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Improvements in Perpendicular Reverse Parking by Directing Drivers' Preliminary Behavior

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ABSTRACT Driving vehicles requires mastery of a multitude of tasks. Among these, parking is one task that most drivers feel they are not as skilled as they would like to be. In this paper, we focus on improvement of reverse perpendicular parking performance. We began our research by conducting fixed-point observations in a private parking lot to analyze parking behavior in situ. Our analysis indicated that the start position of reversing is the most important aspect of successfully navigating into a target parking space. We then examined the effect of delivering instructions to assist in preliminary vehicle control by giving a target drawn on the road using a head-mounted display-based driving simulator. The results indicated that explicit instructions improve the parking performance for spatial offset, but the effect on the time required for the task could not be clearly confirmed. In summary, directing drivers to alter their preliminary behavior in the perpendicular parking task might be practically useful for improving their performance.

INDEX TERMS Driving assistance, human factors, interactive systems, vehicle driving.

I. INTRODUCTION

Although autonomous vehicle technologies are still a long way from achieving automation levels [1]–[3] that would allow vehicles to be operated without any human intervention, significant progress has been made in recent years. There are now several commercially available vehicles that offer partially automated functions, such as lane-keeping, adaptive cruise control, and autonomous parking. However, it is often been pointed out that, from the human factors perspective, such partial automation has the potential to erode user skill, rendering drivers unable to appropriately control their vehicles [4], [5]. Parking is one task for which most drivers feel they are not as skilled as they would like to be. For the parking task, several fully automated valet parking systems and partially automated parking systems have been presented [6]–[10] in addition to visual and auditory guidance systems [11]–[15], which might also erode user skill. However, even if the number of driving situations that can be automated increases, vehicles will still have to be driven by hand in situations that the automated system does not anticipate. Therefore, it is important to maintain and improve driving skills.

Michon's three-layer driver behavior model consists of a strategic-level, a maneuvering-level, and a control-level [16], and various driving tasks have been examined for all three levels [17]–[19]. In contrast, most discussions about parking tasks are either at the strategic-level, such as which parking lot the car should be parked in, or at the control-level, such as how accurately the car was parked. In other words, the automated valet parking systems perform strategic-level driving behavior on behalf of drivers, and partially automated parking and guidance systems assist at the control level. Although parking tasks have been rarely considered at the maneuvering-level, Hirokawa *et al.* reported improvement of positional variances of the perpendicular parking tasks related to the position before the start of reversing [20]. They pointed out only this relationship, but the results suggested that appropriate preliminary behavior, which is information at the maneuvering-level, might improve parking performance or skill. Considering the position before the start of reversing as such information, we hypothesized that this

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information might improve perpendicular reverse parking performance.

This paper fills this research gap and provides evidence obtained from three experiments that support the hypothesis together with a potential implementation idea. At first, we conducted fixed-point observations at a private parking lot to survey the preliminary behavior under ordinary driving conditions and to analyze the distinctive features statistically. Next, an experiment using a driving simulator implemented with a head-mounted display (HMD) was conducted to confirm whether the maneuvering-level instructions led to better parking performance. Based on those observations, we examined the possibility of a more practical approach using a rearview monitor that could compensate for the driver's perceptual bias at the maneuvering-level. In the final section of the paper, the results are summarized, and conclusions are given.

The contributions of this paper in each phase of the experiments are as follows:

A. FIXED-POINT OBSERVATION OF NORMAL PARKING BEHAVIOR

We found that there is a high correlation between lateral distance from the parking space and the vehicle headway angle at direction changing positions (DCPs) when the parking task is completed successfully on the first attempt.

B. IMPROVING REVERSE PARKING PERFORMANCE

We confirmed that providing maneuvering-level instructions about DCPs to drivers resulted in improved performance of final alignment to the parking space.

C. PERCEPTUAL COMPENSATION USING PARKING ASSISTANCE SYSTEM

We explored the possibility of using a rearview display to provide implicit maneuvering-level instructions by adding bias to the image to direct drivers to the appropriate headway.

All subjects participating in this study were provided with an explanation of its purpose, and they gave appropriate informed consent in keeping with the ethical guidelines established by the Society of Automotive Engineers of Japan [21]. The experimental procedure was approved by the Ethical Committee of Toyota Central Research and Development Laboratories, Inc. (TCRDL) and the Toyohashi University of Technology.

II. RELATED WORK

Several studies have looked at manual parking behavior, including typical strategic-level behavior such as route choice for parking spaces [22]–[24]. Bonsall *et al.* presented a route-choice model for parking spots based on experimental observations of subjects using their simulator [22]. The result suggested that choosing the correct route is affected by the distance from the destination, guidance information signs, the queuing time for parking, the travel time for the route, and the walking time from the parking spot to the desired destination. Van der Waerden *et al.* experimentally observed that parking space is determined by the distance between the entrance of a parking spot, the entrance of the destination, and payment machines, and further reported that the rules vary slightly by gender [23]. Based on their findings, guidance services and systems have been proposed [24]–[26].

Several studies on control-level behavior analyzed parking orientation and preferences [27], gender differences [28], age and the extent of the field of view [29], parking-related crashes and incidents [30], and gaps between vehicles [31]. These studies primarily evaluated the accuracy of vehicle placement in a parking space after completion of parking. Therefore, the findings have been useful for designing in-vehicle parking assistance systems with visual, auditory, or haptic guidance [20], [32], [33].

Hirokawa *et al.* [20] also found that the statistical variance of the DCP, which refers to the position when the driver changes the gear selector from a forward gear to the reverse gear, was smaller for subjects who received haptic feedback about their parking status. These results indicated that directing drivers to the appropriate DCP improves their performance in the parking task, but it is unclear whether it improved their parking task skills, because the study did not evaluate aftereffects. In light of this result, it was considered likely that preliminary behavior, such as the DCP, has a direct correlation with parking task performance. Based on that assumption, we hypothesized that inducing more appropriate preliminary behavior via relevant and timely instructions would improve the reverse parking performance and skill.

III. FIXED-POINT OBSERVATION OF NATURAL PARKING BEHAVIOR

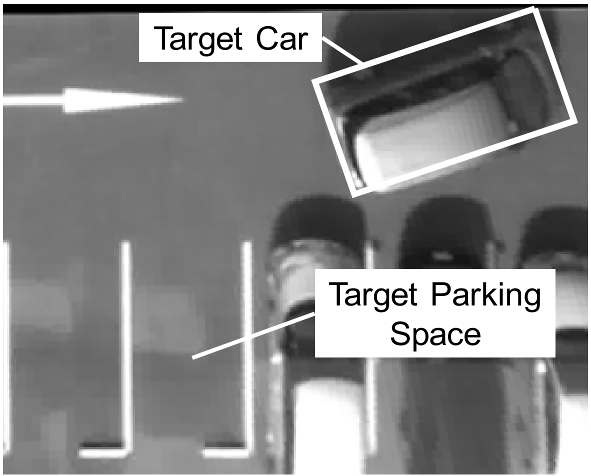
The existence of a significant relationship between the DCP and perpendicular reverse parking performance has been observed in experiments using a driving simulator [20], but not in experiments using a real vehicle. Therefore, we first conducted fixed-point observation to survey the relationship between the DCP, the number of retries, and the final alignment accuracy during perpendicular reverse parking using real vehicles.

A. EXPERIMENTAL SETUP

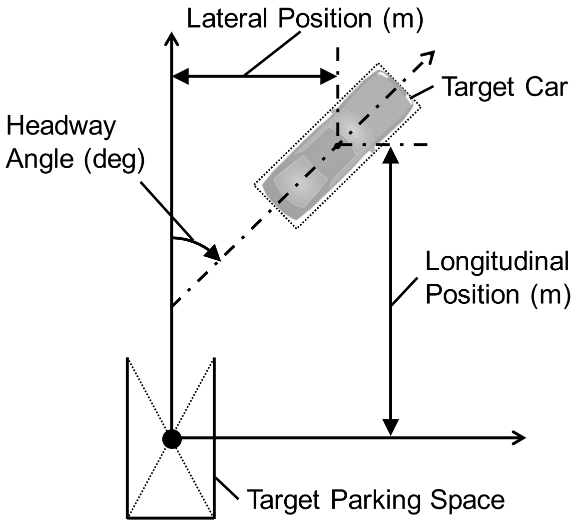
The experiments were performed at a TCRDL parking lot. The parking behavior was recorded with full high-definition resolution (1920 × 1080 pixels) at 30 frames per second with a digital video camera (HRD-HC3, Sony, Inc.) that was placed near a building window where it had a good view of the parking lot. The experimental period spanned three sunny days.

