Braking

1. INTRODUCTION

According to the World Health Organization (WHO), the fatalities from traffic accidents worldwide numbered 1.25 million in 2013 and 1.35 million in 2016 (WHO, 2015; WHO, 2018). In this study, the response times and behavioral characteristics of drivers in response to cut-in/lane changes were investigated; because cut-in/lane changes cause dangerous conditions and have led to many accidents, they should be thoroughly studied.

Traffic accidents caused by lane changes account for approximately 4 to 10 % of all traffic accidents in the European Union; 75 % of these accidents are caused by human factors. (Shan *et al*., 2017). According to the US traffic accident data analyzed by the Santarosa Lawyer Group, 8.5 % of fatal car accidents are caused by veering into another lane; this cause ranks 3rd in the causes of car accidents (Santarosa-Lawyer Group, 2020). According to the National Highway Traffic Safety Administration (NHTSA, 2001), there are between 240,000 and 610,000 reported lane-change crashes every year, which result in 60,000 annual injuries (Zhao *et al*., 2015). In the Republic of Korea, lane-change accidents accounted for 19.8 % of all traffic accidents between 2012 and 2016 (Park *et al*., 2017); this percentage increases each year (Park *et al*., 2017). According to the Dammam traffic police department (Saudi Arabia), between 2009 and 2016, 25.2 % of all traffic accidents were caused by sudden lane changes (Jamal *et al*., 2020).

These data show that cut-in/lane changes by ego or nearby vehicles are a common cause of traffic accidents worldwide. Moreover, according to the 2014 ~ 2015 statistics provided by the Korean Financial Supervisory Service, 2.6 % of all automobile insurance frauds were committed by drivers who intentionally caused traffic accidents via cut-in/lane changes and claimed insurance money (Financial Supervisory Service, 2015). Unfortunately, these automobile insurance fraud cases are becoming increasingly furtive and frequent (Financial Supervisory Service, 2014).

Collecting data related to the driver's response time and behavior during cut-in/lane change situations and constructing a relevant database will help analyze the causes of traffic accidents and determine whether accidents have been caused intentionally. The following section presents some of the most relevant studies that best represent the premise of this study.

1.1. Relatated Research Studies

Benderius *et al*. (2014) studied the steering behavior of truck drivers in cut-in driving scenarios. The 24 participants

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drove at approximately 80 kph in a truck driving simulator, and the researchers compared the steering wheel angles and rates during unexpected and repeated avoidance situations. The drivers generally exhibited the same behaviors in unexpected and repeated situations. More specifically, the researchers focused on the drivers' avoidance reactions to unforeseen situations; for example, the perceived reaction time (PT), which is determined according to the application of the accelerator or brakes, was not analyzed. Moreover, the different dynamics between the trucks and passenger vehicles were considered.

Markkula *et al*. (2016) used the brake reaction time to measure the drivers' PTs. The drivers' deceleration rates increased when the situation became more dangerous. However, the researchers did not evaluate the drivers' reactions to cut-ins or lane changes or investigated other indicators of the PT by, for example, evaluating the steering or acceleration behavior.

McGehee *et al*. (2000) measured the reaction time from various aspects such as the braking, accelerating, and steering behavior. However, they compared the differences between the simulator and test track in an intersection incursion crash scenario and did not analyze the drivers' response times or behavioral characteristics in a cut-in scenario.

Jurecki *et al*. (2014) studied the reaction time difference when a pedestrian suddenly enters from the left and right side in a simulated test environment. The driver's reaction time was 0.05 to 0.35 s longer when the pedestrian entered from the left.

In addition, Choi *et al*. (2017) used a driving simulator to measure the perception–reaction time in a high-speed situation. The researchers used only the brake information to measure the reaction time and conducted the tests at a velocity of 100 kph or higher.

A number of researchers evaluated the drivers' PTs and behaviors during dangerous situations. However, most of them focused only on the basic reaction time for braking. Therefore, in this study, the PTs and behaviors (in particular, the reaction/avoidance behaviors) during cut-in situations in urban areas were investigated. A virtual urban street was constructed for the driving simulator, and the data from 105 male and female test participants between ages of 20 and 49 were collected.

The setup used in our study is similar to that used by Muhrer *et al*. (2012). In both studies, dangerous driving situations were implemented, and drivers' behavior and gaze were acquired using a driving simulator. The difference is that our study focused on the response time and defensive behavior in the cut-in situation, which represents an unexpected event, whereas Muhrer *et al*. (2012) used the repetitive hazard situation to evaluate the Forward Collision Warning System. Moreover, our study has some similarities to Piccinini *et al*.'s study conducted in 2020. They, too, implemented a dangerous situation by using a driving simulator and acquired data on a dependent variable called brake reaction time. However, Piccinini *et al*. (2020) aimed to predict the brake reaction time by comparing cruise control and adaptive cruise control systems.

