Effect of Different Distractions on Driving Performance for Drivers Using a Touch Screen

Toru Hagiwara, Ryo Sakakima, Takumi Kamada, and Yutararo Suzuki

This study investigated the effects of various task loadings on driving performance for drivers who used a touch screen. The objectives were to evaluate the influence of three secondary tasks on the primary task, to clarify the effects of the task loadings in combination on driving performance, and to determine effective measures for minimizing the effect of touch screen tasks on driving performance. To achieve these objectives, a field experiment was conducted on a test track with 16 participants. There were three secondary tasks: viewing numbers on the touch screen and reading them aloud in ascending order, viewing numbers on the touch screen and tapping them in ascending order on the touch screen, and tapping the four corners of the touch screen. Vehicle motions, the duration of the driver’s glance at the screen, and the duration of the driver’s tapping the screen were measured. The driving performance indicators were speed, headway distance, and lateral distance from the center of the lane. When drivers operated the touch screen while driving, each task loading was found to have a different effect on each driving performance indicator. The analysis found that measures that were effective in maintaining high driving performance decreased the individual duration of each secondary behavior and reduced the variety of task loadings and their combinations. Driving style also influenced the degree to which each task loading affected driving performance.

Distractions tasks that result from the use of in-vehicle information systems (IVIS) have the potential to affect drivers in different ways. Studies have shown that interactions with IVIS while driving negatively affect driving performance (1–3). Crandall and Chaparro reported that the touch screen interface was associated with poorer vehicle control than the physical interface, based on the Daimler Chrysler AG Research and Technology Lane Change Test driving simulator version 1.2 (4). Ranney et al. assessed the distraction potential of secondary tasks performed when drivers used in-vehicle systems and portable phones while driving. That study found text messaging to have the highest distraction potential, followed by 10-digit phone dialing. The use of a portable touch screen interface was found to be slightly more distracting than the use of a hard-button interface (5). Blaschke et al. investigated the influence of typical IVIS tasks on lane-keeping (6). They found that most IVIS tasks caused lateral deviations to increase, but in the majority of cases the drivers were still able to stay in the lane. Many studies have examined how the use of IVIS with touch screen interface affects driving performance.

Wickens proposed the multiple resource theory of attention and noted that various pools of cognitive resources can be used in parallel (7). Tasks that require the same input (visual or auditory) or output (manual or speech) modalities will mutually interfere. Interacting with a touch-controlled IVIS, for example, requires visual inputs and manual outputs, which are exactly the same inputs and outputs required by the driving task. Voice-controlled IVIS might have less impact on the driving task, as they require different input and output modalities from those required by the driving task (8, 9). Task loadings that use the touch screen while driving could consist of glancing, tapping, and recognizing information displayed on the screen. Many studies have addressed the effects of one task loading selected from among the three task loadings. However, few studies have addressed the effects of the task loadings, single and in combination, on discrete components of driving performance.

A driver’s headway and lateral control may be influenced by touch screen use in several possible ways. First, a glance at the touch screen may interfere with the driver’s visual scanning of the traffic environment. Second, a tap on the touch screen may interfere with the driver’s actions used to control the vehicle. However, these assumptions are not clearly revealed. The objective of this study was to investigate whether the touch screen task had any effects on driving performance through the driver’s behaviors. This study sought to clarify how various task loadings and their combinations that are caused by operating a touch screen affect driving performance.

The study measured drivers’ glancing and tapping behaviors on a touch screen and assessed interactions between the touch screen task and driving performance through drivers’ glancing and tapping behaviors. The primary task consisted of following a leading vehicle while maintaining a constant headway and speed to assess interference with the driver’s visual scanning and the driver’s actions. The secondary task, which involved use of the touch screen while driving, consisted of three tasks to assess interference with the driver’s visual scanning and actions: viewing numbers displayed on the touch screen and reading them aloud in ascending order (Voice), viewing numbers displayed on the touch screen and tapping them in ascending order on the touch screen (Touch), and tapping the four corners of the touch screen (Tap). Driving performance was divided into two components: longitudinal control (speed and headway) and lateral control (lateral position). To achieve the study’s objectives, a field experiment was conducted on a test track with 16 participants.