B. PROCEDURE

The recorded videos were first transformed to provide a top-down view as shown in Fig. 1(a). The frames that corresponded to DCPs and the completion of the parking task, which we call the finishing parking position (FPP), were then extracted manually. In cases where the subject aborted



(a) Transformed image example



(b) Measurement coordinates

FIGURE 1. **Overview of vehicle positioning at the DCP.**

his or her first attempt and retried the parking maneuver, only the frames containing their first DCP were used for subsequent analysis. The positions of the automobile and the parking spaces were visually annotated as bounding boxes by hand. Because we were able to measure the actual dimensions of the parking lot in the field, the dimensions per pixel could be calculated. This allowed us to convert the size of each bounding box and the relative positions to metric units.

The lateral position, longitudinal position, and headway angle were calculated, as illustrated in Fig. 1(b). These features in each extracted frame at the DCPs and FPPs are described as follows:

$$X_{DCP} = \left[x_{DCP,lat}, x_{DCP,lon}, \theta_{DCP}\right]^T, \tag{1}$$

$$X_{FPP} = \left[x_{FPP,lat}, x_{FPP,lon}, \theta_{FPP}\right]^T, \tag{2}$$

where $x_{DCP,lat}$, $x_{DCP,lon}$, and θ_{DCP} are the lateral position, longitudinal position, and headway angle at the DCP, respectively, and $x_{FPP,lat}$, $x_{FPP,lon}$, and θ_{FPP} have the lateral position, longitudinal position, and headway angle at the FPP, respectively. The origin of the positions is the center of the parking space, and the angles are clockwise disparity from an outward vector parallel to the parking space. Whether each trial included a retry was also recorded as a binary variable, F_{trial}. If the trial did not include more than one effort, F_{trial} was set to 0; otherwise, F_{trial} was set to 1.

C. SUBJECTS

We observed 55 natural parking behaviors of TCRDL employees using video recordings. To ensure conformity to the ethical guidelines [21], the place and date of the recordings were announced to all employees one week in advance.

D. RESULTS AND DISCUSSION

Among the 55 samples obtained in the experiment, 31 required multiple attempts. First, we conducted multiple logistic regressions with the following model:

$$\log \frac{F_{trial}}{1 - F_{trial}} = \left[X_{DCP}^T \quad X_{FPP}^T\right] \Omega, \tag{3}$$

where F_{trial} is a dependent variable, X_{DCP} and X_{FPP} are explanatory variables, and $\Omega \in \mathbb{R}^6$ refers to the coefficient of the regressions. The analysis results rejected all of the explanatory variables by a forward-backward stepwise model selection using the Akaike information criterion. As a result, we conclude that X_{DCP} and X_{FPP} did not have suitable features for making predictions.

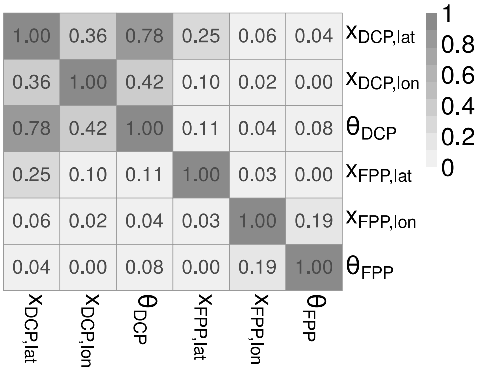
Next, dividing X_{DCP} and X_{FPP} into the subgroups single attempt and multiple attempts, a correlation analysis was conducted. Squared correlations were calculated over all combinations of elements X_{DCP} and X_{FPP} and are visualized as the correlation matrix in Fig. 2. The results indicate that correlations between $x_{DCP,lat}$ and θ_{DCP} for the single attempt group, $F_{trial} = 0$, is large.

A scatter plot of $x_{DCP,lat}$ and θ_{DCP} is shown in Fig. 3. Filled circles indicate tasks that were completed in a single attempt without retrying, while cross marks indicate tasks that were completed after multiple attempts. Linear regression lines are drawn in each group in the figure. In this analysis, only the single-attempt group has a significant correlation. Thus, there is a strong correlation between $x_{DCP,lat}$ and θ_{DCP} when the tasks were completed in a single attempt without retrying.

These results suggest that the relationship between the DCP and reverse parking performance could be confirmed not only for the driving simulator but also for driving real cars. Although achieving an appropriate DCP is important for successfully completing parking in a single attempt, the experiments could not reveal whether an appropriate DCP causes an improvement in parking performance.

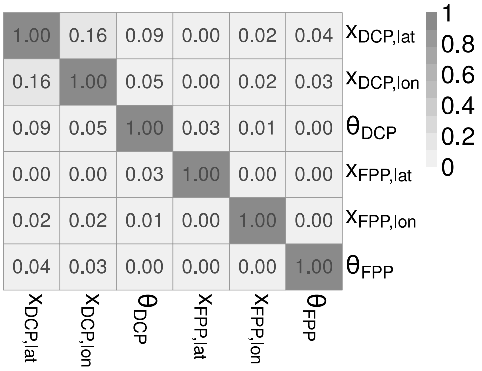
IV. IMPROVING PARKING PERFORMANCE BY PROVIDING INSTRUCTIONS

After we observed the relationship between DCP and parking performance, the next question would be whether giving instructions on the appropriate DCP improves performance.



	$x_{DCP,lat}$	$x_{DCP,lon}$	θ_{DCP}	$x_{FPP,lat}$	$x_{FPP,lon}$	θ_{FPP}
$x_{DCP,lat}$	1.00	0.36	0.78	0.25	0.06	0.04
$x_{DCP,lon}$	0.36	1.00	0.42	0.10	0.02	0.00
θ_{DCP}	0.78	0.42	1.00	0.11	0.04	0.08
$x_{FPP,lat}$	0.25	0.10	0.11	1.00	0.03	0.00
$x_{FPP,lon}$	0.06	0.02	0.04	0.03	1.00	0.19
θ_{FPP}	0.04	0.00	0.08	0.00	0.19	1.00

(a) Single attempt



	$x_{DCP,lat}$	$x_{DCP,lon}$	θ_{DCP}	$x_{FPP,lat}$	$x_{FPP,lon}$	θ_{FPP}
$x_{DCP,lat}$	1.00	0.16	0.09	0.00	0.02	0.04
$x_{DCP,lon}$	0.16	1.00	0.05	0.00	0.02	0.03
θ_{DCP}	0.09	0.05	1.00	0.03	0.01	0.00
$x_{FPP,lat}$	0.00	0.00	0.03	1.00	0.00	0.00
$x_{FPP,lon}$	0.02	0.02	0.01	0.00	1.00	0.00
θ_{FPP}	0.04	0.03	0.00	0.00	0.00	1.00

(b) Multiple attempts

FIGURE 2. **Correlation matrix (R^2) between features depending on success of task performance.**

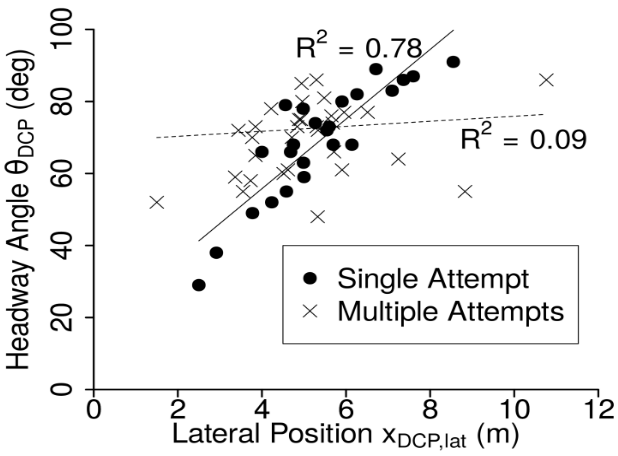


FIGURE 3. **Lateral position and headway angles at DCPs relative to parking space center.**

The impact of the instructions was investigated using a HMD-based driving simulator. The simulator was used to avoid the risk of potential accidents from fatigue while performing numerous parking tasks using a real car.