As previously mentioned, cut-in driving behavior commonly results in traffic accidents worldwide. Because Asia has a fast-growing market, the research results of this study may serve as guidance for the analysis of traffic accidents worldwide. For example, it should be determined whether people react differently in cut-in situations, whether they prefer different behaviors in response to cut-in situations, and what the implications of these differences are. Although directly comparing the research results with those from other countries may be challenging because no replication study was performed, the presented results are generally compatible with those of relevant studies (see the Results section).

2. METHOD

2.1. Experimental Objective and Hypotheses

The primary objective of this study was to build a database of various driver response times and behavioral characteristics regarding cut-in situations. The following hypotheses should be examined with the database.

- H_{RT1}: The drivers' reaction times of different age groups in cut-in driving situations are different.
- H_{RT2}: The drivers' reaction times of the two genders in cut-in driving situations are different.
- H_{RT3}: Age and gender have an interaction effect on the drivers' reactions to cut-in driving situations.
- H_{RB1}: Drivers have a preferred reaction to cut-in driving situations.
- H_{RB2}: The driver's response to cut-in driving depends on his/her age.
- H_{RB3}: The driver's response to cut-in driving depends on his/her gender.
- H_{AC1}: The drivers' reaction times in cut-in driving situations that lead and do not lead to accidents are different.
- H_{AC2}: The drivers' responses to cut-in driving situations that lead and do not lead to accidents are different.

2.2. Experimental Equipment

A driving simulator and eye trackers owned by Kookmin University's Human Vehicle Automation Laboratory were used in the experiment. The full-scale Kookmin University Driving Simulator consists of a real car cabin built on the 2016 modern LF Sonata cabin. Figure 1 presents the external view of the driving simulator. The simulator is operated with a SCANeR studio software-based operating system. Because it has three degrees of freedom (heave, pitch, and roll), vibration effects that vary depending on the speed of the vehicle and type of road surface can be

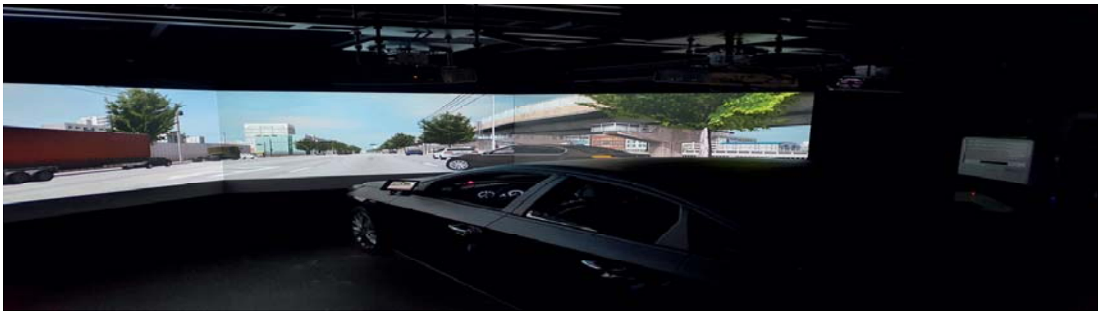

Figure 1. External view of driving simulator.

implemented in addition to the vibration of the starting engine. A camera is installed in the simulator to record video footage of the participant's upper body, the pedal room, and display screen. In addition, the Smart Eye Pro eye tracker tracks the eye movements of the participant; the resulting gaze data are used to measure the PT. In addition, the driver's pedaling force can be measured with the driving simulator. These data are used to set the reference point of the driver's response time.

2.3. Design of Scenario

The cut-in scenarios occurred on a four-lane motorway with two lanes each way, as shown in Figure 2. The participants experienced a scenario in which a vehicle parked on a shoulder suddenly cut into the lane of the participants. According to the 'American Association of State Highway and Transportation Officials (AASHTO)', a brake reaction time of 2.5 s for stopping sight situations encompasses the capabilities of most drivers, including older drivers. The 2.5 s brake reaction time is a geometric design standard for highways and streets (AASHTO, 2011). Therefore, the time-to-collision of the vehicle that cut in from the shoulder was set to 2.5 s. Each participant experienced the cut-in situation twice, at 60 kph and 80 kph. Moreover, the participants could not predict the location of the incident.