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METHODS

Experiment Date and Participants

Sixteen drivers (aged 20 to 50 years; four females and 12 males) participated in the experiment. Participants were recruited through local advertisements and were screened to ensure that they were active drivers with a valid Japanese driver’s license, a minimum of 5,000 km driven per year, and normal vision. Participants were paid US$70 for their participation. Data for the experiments were collected between July 2 and July 8, 2011. The experiments were conducted under dry conditions only. The experiments were conducted at the test track of the Civil Engineering Research Institute for Cold Region, a 2,700-m oval track in Tomakomai City, Japan.

Primary and Secondary Tasks

Maintenance of 30 m of headway was selected as the primary task with a speed of about 60 km/h. The headway time was less than 2 s. It was thought that the participants might spend a greater amount of time glancing away from the road than they would in a real driving task and that this could influence the secondary task. The license plate of the leading car was selected as an appropriate visual target for the participants to maintain about 30 m of headway while following the leading vehicle.

The secondary tasks in this experiment used a Century display 8-in. touch screen (LCD-8000), which is shown in Figure 1. The three secondary tasks were configured as follows:

- Voice. The participants were required to read aloud, in ascending order, the numbers in a gray square that were displayed on the screen (Figure 1). Visual distraction and cognitive distraction can occur during such a search while the driver maintains headway and lateral position.
- Touch. The participants were required to tap with their left index finger, in ascending order, the numbers that were displayed in a gray square on the screen. As with Voice, visual distraction and cognitive distraction can occur during such a search. Manual distraction can occur after the driver takes the left hand off the steering wheel and taps the correct number on the touch screen with the index finger while maintaining headway and lateral position.
- Tap. The participants were required to tap the four corners of the screen in clockwise order (top left, top right, bottom right, bottom left). Visual and cognitive distractions were minimized. Manual distraction can occur after the driver takes the left hand off the steering wheel and taps the four corners of the screen with the index finger while maintaining headway and lateral position.

Task Duration Conditions

To evaluate the effect of secondary task duration on driving performance, tasks of short and long duration were used (Figure 1). Standard SAE J2364 specifies that drivers should not be allowed to perform navigation system tasks in a moving vehicle if the tasks take more than 15 s to complete when measured under static conditions (10). The short-duration condition used seven numbers highlighted on the screen (Figure 1a) and the duration to complete this task was found to be roughly 10 s by repeated pretests before the experiment. The long-duration condition was approximately double the short-duration condition. The long-duration condition used 14 numbers highlighted on the screen (Figure 1b) and the duration to complete this task was found to be roughly 20 s.

Touch Screen Position

Japan Automobile Manufacturers Association reported on positions of the display that would minimize visual distraction while driving (11). They found that the lower limit of the elevation angle for an in-vehicle display in a passenger car was 30°. To evaluate the effect of touch screen position on driving performance, the present study used the high and low positions shown in Figure 2. The elevation angle for the high position was 18.7° and that for the low position was 54.5°. Screen position was not adjusted for each participant.

Measurement Systems

Measuring Vehicle Motion

Two vehicles (a leading vehicle and an instrumented vehicle) were used for the experiment. Data were recorded with the RTK-GVS, which is a simple, real-time location recording system produced by Vios System Co., Ltd. in Japan. The RTK-GVS GPS used an accelerometer and a gyrocompass to record the location of the two vehicles in real time. The sampling and output rate of the system is 100 Hz and the system accuracy is 3 mm each for the longitudinal and lateral positions. In this experiment, the headway distance and lateral distance between the two vehicles and the driving speed of the
instrumented vehicle were continuously recorded by the RTK-GVS installed in the leading vehicle and the instrumented vehicle.

Measuring Duration of Glance at the Screen

A small, static, onboard video camera, shown in Figure 3 and installed on the dashboard, was used to record the duration of glances at the screen by the driver. After the experiments, the experimenter recorded the time codes for when the participant started and ended each glance at the screen on a sheet by advancing the video image frame by frame.

Measuring Duration of Tapping the Screen

A small, wearable, wireless sensor that contains a three-axis gyro accelerometer chip was used to measure the driver’s duration of tapping the screen. This sensor (WAA-010) was recently developed by Advanced Telecommunications Research Institute International in Japan. The sensor is small enough (39.0 mm wide × 44.0 mm high × 12.0 mm deep; 20 g) so as not to disturb the driver while driving. The sensor was placed on the driver’s left arm, as shown in Figure 3. The sensor sent measured data sampled at 20 Hz. A tap to the screen was defined according to the following threshold: triaxial synthesized angular velocity exceeding 200 degrees/s with duration exceeding 0.2 s.