A. EXPERIMENTAL SETUP

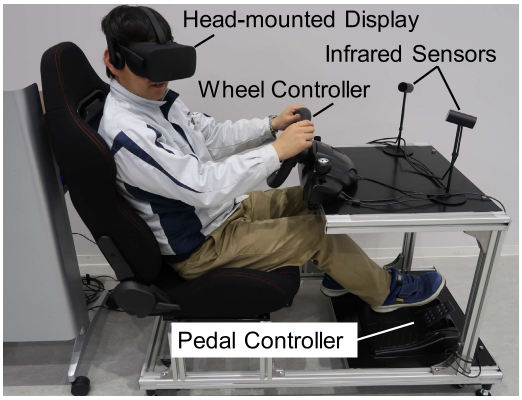


FIGURE 4. **Overview of experimental driving simulator cockpit. Each subject grasped a wheel controller and wore a head-mounted display. Two infrared sensors behind the controller on the shelving unit measured the three-dimensional position and three-axis angular posture of the display.**

A simple cockpit with a seat and a gaming controller (Driving Force GT, Logicool, Inc.) was used in the experiment, as shown in Fig. 4. Subjects wore a HMD (Rift CV1, Oculus, Inc.) that was connected to a desktop computer (CPU, Intel Xeon E5-2603V2; memory, 8 GB; GPU, MSI GeForce GTX 1080 GAMING X 8G). The HMD showed images of the virtual environment in relation to the head position and orientation. The images were generated in real-time by game engine software (Unity 5.50f3, Unity, Inc.).

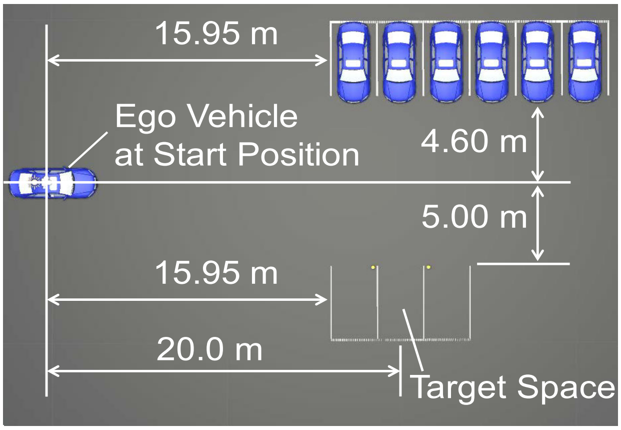
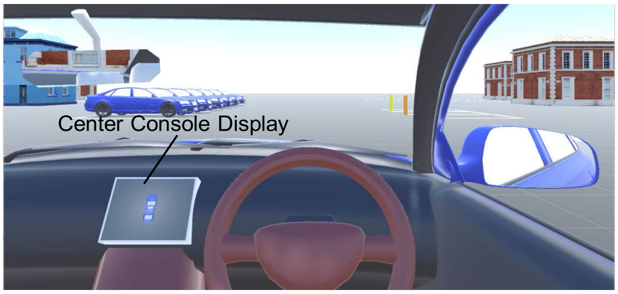
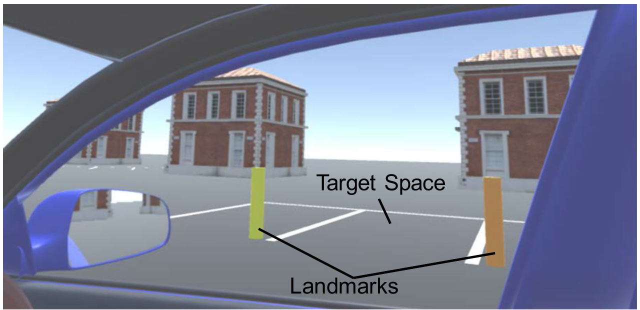


FIGURE 5. **Initial layout of seven cars and nine parking spaces in a virtual flat paved parking lot. Subjects were asked to park the ego vehicle in the target space.**

The virtual parking lot was designed as shown in Fig. 5. There were seven cars and nine parking spaces on a flat paved parking lot. The cars' dimensions were 5.4 m long by 1.9 m wide, while the size of the parking spaces was 5.0 m long by 2.7 m wide. One "ego" car was located at a starting position away from the parking spaces, as drawn at the middle left side in Fig. 5. By using the wheel controller and pedal controller, subjects could move this ego vehicle freely in the plane shown in Fig. 5. The state of the wheel controller and the pedal controller, the position and orientation of the ego vehicle, and the gear selector position were continuously recorded at 100 Hz. The parking space in which the subjects were asked



(a) Front view



(b) Side view

FIGURE 6. **Examples of visual stimuli displayed on the HMD, as rendered from the ego vehicle located in front of the target space.**

to park was called the target space. Fig. 6 shows examples of the rendered images: (a) is when the subject is facing forward and (b) is when the subject is turned slightly toward the right. Reflections in the rearview and side mirrors were also rendered in real-time. Moreover, a monitor mounted on the center console displayed a top-down view in real-time from 8.83 m above the head.

When we conducted a preliminary experiment, it was too difficult to park the ego vehicle in the target space because the subjects lost sight of it. Therefore, two poles were installed near the edges of the opening of the target space as shown in Fig. 6(b). These poles were used purely as visual landmarks, and collision detection was performed to prevent the parking task from being too easy. To suppress the inducement of simulator sickness due to spatial disorientation, several buildings were placed in the field of view distant from the ego vehicle and the target space as shown in Fig. 6.

B. PROCEDURE

The experimental procedure consisted of three steps. The subjects were asked to control the ego vehicle from the starting position to the target space 20 times in each step via a perpendicular reverse parking maneuver. Thus, the subjects were asked to park 60 times in total without any DCP instructions except the second step for the experimental group. The subjects in the experimental group were instructed to follow the appropriate DCP location at the second step as shown in Fig. 7. The instructions were provided by overlaying curves on the display as guidance. Each curve was a set of line segments that followed the equation $\theta_{DCP} = \alpha x_{DCP,lat} + \beta$, whose coefficients $(\alpha = 9.67, \beta = 17.1)$ were estimated from a fixed-point observation for single attempts. The line segments were iteratively produced from several defined initial points $\left(x_{m,0}, y_{m,0}\right)$ on the parking lot using the following equations:

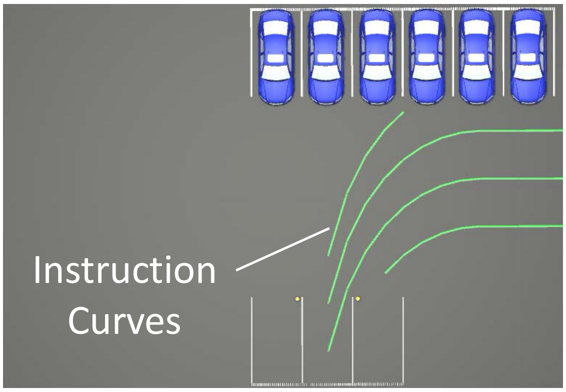


FIGURE 7. **Instruction curves for experimental group in the second step. The appropriate headway angles at DCPs were determined from tangents to the curves. Subjects in the experimental group performed perpendicular reverse parking along the curves 20 times in this step.**

$$\theta_{m,i+1} = 9.67 x_{m,i} + 17.1, \tag{4}$$

$$x_{m,i+1} = x_{m,i} + \Delta x_i, \tag{5}$$

$$y_{m,i+1} = \begin{cases} y_{m,i} + \dfrac{\Delta x_i}{\tan \theta_{m,i+1}} & \left(\theta_{m,i+1} < 90\right) \\ y_{m,i} & \left(\theta_{m,i+1} \geq 90\right), \end{cases} \tag{6}$$

where i is an integer index of edges, the initial step width Δx_o was set to 0, and the step widths $\Delta x_1, \Delta x_2, \cdots$ were set to 1.0. In the experiment, four points $(0, -1.55)$, $(0, 1.15)$, $(0, 3.85)$, and $(2.7, 2.5)$ were respectively used as the initial points $\left(x_{m,0}, y_{m,0}\right)$ for $m = 1, 2, 3, 4$.

We recorded the ego vehicle's position and orientation from a starting point to when the vehicle was parked in the target space. The starting timings were detected from the gear position change from parking to driving. Similarly, the ends were detected by the change from reversing to parking. Although the subjects could retry the task when they changed the gear selector from reverse to park outside of the target space, those measurements were not used in the analysis. In addition, in order to make sure that we use the measurements after the subjects became accustomed to the task, only the latter half of the 20 trials in each step were used for the later analysis. Furthermore, the center console monitor was blacked out when the gear selector was in the reverse position. Thus, the subjects could use the monitor to confirm their positions at the DCPs and the FPP, but could not use it for real-time feedback to control the vehicle during the task. After finishing the task, the ego vehicle was automatically returned to the starting position.