2.4. Independent and Dependent Variables

The age groups (20 s, 30 s, and 40 s) and genders (male and female) were used as two independent variables to reflect the demographic characteristics. The various reaction times PT, accelerator release time (ART), perceived brake reaction time (PBRT), and perceived steering reaction time (PSRT) and types of reactive behaviors (ToRB) used to characterize the driver's reaction were dependent variables (see Figure 3). The terms are defined as follows:

Figure 2. Cut-in scenario.

2.4.1. Perceived reaction time (PT)

The PT is defined as the fixation time; it starts at the start of the dangerous situation and ends at the start of the driver's response to the dangerous situation (ISO 15007-1, 2014; Ciceri *et al*., 2013; Recarte and Nunes, 2003).

2.4.2. Accelerator release time (ART)

The ART is the time the participant needs to release completely the foot from the accelerator pedal from the start of the dangerous situation. This parameter is defined in the SAE J2944 Standard (SAE, 2015).

2.4.3. Perceived brake reaction time (PBRT)

The PBRT is the time the participant needs to operate the brake pedal for the first time when he or she perceives the dangerous situation. This parameter is defined in the SAE J2944 Standard (SAE, 2015).

2.4.4. Perceived steering reaction time (PSRT)

The PSRT is the time the participant needs to operate the steering wheel from the moment when the participant perceives the dangerous situation. The steering action must include a rotation of more than 10° at a steering angular speed of more than 15°/s (D'Addario and Donmez, 2019). The PSRT is described in the SAE J2944 Standard (SAE, 2015).

2.4.5. Types of reactive behavior (ToRB)

In this study, the behaviors of the drivers who tried to avoid the dangerous situation were categorized into six types: "no response", "steering only", "braking only", "braking after steering", "steering after braking", and "steering and braking"; "no response" represents the case in which the

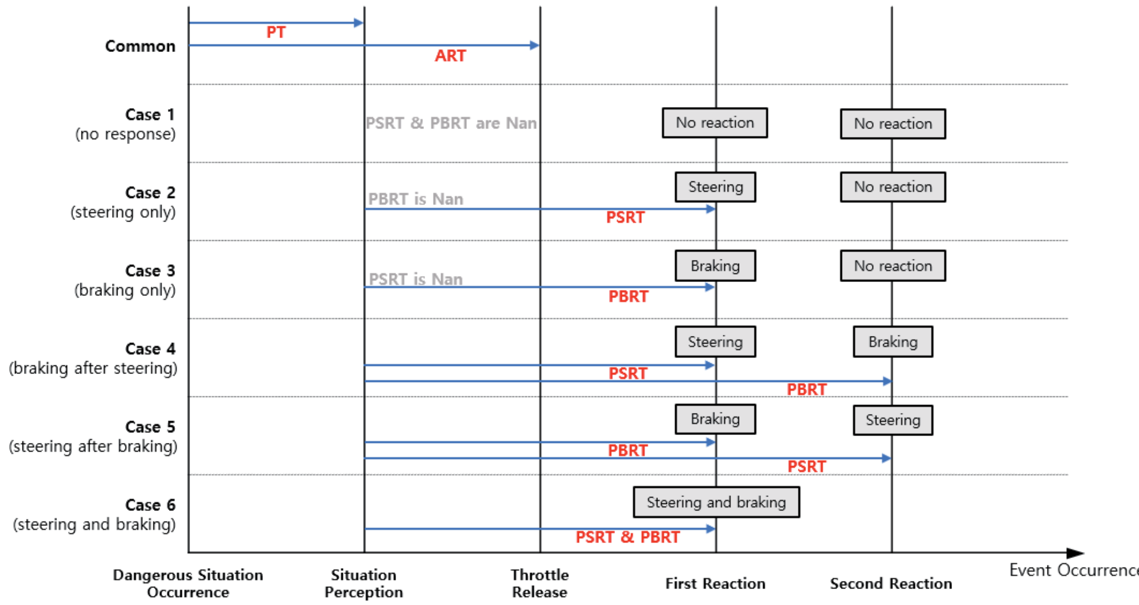

Figure 3. Schematic diagram of dependent variables.

PBRT and PSRT values are not numbers (Nan). The participants only steered when the PBRT value is Nan and a PSRT value exists. The driver used the brake pedal when the PSRT value is Nan and a PBRT value exists. The "braking after steering", "steering after braking", and "steering and braking" actions occurred when both PBRT and PSRT values exist. Finally, the driver steered and braked when the PBRT and PSRT values are identical.

2.5. Experimental Procedure

Before the experiment, a researcher explained the overall content of the experiments to the participants. In the next step, the participants were given time to become familiar with the road and simulator during a practice drive. If they exhibited certain symptoms such as eye fatigue, dizziness, or motion sickness during the experiment, they could immediately take a break or quit the experiment. The experiment consisted of two main experiments, and the participants were instructed to drive at vehicle speeds of 60 kph and 80 kph, respectively. The participants experienced unexpected cut-in scenarios in the two main experiments.