Generating the Synchronization Signal

The push-button switch shown in Figure 3 was prepared to establish time synchronization of the vehicle motion data recorded by the RTK-GVS, left-arm motion data recorded by a small, wearable, wireless sensor, and glancing behavior data recorded by the small charge coupled device (CCD) camera. The push-button switch activates a 5-V pulse and all data acquisition systems record this electrical event.
on their respective dedicated channels, regardless of when the actual data sampling was started. The push-button switch turned on an LED light that the small CCD camera recorded.

**Experimental Design and Procedure**

The study employed a repeated-measures design. There were three independent variables: secondary task, with three levels; screen position, with two levels; and task duration, with two levels. The 13 test conditions, including the baseline condition, were randomly assigned to a sequence of 13 test conditions for each participant. The baseline condition, which was only the primary task, was performed at the beginning by each participant. At the beginning of the session, the experimenters briefly explained the schedule, the experimental overview, and the secondary tasks to be performed while driving. The instructions specified that the car-following task was the first priority and the touch screen tasks were the second.

After all the questions were answered, the participant gave written informed consent for participation. No individual declined to participate. The participants went to the starting area of the test track, where they were instructed on how to complete the three secondary tasks. After adjusting the seat and the steering wheel, the participants had a training session. They drove the test vehicle a few times and familiarized themselves with the primary car-following task and the secondary tasks. At each run, the participants had to maintain an approximate speed of 60 km/h and headway of 30 m relative to the leading vehicle. The process was repeated 13 times.

**RESULTS**

**Driver Behavior**

All 16 participants performed 13 runs of the 13 assigned test conditions. The target data were successfully recorded for the 208 runs. Except for the baseline condition (192 runs), the start and end times for glancing at the screen were computed repeatedly based on the video scene recorded by the small CCD camera. The total number of glances was 1,638 for the 192 runs. The start and end times for each screen tap were computed from each run based on motion data stored in the personal digital assistant. The total number of taps was 1,287 for the 192 runs. In addition, the duration of combination for each action of glancing at the screen and tapping the screen was computed. The total number of combinations of glance and tap was 946 for the 192 runs.

**Total Glance Duration and Total Tap Duration**

Total glance duration was defined as the combined duration of all glances at the screen per run. Figure 4 shows the mean and standard deviation of total glance duration and total tap duration for 13 test conditions for each secondary task, with three levels; screen position, with two levels; and task duration, with two levels. The 13 test conditions, including the baseline condition, were randomly assigned to a sequence of 13 test conditions for each participant. The baseline condition, which was only the primary task, was performed at the beginning by each participant. At the beginning of the session, the experimenters briefly explained the schedule, the experimental overview, and the secondary tasks to be performed while driving. The instructions specified that the car-following task was the first priority and the touch screen tasks were the second.

After all the questions were answered, the participant gave written informed consent for participation. No individual declined to participate. The participants went to the starting area of the test track, where they were instructed on how to complete the three secondary tasks. After adjusting the seat and the steering wheel, the participants had a training session. They drove the test vehicle a few times and familiarized themselves with the primary car-following task and the

![Figure 4](image-url)
deviation of total glance duration as a function of the three secondary tasks, the two screen positions, and the two task durations. Figure 4c shows the mean and standard deviation of the total number of glances per each distraction condition. The means of total glance duration for the baseline and Tap conditions were approximately 0 s. Three-way, within-subjects analysis of variance (ANOVA), excluding the baseline and Tap conditions, was conducted to evaluate the effect of the three independent variables on the total glance duration. No interaction effects were found. Secondary task $F(1,122) = 3.30, p < .1$ and task duration $F(1,122) = 175.1, p < .01$ had a significant effect on the mean total glance duration. The mean total glance duration for Touch was significantly greater than that for Voice.