The DCPs and FPPs were detected by scanning the ego vehicle's trajectory. As a part of preprocessing, we added a 0.4 m offset to the measurements of the longitudinal position so that it would be zero when the ego vehicle is perfectly centered. This adjustment was necessary because the length of the ego vehicle was longer than the target space. Thus, the center of the ego vehicle and its headway angle would approach zero if the trial ended with complete success. Next, the time of the DCP, t_{DCP}, was detected when the speed increased to over 0.01 m/s immediately after changing the gear selector from a driving position to the reverse position in each trial. The lateral position $x_{DCP,lat}$, longitudinal position $x_{DCP,lon}$, and headway angle θ_{DCP} were measured at time t_{DCP}. The time of the FPP, t_{FPP}, was detected when the speed fell below 0.01 m/s and when the center of the ego vehicle was within a 2.0-m square centered on the parking space. The lateral position $x_{FPP,lat}$, the longitudinal position $x_{FPP,lon}$, and the headway angle θ_{FPP} were measured at time t_{FPP}. As a quantitative metric of the performance, the root square error at the FPP, RSE_{FPP}, and the duration from the DCP to the FPP, $t_{DCP:FPP}$ were defined as follows:

$$RSE_{FPP} = \sqrt{x_{FPP,lat}^2 + x_{FPP,lon}^2}, \tag{7}$$

$$t_{DCP:FPP} = t_{FPP} - t_{DCP}. \tag{8}$$

C. SUBJECTS

A statistical power analysis using G*Power 3.1 [34] was conducted to determine the appropriate number of subjects. Assuming that the instructions had a strong effect, that is, partial eta squared $\eta^2 = 0.2$, the power analysis showed that the total sample size with power $1 - \beta > 0.8$ should be 27 at a significance level of $\alpha = 0.05$ in the repeated measure two-way analysis of variance (ANOVA) for three groups.

Based on these results, a total of 30 subjects under 60 years old were recruited to avoid aging factors for driving behavior, because it has been reported that young drivers and elderly drivers have significantly different visual behavior when parking [29]. Then, 23 males and 7 females between the ages of 21 and 52 with valid Japanese driver's licenses participated in this series of experiments. These subjects were divided into an experimental group and a control group. The grouping was determined to balance the demographics, including age, gender, number of years since obtaining a license, and frequency of driving. As a result, the experimental group consisted of 12 males and 3 females with an average age of 31.9 and a standard deviation of 9.50. The control group consisted of 11 male and 4 female subjects with an average age of 33.1 and a standard deviation of 10.86.

D. RESULTS AND DISCUSSION

In the series of experiments, a larger than expected number of subjects were unable to complete the parking task. Because visual stimulus using a HMD sometimes causes motion sickness, 12 of the 30 subjects could not complete the tasks. Furthermore, 2 subjects had trouble performing the parking tasks in the driving simulator environment. After excluding these subjects, measurements from a total of 16 subjects were analyzed. Because the number of subjects who were able to complete the experiment did not reach the design value, statistical powers were recomputed. As a result, a $1 - \beta$ value of 0.7 in a two-way ANOVA was obtained for two groups, while a $1 - \beta$ value of 0.6 was obtained for three groups. Therefore, in the following analysis, the results of within-group evaluations are considered less reliable than the between-group evaluation results. The experimental group consisted of 8 males and 1 female between the ages of 21 and 44 with an average age of 27.9 and a standard deviation of 8.18. The control group consisted of 5 male and 2 female subjects between the ages of 21 and 46 with an average age of 29.0 and a standard deviation of 9.38.

Because the statistical power was diminished, it was necessary to limit the conditions and eliminate outliers as much as possible in the analysis. Although measurements in the latter half of the 20 trials in each step were intended to be used for the analysis, those with more than one effort and those that clearly failed the manipulation were excluded. These screenings resulted in a total sample size of 437, and the sample size for each combination of factors is shown in Table 1.

TABLE 1. Sample size for each combination of factors.

Group	First step	Second step	Third step
Experiment	76	82	87
Control	57	69	66

To investigate the effects of the instructions, a two-way ANOVA between groups and step factors was conducted with regard to RSE_{FPP} and $t_{DCP:FPP}$. Here, the group factor has two levels, experiment and control, and the step factor has three levels, at the first, second, and third steps. The analysis results in Table 2 show no interactions, but strong effects were found for both the group and step factor. In the following analysis, we looked into the differences in detail.

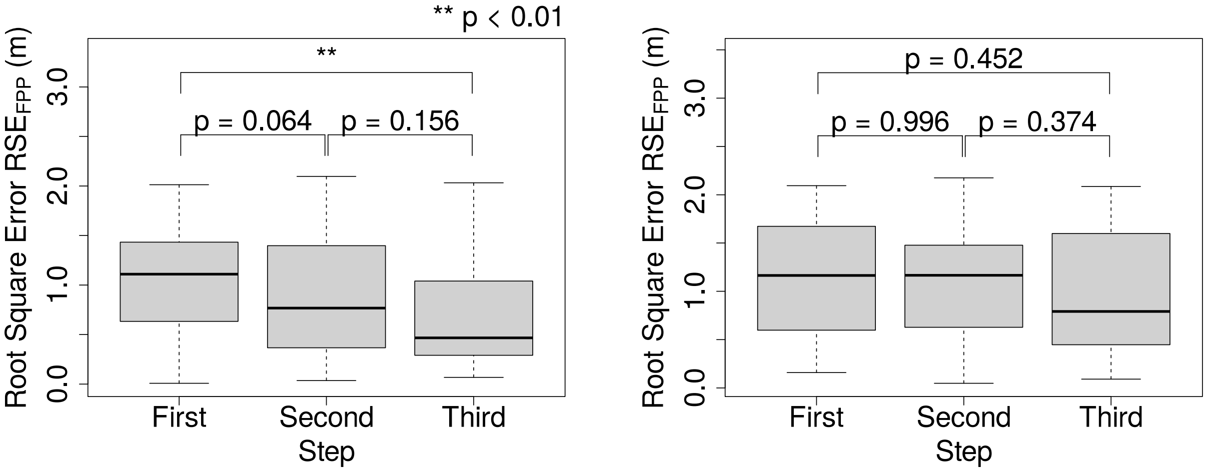
We first analyzed the group factor regarding RSE_{FPP} by a Wilcoxon rank test. The results were $W = 2,117, p = 0.826$, and $d_{cl} = 0.023$ at the first step; $W = 2,257$, $p = 0.033$, and $d_{cl} = 0.202$ at the second step; and $W = 2,224$, $p = 0.017$, and $d_{cl} = 0.225$ at the third step. Here, d_{cl} denotes Cliff's delta, which is one of the effect sizes. The significant difference between both the second and third steps indicates the existence of aftereffects from the instructions in the second step. In contrast, no significant difference was found at the first step. This indicates that the subjects' skills were well balanced in terms of their RSE_{FPP}. Next, the step factor with regard to RSE_{FPP} was analyzed by a Steel-Dwass multiple comparison test for each group. The results for the experimental group were $t(\infty) = 1.970$, $p = 0.120$ and $d_{co} = 0.251$ between the first and second steps; $t(\infty) = 4.062$, $p = 1.44\times10^{-4}$, and $d_{co} = 0.267$ between the first and third steps; and $t(\infty) = 2.158$, $p = 0.079$, and $d_{co} = 0.576$ between the second and third steps, as shown in Fig. 8(a). Here, d_{co} denotes Cohen's delta. Similarly, the test results for the step factor in the control group were $t(\infty) = 0.184$, $p = 0.982$, and $d_{co} = 0.024$ between the first and second steps; $t(\infty) = 1.025$, $p = 0.561$, and $d_{co} = 0.173$ between the first and third steps; and

TABLE 2. Results of two-way ANOVA for performance indices.