2.6. Participants

The participants must be male or female adults between ages 20 and 49 with a driver's license and actual driving experience of at least one year. To realize smooth PT measurements with the eye tracker, people who were not wearing glasses were recruited. The first experimental group consisted of 15 males and 17 females in their 20 s, the second group consisted of 15 males and 16 females in their 30 s, and the third group consisted of 28 males and 14 females in their 40 s; there were 105 participants in total. Because they experienced motion sickness in the driving simulator during the experiment, one female in her 20 s, one female in her 30 s, and six males and four females in their 40 s withdrew from the experiment. Therefore, 93 participants completed the experiment. Some screenshots of the experimental footage obtained during the experiment are shown in Figure 4. The research complied with the tenets of the Declaration of Helsinki, and was approved by the Institutional Review Board at Kookmin University (KMU-201914-HR-205). Informed consent was obtained from each participant.

3. RESULTS

The vehicle operation input and eye-tracking data of the participant were recorded with the SCANeR studio simulator software. MATLAB 2020a was used to calculate and analyze each driver's response time and behavioral characteristics. In addition, statistical tests such as the two-way ANOVA, t-test, and chi-square tests were performed to evaluate the hypotheses. The significance level of these tests was set to 0.05. The statistics and hypothesis testing results are described in the following sections.

3.1. Driver Response Time: Main and Interaction Effects of Age and Gender (H_{RT1}, H_{RT2}, H_{RT3})

Table 1 lists the number of samples, mean, standard deviation, minimum, 25th percentile, median, 75th percentile, and maximum values of the PT, ART, PBRT, and PSRT for each age group (i.e., 20 s, 30 s, and 40 s). Table 2 shows the same statistics for each gender group. The number of

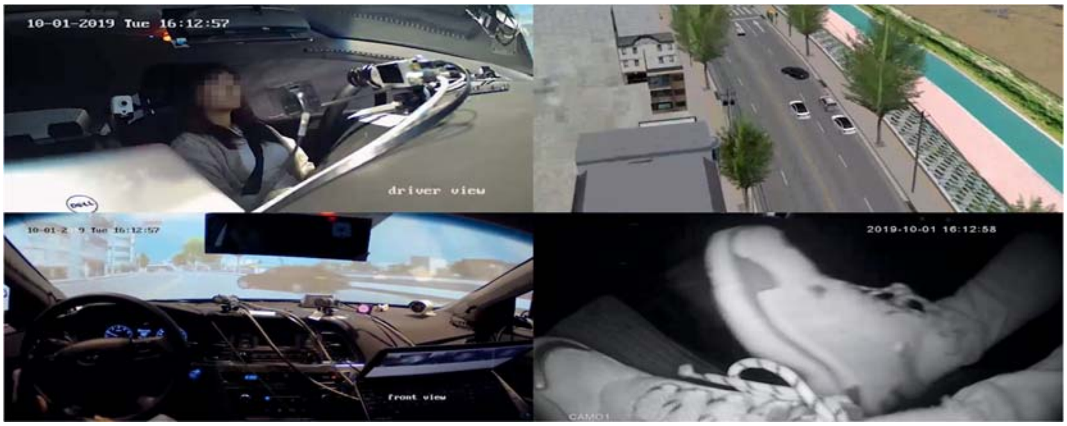

Figure 4. Selected screen shots from Human-in-the-Loop experiment.

Table 1. Selected statistics of PT, ART, PBRT and PSRT for each age group.

Age group		PT	ART	PBRT	PSRT
20 s	sample	62	62	62	62
	mean	1.00	1.35	0.65	0.57
	SD	0.41	0.76	0.40	0.38
	minimum	0	0.05	0.21	0.12
	25th	0.84	1.01	0.36	0.31
	median	1.07	1.3	0.58	0.50
	75th	1.29	1.53	0.67	0.68
	maximum	1.78	4.83	2.22	1.72
30 s	sample	60	60	60	60
	mean	1.00	1.33	0.68	0.69
	SD	0.49	0.33	0.48	0.54
	minimum	0	0.22	0	0.1
	25th	0.79	1.22	0.31	0.29
	median	1.06	1.31	0.58	0.55
	75th	1.41	1.55	0.75	0.98
	maximum	1.75	2.01	1.92	1.94
40 s	sample	64	64	64	64
	mean	1.14	1.08	0.45	0.44
	SD	0.40	0.53	0.27	0.32
	minimum	0	0	0.15	0.11
	25th	0.89	0.68	0.305	0.19
	median	1.22	1.21	0.36	0.31
	75th	1.43	1.52	0.56	0.58
	maximum	1.84	1.8	1.55	1.34