Total tap duration was defined as the combined duration of tapping the screen per run. Figure 4b shows the mean and standard deviation of total tap duration as a function of the three secondary tasks, the two screen positions, and the two task durations. Figure 4d shows the mean and standard deviation of the total number of taps per each distraction condition. The means of total tap duration for the baseline and Voice conditions were approximately 0 s. Three-way within-subjects ANOVA, excluding the baseline and Voice conditions, was conducted to evaluate the effect of the three independent variables on the mean total tap duration. No interaction effects were found. Secondary task $F(1,122) = 6.20, p < .05$ and task duration $F(1,122) = 80.7, p < .01$ had a significant effect on mean total tap duration. The mean total tap duration for Touch was significantly greater than that for Tap.

Vehicle Motion Versus Driver Behavior

In this experiment, the leading vehicle ran at a constant speed. The combined mean driving speed of the leading vehicle during the secondary task was 60.3 km/h and the standard deviation was 0.43 km/h. Figure 5a plots headway distance against the 1,683 glances. A positive headway distance means that the subject’s vehicle was closer to the leading vehicle than the instructed headway distance. There was a clear tendency for the absolute value of headway distance to increase with increases in the duration of each glance, until the glance duration of 1.5 s. Figure 5b plots headway distance against the 1,287 taps. There was a clear tendency for the absolute value of headway distance to increase with increases in the duration of each tap, until the tap duration of 2.0 s. Figure 5c plots headway distance against the 946 combinations of glance and tap. There was a clear tendency for the absolute value of headway distance to increase with increases in the duration of each combination, until the duration of 1.5 s. Based on these three plots, the absolute value of the headway distance increased with increases in the duration of the three driver behaviors. However, it could not be determined whether headway distance increased or decreased.

Figure 6a plots lateral distance against the 1,638 glances. Positive lateral distance means that the vehicle deviated leftward. There was a nearly constant tendency for the absolute value of lateral distance to increase with increases in the duration of each glance. Figure 6b plots lateral distance against the 1,287 taps. There was a nearly
constant tendency for the absolute value of lateral distance to increase with increases in the duration of each tap. Figure 6c plots lateral distance against the 946 combinations of glance and tap. There was also a nearly constant tendency for the absolute value of lateral distance to increase with increases in duration for each combination. Based on these three plots, the absolute value of lateral distances did not show a clear tendency to increase with increases in each of the three driver behaviors; instead, it showed a nearly constant value. However, it could not be determined whether lateral distances had negative or positive value.

### Mean Speed, Mean Headway Distance, and Mean Lateral Distance

Figure 7 shows the results for mean speed, mean headway distance, and mean lateral distance for each of the 13 test conditions. The means and standard deviations were calculated for each of the three driving performance indicators. Figure 7a shows the results for mean speeds while drivers performed the secondary tasks. The mean speed for the baseline was 60.0 km/h and the standard deviation was 0.47 km/h, which was the smallest among the 13 test conditions. Within-subjects ANOVA was performed with R-2.15.2, which is a statistical analysis software package. There were no significant interaction effects among the three independent variables. The secondary tasks \[F(2,186) = 6.17, p < .01\] had a significant effect on speed and the task durations \[F(1,186) = 3.16, p < .10\] had a significant tendency to affect speed. Post hoc tests for the secondary tasks showed that the speed for Tap was significantly higher than that for the other two task conditions.

Figure 7b shows the results for mean headway distance. The mean headway distance for the baseline was 31.0 m (standard deviation 10.0 m). There were no significant interaction effects among the three independent variables. And there were no significant main effects. Figure 7c shows the results for mean lateral distance. There were no significant interaction effects among the three independent variables. The secondary tasks \[F(2,186) = 2.55, p < .10\] and the touch screen position \[F(1,186) = 3.53, p < .10\] had a significant tendency to affect the mean lateral position. Post hoc tests for the secondary tasks showed that the lateral distance for Touch was significantly greater than that for Voice and Tap. For the high position, the mean lateral distance was significantly greater than that for the low position.

### Mean Standard Deviation of Speed, Headway Distance, and Lateral Distance

Figure 8 shows the results for the mean standard deviation of speed, headway distance, and lateral distance for each of the 13 test conditions. The means of the standard deviations were calculated for the three driving performance indicators. Figure 8a shows the results of the mean standard deviations for speed. Within-subjects ANOVA was performed. There were no significant interaction effects among the three independent variables. The secondary tasks...
the three independent variables. The secondary tasks \( F(2,186) = 2.39, p < .10 \) had a significant tendency to affect the mean standard deviation for speed, and the task durations \( F(1,186) = 9.80, p < .01 \) had significant effects on the mean standard deviation for speed. Post hoc tests for the secondary task showed significant differences between that for Voice and that for Tap and significant differences between that for Touch and that for Tap. The mean standard deviation of speed for Tap was the lowest of the three secondary conditions.