		Root Square Error at FPP RSE_{FPP}					Duration Time from DCP to FPP $t_{DCP:FPP}$				
Source	DF	SS	MS	F-value	p-value	η^2	SS	MS	F-value	p-value	η^2
Group	1	3.7	3.7	9.22	<0.001**	0.021	263	263	29.43	<0.001**	0.064
Step	2	6.0	3.0	7.54	<0.001**	0.034	8	4	0.50	0.639	0.002
Interaction	2	1.3	0.7	1.63	0.198	0.007	27	14	1.53	0.219	0.007
Error	431	173	0.4				3,857	9			
Total	436	184					4,155				

* $p < 0.05$, ** $p < 0.01$

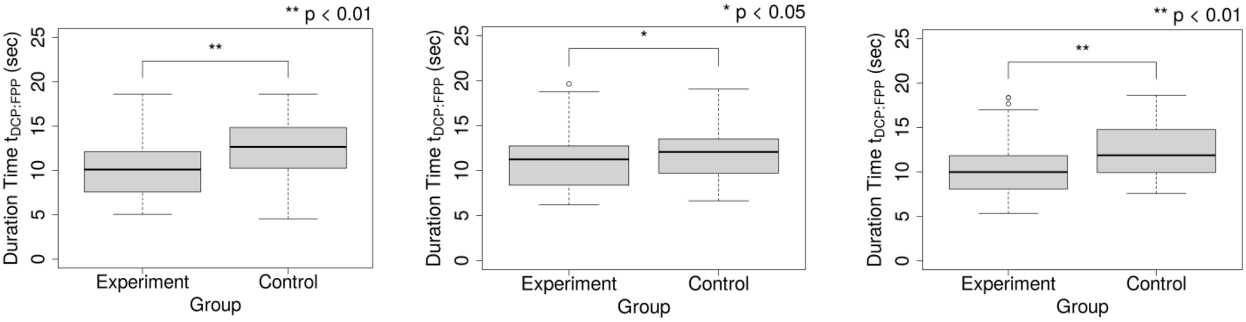
Notes: DF = degrees of freedom, SS = sum of squares, MS = mean of squares, and η^2 = partial eta squared.



(a) Experimental group

(b) Control group

FIGURE 8. Root square error RSE_{FPP} distributions with respect to step factor. As a result of multiple comparisons, significant differences were found between the first and third steps in the experimental group. These suggest that the instructions might be useful for improving RSE_{FPP}.



(a) First step

(b) Second step

(c) Third step

FIGURE 9. Duration time, $t_{DCP:FPP}$, distributions with respect to group factor. The experimental group medians were significantly lower than those for the control group.

$t(\infty) = 1.294$, $p = 0.398$, and $d_{co} = 0.142$ between the second and third steps, as shown in Fig. 8(b). Fig. 8(a), indicate that the median RSE_{FPP} in the experimental group decreased for both the second and third steps and the difference between the first and third steps was significant. In contrast, no significant differences were found among the steps for the control group. These results indicate that the instruction improved the final alignment performance, RSE_{FPP}.

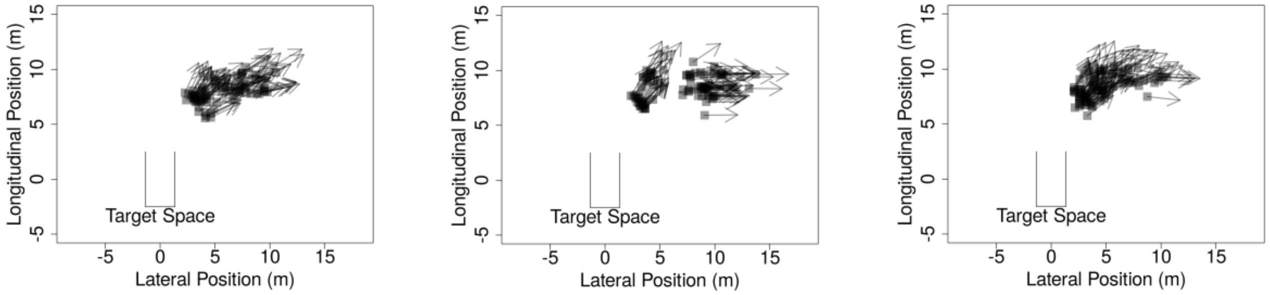
In the same manner, we analyzed the impacts of the factors on $t_{DCP:FPP}$. The group factors were analyzed by the Wilcoxon rank test. The results were $W = 1,301$, $p = 8.473 \times 10^{-5}$, and $d_{cl} = 0.399$ at the first step; $W = 2,289$, $p = 0.044$, and $d_{cl} = 0.191$ at the second step; and $W = 1,859$, $p = 1.944 \times 10^{-4}$, and $d_{cl} = 0.352$ at the third step, as shown in Fig. 9. These results indicate that $t_{DCP:FPP}$ values in the experimental group were significantly smaller than those in the control group for all steps. Because Table 2 indicates that there are no significant effects of the steps or interactions, $t_{DCP:FPP}$ is not influenced by the number of trials. This means that the subjects' parking skill in terms of the task time, $t_{DCP:FPP}$, in the two groups was not well balanced.

TABLE 3. Results of two-way ANOVA for ego vehicle position and posture at DCPs and FPP.

		Lateral Position at DCP $x_{DCP,lat}$					Longitudinal Position at DCP $x_{DCP,lon}$					Headway Position at DCP θ_{DCP}				
Source	DF	SS	MS	F-value	p-value	η^2	SS	MS	F-value	p-value	η^2	SS	MS	F-value	p-value	η^2
Group	1	69	69	12.02	<0.001**	0.027	0.4	0.4	0.41	0.523	0.001	119	119	0.368	0.545	<0.001
Step	2	118	59	10.28	<0.001**	0.046	8.3	4.2	4.43	0.012*	0.020	5,834	2,917	8.98	<0.001**	0.040
Interaction	2	82	41	7.15	<0.001**	0.032	2.5	1.3	1.35	0.260	0.006	5,851	2,926	9.00	<0.001**	0.040
Error	431	2,475	5.7				405	0.9				140,048	325			
Total	436	2,744					416					151,852				

		Lateral Position at FPP $x_{FPP,lat}$					Longitudinal Position at FPP $x_{FPP,lon}$					Headway Position at FPP θ_{FPP}				
Source	DF	SS	MS	F-value	p-value	η^2	SS	MS	F-value	p-value	η^2	SS	MS	F-value	p-value	η^2
Group	1	0.80	0.80	17.52	<0.001**	0.039	0.2	0.2	0.33	0.569	0.001	164	164	10.11	0.002**	0.023
Step	2	0.70	0.35	7.72	<0.001**	0.035	3.9	2.0	3.07	0.047*	0.014	495	248	15.30	<0.001**	0.066
Interaction	2	0.15	0.08	1.67	0.190	0.008	2.3	1.2	1.81	0.164	0.008	15	7.7	0.47	0.623	0.002
Error	431	19.64	0.05				274	0.6				6,977	16.2			
Total	436	21.29					280					7,651				

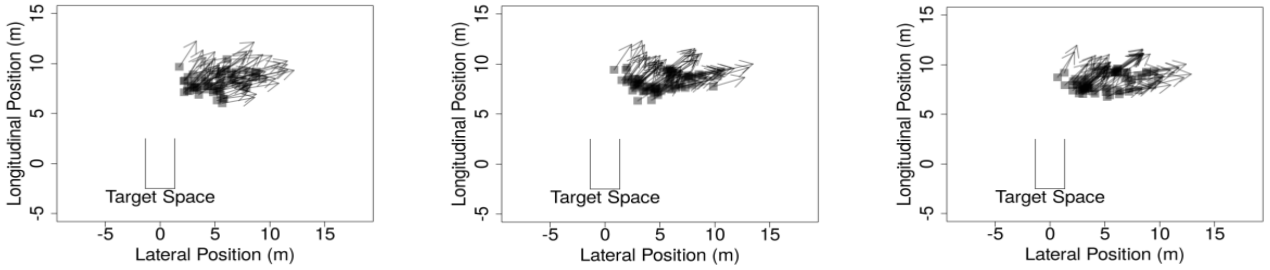
* $p < 0.05$, ** $p < 0.01$; see Table II for key to abbreviations.