samples total 186, which is equal to 2 times the 93 valid participants because the cut-in event was experienced twice, at 60 kph and 80 kph. The mean values of the reaction times range from 0.44 to 1.35 s, and the standard deviation ranges from 0.27 to 0.76. The minimum ranges from 0 s (the eyes discovered the object even before the cut-in situation occurred; thus, the PT was assumed to be 0) to 0.22 s, and the maximum ranges from 1.34 to 4.83 s. Figures 5 and 6 present the boxplots (with the median, interquartile ranges, and outliers) of the PT, ART, PBRT, and PSRT for each age and gender group.

According to the results of the two-way ANOVA analysis, only the PSRT shows statistical significance ($p = 0.0027$) regarding the effects of age. However, the results of the Bonferroni post-hoc analysis with a modified alpha of 0.0167 show no statistical significance between the three

Table 2. Selected statistics of PT, ART, PBRT and PSRT for each gender.

Gender		PT	ART	PBRT	PSRT
Male	sample	104	104	104	104
	mean	1.05	1.30	0.54	0.47
	SD	0.39	0.68	0.36	0.31
	minimum	0	0	0.15	0.11
	25th	0.85	0.99	0.32	0.22
	median	1.07	1.29	0.51	0.40
	75th	1.35	1.54	0.64	0.63
	maximum	1.75	4.83	2.22	1.41
Female	sample	82	82	82	82
	mean	1.04	1.20	0.65	0.68
	SD	0.48	0.44	0.44	0.51
	minimum	0	0.14	0	0.10
	25th	0.80	1.03	0.31	0.29
	median	1.20	1.30	0.58	0.50
	75th	1.41	1.52	0.75	0.99
	maximum	1.84	1.78	1.92	1.94

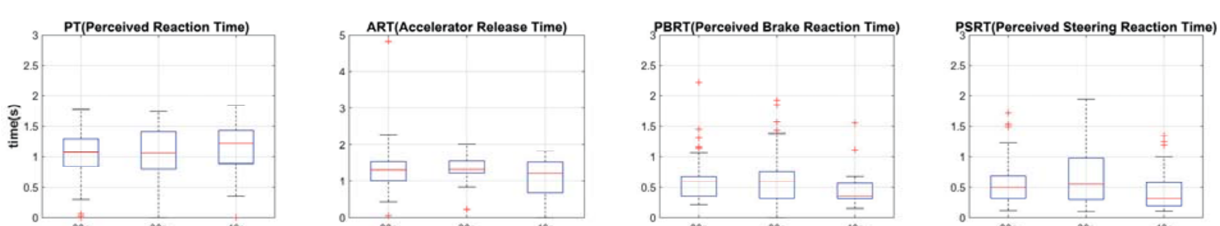

Figure 5. Boxplots of dependent variables for each age group.

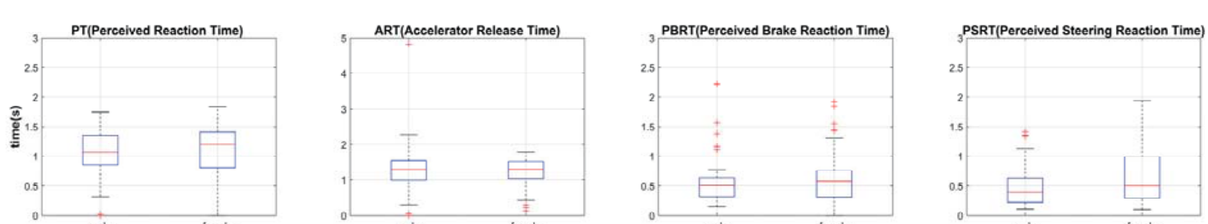

Figure 6. Boxplots of dependent variables for each gender.

age groups ($p = 0.553$ (20 s, 30 s), 0.368 (20 s, 40 s), 0.017 (30 s, 40 s)). Similarly, the PT, ART, and PBRT exhibit no significant statistical differences ($p = 0.270$, 0.112, and 0.087, respectively) between the age groups. Regarding the differences between the genders, only the PSRT shows statistical significance ($p = 0.010$). That is, the PSRTs of the female drivers are longer than those of the males. However, the PT, ART, and PBRT show no significant statistical differences ($p = 0.908$, 0.185, and 0.431, respectively) between the genders. Moreover, the PT, ART, PBRT, and PSRT exhibit no interaction effects ($F(2,137) = 0.431$, $p = 0.651$; $F(2,89) = 0.301$, $p = 0.741$; $F(2,111) = 0.461$, $p = 0.632$; $F(2,129) = 0.515$, $p = 0.599$). Figure 7 presents the boxplots of each age group and gender; no notable interaction effect can be observed.

The results confirm that the drivers' PSRTs in response to cut-in driving can be differentiated according to the age groups (i.e., accept H_{RT1}) and genders (i.e., accept H_{RT2}). However, age and gender do not have an interaction effect on the drivers' response times while they react to cut-in driving (i.e., cannot accept H_{RT3}).

3.2. Driving Behaviors: Frequency of Actions and Dependence on Age and Gender (H_{RB1}, H_{RB2}, H_{RB3})

Table 3 shows how the participants behaved to avoid the dangerous situation based on percentages caused by cut-in driving. Most participants braked after steering to avoid collision (47.3 %). Regarding the age groups, 28 of the 62 participants in their 20's, 31 of the 60 in their 30's, and 29 of the 64 in their 40's chose "braking after steering". Moreover, 50 of the 104 males and 38 of the 82 females braked after steering.

The next most common action is "steering after braking" (29.6 %), followed by "steering only" (14.0 %), and "braking only" (7.5 %). This order is identical for all age groups and genders. No participant braked and steered simultaneously to avoid collision.

The chi-square test results show a statistically significant difference between the preferred behaviors of the drivers ($\chi^2 = 127.172$, DOF = 4, $p < 0.001$) and no difference between the age groups ($\chi^2 = 4.221$, DOF = 8, $p = 0.837$) and genders ($\chi^2 = 5.087$, DOF = 4, $p = 0.278$).

Thus, the drivers show preferred reactions to cut-in driving (i.e., accept H_{RB1}). However, the drivers' reactions to cut-in driving was independent of age and gender (i.e., cannot accept H_{RB2} and H_{RB3}).

3.3. Effects of Accident Occurrence (H_{AC1} and H_{AC2})

Because this study focuses on near-accident situations, it was evaluated whether the occurrence of an accident is

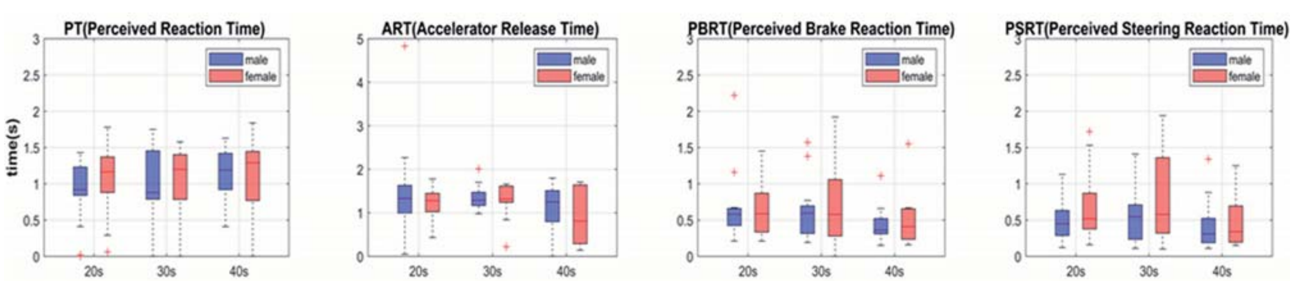

Figure 7. Boxplots of dependent variables according to age and gender.

Table 3. Frequency of drivers' behavior types in response to cut-in driving.

	No response (n (%))	Steering only (n (%))	Braking only (n (%))	Braking after steering (n (%))	Steering after braking (n (%))	Steering and braking (n (%))	Total (n (%))
Total frequency (%)	3 (1.6)	26 (14.0)	14 (7.5)	88 (47.3)	55 (29.6)	0 (0)	186 (100.0)
20s	0 (0.0)	10 (16.1)	6 (9.7)	28 (45.2)	18 (29.0)	0 (0)	62 (100.0)
30s	1 (1.7)	7 (11.7)	5 (8.3)	31 (51.7)	16 (26.7)	0 (0)	60 (100.0)
40s	2 (3.1)	9 (14.1)	3 (4.7)	29 (45.3)	21 (32.8)	0 (0)	64 (100.0)
Male	3 (2.9)	16 (15.4)	5 (4.8)	50 (48.1)	30 (28.8)	0 (0)	104 (100.0)
Female	0 (0.0)	10 (12.2)	9 (11.0)	38 (46.3)	25 (30.5)	0 (0)	82 (100.0)

correlated with the driver's response time and/or behavior in a dangerous situation. Table 4 lists the number of samples, mean, standard deviation, minimum, 25th percentile, median, 75th percentile, and maximum values of the PT, ART, PBRT, and

PSRT based on the occurrence of an accident. An accident occurred in 35 (18.8 %) of 186 cases. Table 5 shows how all the participants of the accident and no-accident cases reacted to avoid the dangerous situation caused by cut-in driving; the corresponding reaction is described based on percentages. Most participants who did or did not experience an accident braked after steering. This reaction was observed in 73 of the 151 cases with an accident and in 15 of the 35 cases without an accident. The next most common reaction was "steering after braking", which was followed by "braking only" for cases with an accident and "steering only" for cases without an accident.