(a) Experimental group at first step

(b) Experimental group at second step

(c) Experimental group at third step



(d) Control group at first step

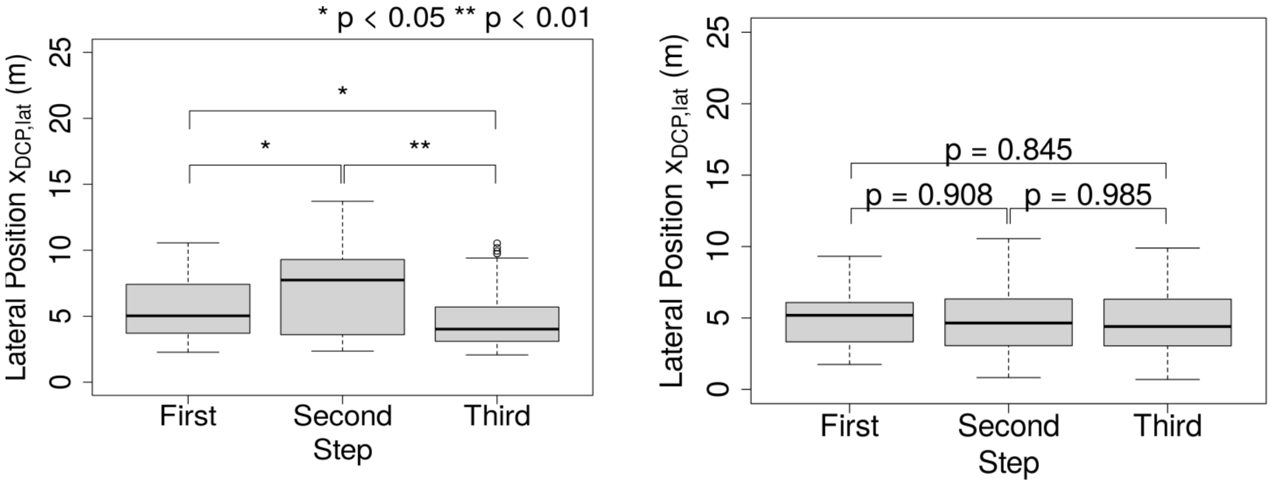
(e) Control group at second step

(f) Control group at third step

FIGURE 10. Dependence of DCPs on different factors. Arrows are headway angles. (a) Most DCPs form a radial pattern from the opening of the target space. (b) The DCPs clearly form two clusters that avoid the centers of the DCPs for the first step. (c) The DCPs are spread along the instruction curves and the headway angles are tangential to the curves. (d) The DCPs are similar to those in (a). (e) The DCPs exhibit a slight lateral spread compared to (d). (f) The DCPs are similar to those in (e).

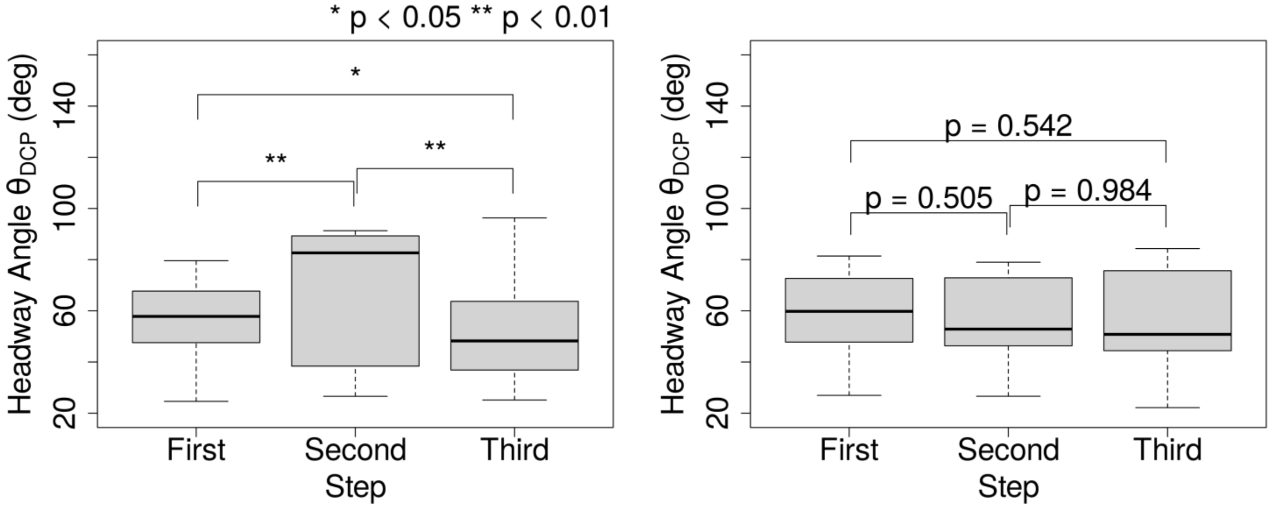
To obtain more insights on the skill bias existing between the groups, lateral position, longitudinal position, and headway angle at the DCP and the FPP were analyzed by a two-way ANOVA as shown in Table 3. The results show strong effects of the group factor on the lateral position at both the DCP and the FPP, and the headway at the FPP. There was a strong interaction between the lateral position and the headway at the DCP.

The interactions for the lateral position and headway angle at DCPs were investigated in detail to make statistical comparisons over all combinations of factors. Wilcoxon rank test results for the group factor in the variables for the lateral position were $W = 2,454$, $p = 0.1912$, and $d_{cl} = 0.133$ at the first step; $W = 3,890$, $p = 7.45 \times 10^{-5}$, and $d_{cl} = 0.375$ at the second step; and $W = 2,774$, $p = 0.722$, and $d_{cl} = 0.034$ at the third step. The test results for the headway angle were $W = 1,921$, $p = 0.2663$, and $d_{cl} = 0.113$ at the first step; $W = 3,610$, $p = 0.004$, and $d_{cl} = 0.276$ at the second step; and $W = 2,338$, $p = 0.050$, and $d_{cl} = 0.186$ at the third step. No significant differences between either the lateral position or the headway angle could be found at the first step. In combination with the ANOVA results, these results indicate that skills for position and headway alignment at the DCP were well balanced between the groups. Therefore, we can reliably investigate the impacts of the instructions on these performance metrics. Fig. 10 shows the



(a) Experimental group results for lateral position

(b) Control group results for lateral position



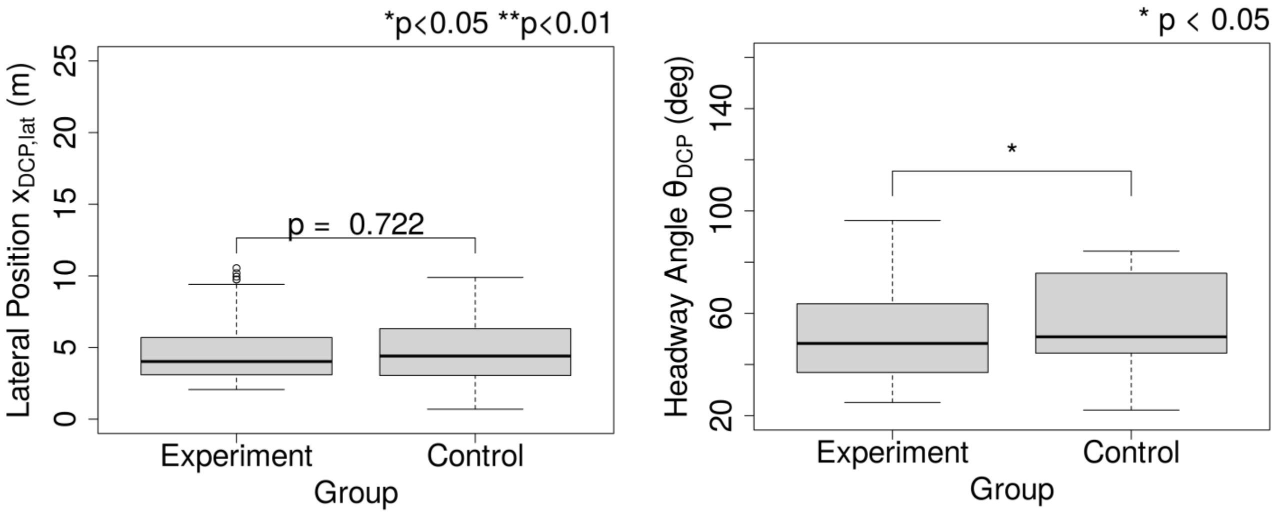
(c) Experimental group for headway angle

(d) Control group for headway angle

FIGURE 11. **Distributions of lateral position and headway angle at DCPs with respect to step factor. Significant differences were found for all combinations of steps in the experimental group.**

distribution of the positions and headways at the DCP for all combinations of steps and groups. The distribution in (b), the experimental group at the second step, clearly shows that the subjects changed the alignment from the first step (a).