The t-test results show a statistically significant difference for the PT ($p = 0.0194$). That is, the PT value is higher in the cases in which an accident occurred. The ART, PBRT, and PSRT show no significant statistical differences ($p = 0.7417$, 0.5289, and 0.6898, respectively) between the accident and no-accident cases. Moreover, the χ^2 test results show no statistically significant differences ($\chi^2 = 5.642$, DOF = 4, $p = 0.228$) between the accident and no-accident cases. Therefore, the drivers' PTs regarding cut-in driving differ

Table 4. Selected statistics of PT, ART, PBRT and PSRT of accident and no-accident cases.

Accident Occurrence		PT	ART	PBRT	PSRT
Accident	sample	35	35	35	35
	mean	1.23	1.30	0.54	0.59
	SD	0.42	0.40	0.35	0.48
	minimum	0	0.43	0.19	0.11
	25th	1.04	1.01	0.31	0.29
	median	1.39	1.36	0.49	0.39
	75th	1.46	1.63	0.63	0.66
	maximum	1.78	1.78	1.57	1.72
No-accident	sample	151	151	151	151
	mean	1.01	1.25	0.60	0.55
	SD	0.43	0.63	0.41	0.41
	minimum	0	0	0	0.1
	25th	0.84	0.99	0.32	0.23
	median	1.07	1.29	0.54	0.46
	75th	1.30	1.51	0.66	0.70
	maximum	1.84	4.83	2.22	1.94

Table 5. Frequency of driver behavior types in response to cut-in driving based on whether or not an accident occurred.

	No response (n (%))	Steering only (n (%))	Braking only (n (%))	Braking after steering (n (%))	Steering after braking (n (%))	Steering and braking (n (%))	Total (n (%))
Total frequency (%)	1 (2.9)	2 (5.7)	5 (14.3)	15 (42.9)	12 (34.3)	0 (0)	35 (100.0)
Accident	2 (1.3)	24 (15.9)	9 (6.0)	73 (48.3)	43 (28.5)	0 (0)	151 (100.0)
No Accident	3 (1.6)	26 (14.0)	14 (7.5)	88 (47.3)	55 (30.0)	0 (0)	186 (100.0)

between the accident and no-accident cases (i.e., accept H_{AC1}), whereas the driving behaviors do not exhibit this difference (i.e., cannot accept H_{AC2}).

4. DISCUSSION

The results of the experiments indicate that the gender only affects the PSRT, which is the time the participant needs to operate the steering wheel after having perceived the cut-in situation. This effect of the gender on the PSRT has been reported in related study reports. For example, Han *et al*. (2020) studied the influence of the gender on the SRT when a jaywalker must be avoided. Both studies show that the PSRTs of male drivers are shorter than those of female drivers. However, gender does not influence the PBRTs of drivers. Moreover, the influence of age on the PSRT was observed although the post-hoc analyses did not reveal pairwise differences.

Furthermore, the experimental results indicate that drivers generally prefer “braking after steering” in the cut-in driving situation. In approximately half the cases, the drivers braked after steering. It can be assumed that they steered first to move laterally to avoid collision. “Steering after braking” was the second most frequent action (30 % of the cases). In the remaining 20 % of the cases, the drivers only reacted by steering or braking the car. Gender and age do not affect the driver’s response to the cut-in situation.

Only the PTs of the accident and no-accident cases exhibit a significant statistical difference. It can be assumed that a longer PT results in the inability to react properly to the dangerous situation owing to the insufficient time interval.

Some of the recorded reaction times are 0 s. The PT was assumed to be 0 s when the participant moved his or her gaze to the point where the dangerous situation was to occur even before its occurrence. In addition, the ART was assumed to be 0 s when the participant did not put his or her foot on the accelerator pedal upon the occurrence of the dangerous situation; i.e., the pedal was released in the beginning.

We recorded the perception/reaction times of drivers in cut-in situations according to their demographic characteristics. The result was a dataset from 93 valid participants. The novelty of our study lies in the following facts. First, in contrast to Benderius *et al*. (2014) and D’Addario and Donmez (2019) who recruited 24 participants, we recruited 93 valid participants to obtain more representative age group data. Second, Benderius *et al*. (2014) and McGehee *et al*. (2000) recorded the perception time, steering maneuvers, and brake reaction time, whereas we recorded differences in the data according to the demographic characteristics of the drivers (i.e., the age group and gender). Third, unlike Benderius *et al*. (2014) and McGehee *et al*. (2000), we recorded data from scenarios with and without accidents. Fourth, various variables that describe dangerous situations were investigated through a literature review. We recorded different variables such as the perceived reaction time, accelerator release time, brake reaction time, steering reaction time, and whether or not an accident occurred to analyze the reactions. Finally, the data were screened to assess their validity by directly comparing data derived through coding with data from videos; thereby, we could improve the quality of the data.

As mentioned in the Introduction, cut-in driving commonly results in traffic accidents worldwide. Therefore, the results of this study are expected to promote traffic safety worldwide. The results can be used to construct a database of the drivers’ response times; the database can be used to assess the behavior of a driver during an accident. Figure 8 presents a percentile plot of the reaction times of all participants. Moreover, the recorded reaction times and behaviors of the drivers according to their age, gender, and accident type can be examined to assess whether the accident has been intentionally committed.

Follow-up studies should focus on various aspects to

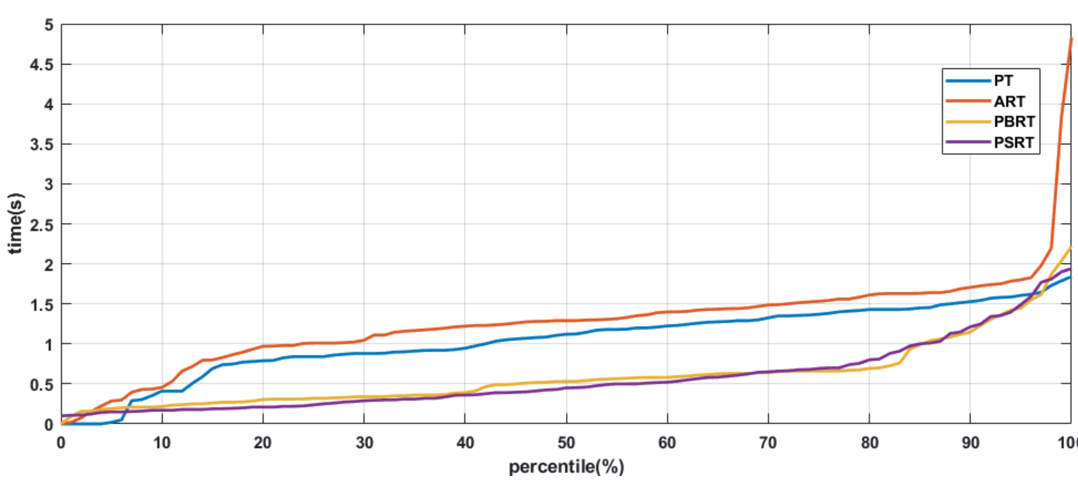

Figure 8. Percentile plot of reaction times.

enhance the applicability of this method. For example, in the future, the authors plan to include test participants who are in their 50 s and 60 s to extend the investigated age range. In addition, the drivers' reaction times and behaviors at night when visibility is significantly reduced should be studied. Finally, a real vehicle is going to be used to evaluate the results from the simulator study.

5. CONCLUSION

In South Korea, it is common to classify participants according to their age into groups of people in their, for example, 20 s, 30 s, and 40 s. The results of this study are meaningful because we recruited male and female participants with a range of different ages. We analyzed the data according to age and gender and derived significant results. In this study, the various reaction times and behaviors of male and female drivers in their 20 s, 30 s, and 40 s in a cut-in situation on a road were determined. The data of 93 (of a total of 105) participants who completed the test were used to determine their response times and behaviors in a simulated environment. Only the steering reaction time was affected by age and gender; the other reaction times such as the PT and braking reaction time were not affected. The PTs of the accident and no-accident cases were different. However, gender and age did not affect the accident and no-accident cases. Approximately half the participants tried to avoid collision by steering and then braking. The next most common action was "braking before steering". The remaining 20 % only steered or braked in the cut-in situation. Finally, gender and age did not affect the drivers' responses to the cut-in situation. Because cut-in situations are one of the most common dangerous situations in road traffic, the National Forensic Service of South Korea must investigate the statistics. Thus, this study provides important data for assessing the behavior of a driver in an accident and ensuring road safety in the future.

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