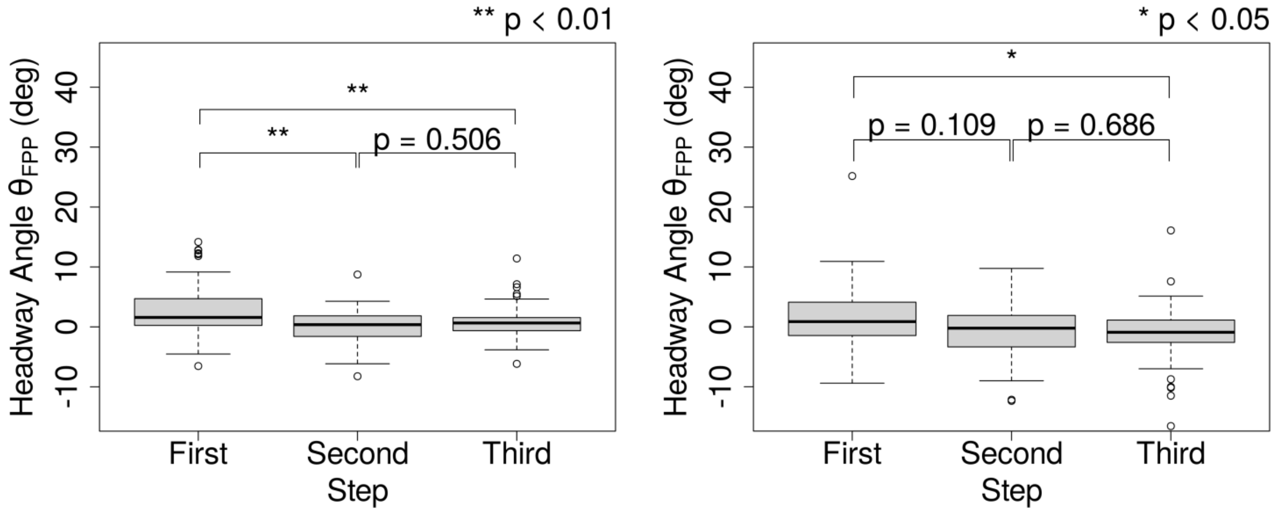
In addition, the Steel-Dwass multiple comparison test confirmed that there were significant differences between steps for the experimental group in both the lateral position and headway, while there was no significant difference for the control group. The step factors for the lateral position in the experimental group were $t(\infty) = 2.513$, $p = 0.003$, and $d_{co} = 0.330$ between the first and second steps; $t(\infty) = 2.705$, $p = 0.002$, and $d_{co} = 0.353$ between the first and third steps; and $t(\infty) = 4.410$, $p = 3.075 \times 10^{-5}$, and $d_{co} = 0.623$ between the second and third steps, as shown in Fig. 11(a). Meanwhile, those for the control group were $t(\infty) = 0.419$, $p = 0.908$, and $d_{co} = 0.056$ between the first and second steps; $t(\infty) = 0.553$, $p = 0.845$, and $d_{co} = 0.075$ between the first and third steps; and $t(\infty) = 0.167$, $p = 0.985$, and $d_{co} = 0.021$ between the second and third steps, as shown in Fig. 11(b). The test results for the headway angle in the experimental group were $t(\infty) = 3.365$, $p = 0.002$, and $d_{co} = 0.466$ between the first and second steps; $t(\infty) = 2.475$, $p = 0.036$, and $d_{co} = 0.319$ between the first and third steps; and $t(\infty) = 3.709$, $p = 0.001$, and $d_{co} = 0.501$ between the second and third steps, as shown in Fig. 11(c). Those for the control group were $t(\infty) = 1.115$, $p = 0.505$, and $d_{co} = 0.154$ between the first and second steps; $t(\infty) = 1.055$, $p = 0.542$, and $d_{co} = 0.147$ between the first and third steps; and $t(\infty) = 0.172$, $p = 0.984$, and $d_{co} = 0.022$ between the second and third steps, as shown in Fig. 11(d). These results indicate that the experimental group explored a wider range of DCPs at the second step along the instruction curve, as we observed in Fig. 10(b).



(a) Distributions of lateral position

(b) Distributions of headway angle

FIGURE 12. **Distributions of DCP at third step with respect to group factor. There was no significant difference between the experimental and control groups for $x_{DCP,lat}$, but the difference for θ_{DCP} was significant.**



(a) Experimental group for headway angle

(b) Control group for headway angle

FIGURE 13. **Distributions of headway angle at FPP with respect to step factor. Although no significant differences for $x_{FPP,lat}$ were found, all variables approached zero as the number of trials increased.**

The main effects for the lateral position and headway angle at the FPP were also analyzed. Wilcoxon rank test results for the group factor for the lateral position were $W = 2,787$, $p = 0.005$, and $d_{cl} = 0.287$ at the first step; $W = 3,349$, $p = 0.0523$, and $d_{cl} = 0.184$ at the second step; and $W = 3,298$, $p = 0.116$, and $d_{cl} = 0.149$ at the third step. The results for the headway angle were $W = 2,487$, $p = 0.1451$, and $d_{cl} = 0.148$ at the first step; $W = 3,046$, $p = 0.4187$, and $d_{cl} = 0.077$ at the second step; and $W = 3,737$, $p = 0.001$, and $d_{cl} = 0.302$ at the third step. Because there was a significant difference in the first step for the lateral position, the lateral position at the FPP was excluded from the following analysis. Steel-Dwass multiple comparison tests for the step factor were conducted regarding the headway angle. Both groups show significant improvements over time. The results for the experimental group were $t(\infty) = 1.653$, $p = 0.224$, and $d_{co} = 0.207$ between the first and second steps; $t(\infty) = 3.572$, $p = 0.001$, and $d_{co} = 0.491$ between the first and third steps; and $t(\infty) = 2.208$, $p = 0.070$, and $d_{co} = 0.274$ between the second and third steps, as shown in Fig. 13(a). Those for the control group were $t(\infty) = 0.086$, $p = 0.996$, and $d_{co} = 0.011$ between the first and second steps; $t(\infty) = 0.249$, $p = 0.967$, and $d_{co} = 0.033$ between the first and third steps; and $t(\infty) = 0.458$, $p = 0.891$, and $d_{co} = 0.059$ between the second and third steps, as shown in Fig. 13(b). These results show that there was bias between the groups regarding the lateral alignment at the FPP in addition to the task time, $t_{DCP:FPP}$. However, we could confirm a clear influence of the instructions on the headway, θ_{FPP}, in addition to RSE_{FPP}. It is unclear whether these biases were from a difference in the subjects' skill or their strategy.

A summary of the results of this experiment is as follows:

- The instructions improved the alignment at the FPP and RSE_{FPP}. This improvement persisted through the third step without further instructions.
- The experiment group subjects changed the alignment at the DCP to comply with the instruction curves.
- There was bias between the experiment and control groups regarding the task time, $t_{DCP:FPP}$, and the lateral alignment at the FPP.

V. APPLICATION EXAMPLE: A REARVIEW MONITOR USING PERCEPTUAL COMPENSATION

Rearview monitors are the most basic parking assist system currently available and are widely used by consumers. Although many systems have improvements such as auxiliary lines on the screen display or sound that changes according to the distance from the obstacle, they are basically control-level support systems because they start operating after the car starts backing up. Therefore, we aimed to develop an instruction method at the maneuvering-level using a rearview monitor to reduce the time required for reverse parking. However, to achieve this aim, it is necessary to resolve the problem of how to provide instructions on the appropriate DCP using the display of a rearview monitor.

Heckman *et al.* [35] reported that drivers look at their rearview monitor less than 30% of the time when engaged in parking. Assuming that drivers occasionally adjust their relative positions based on perceptions obtained from the rearview monitor, we might be able to direct the driver towards the appropriate DCP by adding bias to the rearview monitor image. Based on the findings in the previous sections, having good DCP alignment is correlated with having a smaller error at the FPP, and theoretically should result in reducing the need for retries as well.

Instead of the explicit direction, we altered the camera image to give a view that was biased in the lateral direction to give drivers the impression that their headway was larger than it actually was. Then, the drivers would control the car to decrease the headway that results in the appropriate DCP with a shallow angle headway. From the time that the driver started reversing until the end of the parking maneuver, the bias amount was gradually decreased to ensure there was no effect on the final positioning, as well as to prevent the drivers from noticing the image manipulation.

A. EXPERIMENTAL SETUP

The experiment was performed in a paved TCRDL parking lot that had been reserved for the experiment (see Fig. 14). The subjects were asked to reverse park the experimental car (2009 Toyota Prius) in a specified parking space. The experimental car was additionally equipped with a webcam for capturing the rearview of the car. The images were cropped in real-time to generate biased images, as shown in Fig. 15. These images were then shown on a 10-inch display mounted to the dashboard behind the steering wheel.

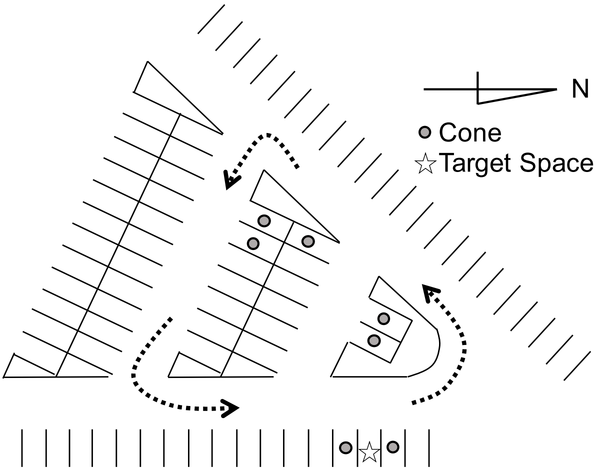


FIGURE 14. Experimental setup for controlled parking task. Subjects operated an experimental car on a paved parking lot.

FIGURE 15. Method for implementing biased rearview image.

The time from the start of reversing to the end of parking for each trial was recorded as the performance index. The start and end times were automatically detected by monitoring the changes in gear shifting signals from driving to reversing, and from reversing to parking. The signals were captured from the car's control area network via an onboard diagnostics scanner at 10 Hz.

B. PROCEDURE

The experimental procedure consisted of two steps, a non-biased stimulus task, and a biased stimulus task. The subjects were allowed to familiarize themselves with the experimental setup by practicing driving and parking the car before the tasks. In the non-biased and biased stimuli tasks, the subjects were asked to navigate the car into the parking space and conduct reverse perpendicular parking 20 times in the manner shown in Fig. 14. After each step, the subjects were asked to report their impressions to determine whether they had noticed the image bias. No subjects noticed the altered image bias in this experiment.

Each subject participated in this experiment over the course of 2 days. Nine of the subjects executed the non-biased stimulus task after they had executed the biased stimulus task (group A), and the procedure was reversed for the other six subjects (group B).

C. SUBJECTS

The number of subjects participating in this experiment was similar to the number of subjects used in the previous driving simulator experiment. A total of 15 male and 1 female employees of TCRDL participated in this experiment. All subjects had valid driver's licenses. Statistical power analysis with $\eta^2 = 0.2$ and $\alpha = 0.05$ employing the number of subjects results in a power of $1 - \beta = 0.7$ in two-way ANOVA for two groups by the G*Power 3.1.

D. RESULTS AND DISCUSSION

As in the driving simulator experiment described in the previous section, measurements in the latter half of the 20 trials were used in the analysis, with the successful completion of the task in one effort. The screening resulted in a total sample size of 507, and the sample size for each combination of factors is shown in Table 4.

TABLE 4. **Sample size for each combination of factors.**

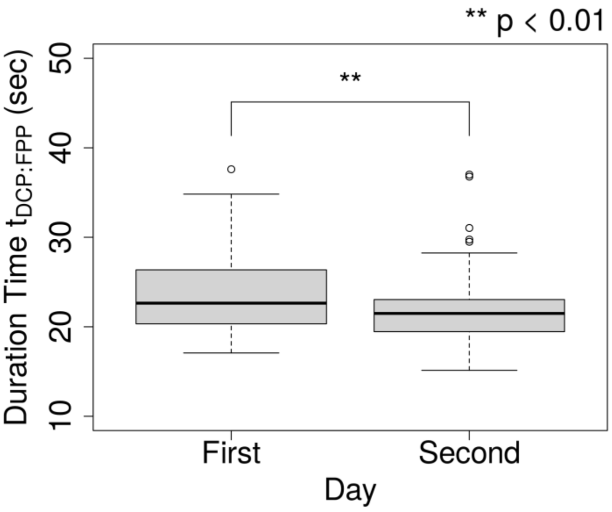
Group	First day	Second day
A	104	137
B	128	138

TABLE 5. **Result of two-way ANOVA for performance indices.**

		Duration Time from DCP to FPP $t_{DCP:FPP}$				
Source	DF	SS	MS	F-value	p-value	η²
Group	1	2	2	0.13	0.724	<0.001
Day	1	227	227	14.96	<0.001**	0.029
Interaction	1	34	34	2.23	0.136	0.004
Error	503	7,640	15			
Total	506	7,903				

** p<0.01; see Table II for key to abbreviations.

Time differences were analyzed using a two-way ANOVA that considered the order of stimuli and the day on which the trial was conducted. Here, the group factor has two levels, and the day factor also has two levels (first and second day). The statistical analysis results shown in Table 5 indicate that the day factor significantly affected the time. Wilcoxon rank test results for all combinations were $W = 8,956$, $p = 9.638\times10^{-4}$, and $d_{cl} = 0.248$ for group A, as shown in Fig. 16(a); $W = 7,561$, $p = 0.053$, and $d_{cl} = 0.138$ for group B, as shown in Fig. 16(b); $W = 7,010$, $p = 0.487$, and $d_{cl} = 0.053$ on the first day; and $W = 10,401$, $p = 0.150$, and $d_{cl} = 0.100$ on the second day. Although there was the reduction in duration for each group from the first day to the second day, only group A had significantly reduced time. Unfortunately, significant improvement by the system was not observed.



(a) Group A (First=biased; Second=non-Biased)

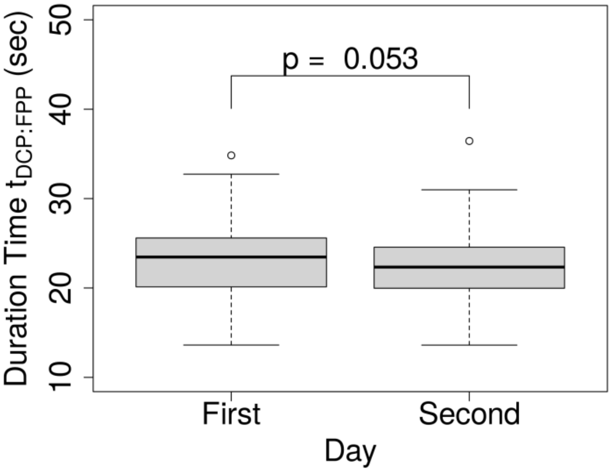


FIGURE 16. **Distributions of duration for verifying perceptual compensation using rearview monitor. There was a significant difference in duration between the biased and non-biased groups.**

Although we could not find a significant effect in this experiment, because no subject noticed the image alternation, this approach can potentially be used for directing the user unconsciously. However, to explore its effectiveness, further investigations should be conducted.

VI. CONCLUSION

This study focused on improving perpendicular parking performance. Through in-situ observations and experiments in a controlled environment, we found that proper positioning before the start of a reversing maneuver is highly correlated with parking performance. Additionally, we hypothesized that giving an instruction regarding the appropriate start position before reversing would result in better parking performance. Our driving simulator study results indicated that the instructions might change the reversing positions and improve the parking alignment accuracy. The improvement lasted even after the instructions were removed.

Furthermore, we tested a system prototype that alters rearview monitor images. While we could not confirm a significant effect for this system, the method has the potential to direct appropriate maneuvers unconsciously during parking. The benefit of our approach is that since we are only modifying the camera feed, it does not add extra workloads for drivers. The existing approaches that superimpose auxiliary lines, for instance, need extra attention for the alignments of lines in the display and, therefore, might lose appropriate situational awareness to the surroundings [36].

A major limitation of this study is that no elderly subjects participated in the controlled experiments. Because the number of older adults is growing worldwide, it is becoming more important to assist them. A lot more factors need to be considered for designing the parking assistance for elderly drivers in comparison with the younger generations. Not only has it been reported that age-related narrowing of the visual field has a negative impact on driving skills [29], elderly drivers tend to be overconfident in their driving skills [37]. Furthermore, appropriate countermeasures need to be considered when conducting experiments using driving simulators, because elderly subjects have been shown to experience simulator sickness more often than younger subjects [38].

In addition, obstacles, including other vehicles and pedestrians, are not considered in this study, while these are important factors for parking tasks [30]. To extend our hypothesis to such a situation, situational awareness and its impact on parking performance need to be incorporated [39], [40].

Another limitation is the lack of sufficient between-subject analysis on the preliminary behavior. While the observation experiment demonstrated a relationship between the DCP and parking performance, individual differences in the DCP were not quantitatively analyzed. These differences may affect acceptance of the given instructions and their effectiveness for performance improvement. A more significant number of measurements would be needed for a statistically meaningful analysis. Conducting a large-scale observation experiment for the between-subject analysis of the DCP is a potential future work.

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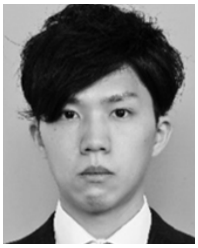

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