Figure 8b shows the results for mean standard deviations for headway distance. There were no significant interaction effects among three independent variables. The secondary tasks \( F(2,186) = 10.6, p < .01 \) and the task durations \( F(1,186) = 23.6, p < .01 \) had a significant effect on the mean standard deviation for speed. Post hoc tests for the secondary tasks showed that there were significant differences in headway distance between Voice and Tap and significant differences in headway distance between Touch and Tap. As was the case for speed, the mean standard deviation for headway distance for Tap was the shortest among the three secondary conditions.

Figure 8c shows the results of the mean standard deviation for lateral distance. There were no significant interaction effects among the three independent variables. The secondary tasks \( F(2,186) = 12.1, p < .01 \) and the task duration \( F(1,186) = 4.51, p < .05 \) had a significant effect on mean lateral position. Post hoc tests for the secondary tasks showed that the mean standard deviation for Touch was significantly greater than those for Voice and Tap.

Parameter Identification

The analysis required effective measures to minimize the effect of touch screen tasks on driving performance. There are two choices for effective measures in reducing the fluctuation of headway distance and lateral distance: decrease the duration of each glance and the duration of each tap, or decrease the total number of glances and taps per run. The mean absolute value of the headway difference in distance per run (the headway difference) and the mean absolute value of the lateral difference in distance per run (the lateral difference) were calculated based on recorded data.

Multiple regression analysis was conducted with headway distance and lateral distance as the dependent variables. The study proposed six linear models as a function of the three secondary tasks and two dependent variables, toward identifying effective measures to minimize the effects of touch screen tasks on driving performance. The independent variables are the mean duration of a glance per run, \( X_1 \); the mean duration of a tap per run, \( X_2 \); the mean duration of both glance and tap per run, \( X_3 \); display position, \( X_4 \); task duration, \( X_5 \); the standard deviation of headway distance for each participant in the case of the baseline condition, \( X_6 \); and standard deviation of lateral distance for each participant in the case of the baseline condition, \( X_7 \). The individual driving styles of each participant are denoted \( X_6 \) and \( X_7 \). Table 1 shows the significant independent variables for each of the six models, the corresponding regression coefficients, and the \( t \)-values. The determination coefficients for the six models range from .26 to .65. These determination coefficients are adjusted by the degrees of freedom.

Headway and lateral differences for Voice increased with increases in the duration of a single glance. Headway difference increased with increases in standard deviation of headway distance and mean absolute value of lateral difference per run increased with increases in standard deviation of lateral distance. Lateral difference increased when the screen position was low. Headway and lateral differences for Touch increased with increases in the duration of a single glance and with increases in the duration of a single tap. Headway difference increased with increases in standard deviation of headway distance and lateral distance increased with increases in standard deviation of lateral distance. Headway and lateral differences for Tap increased with increases in the duration of a single tap.

### Table 1: Significant Independent Variables for Six Models, with Corresponding Regression Coefficients and \( t \)-Values

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Independent Variable</th>
<th>Coefficient</th>
<th>( t )-Value</th>
<th>( p )-Value</th>
<th>( R^2 )</th>
</tr>
</thead>
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<td><strong>Voice</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Headway difference in distance(^a)</td>
<td>Duration time of single glance</td>
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\(^a\)Mean absolute value of headway difference in distance per run.
\(^b\)Averaged SD of headway distance per each subject.
\(^c\)Mean absolute value of lateral difference in distance per run.
\(^d\)Averaged SD of lateral distance per each subject.
tap. Lateral difference decreased when the task duration was long. Headway difference increased with increases in standard deviation of headway distance, and lateral difference increased with increases in standard deviation of lateral distance.

These results indicate that effective measures in reducing headway and lateral differences would be to decrease the duration of a single glance and the duration of a single tap. The models indicate that headway and lateral differences significantly depend on the driver’s individual driving style.

**DISCUSSION AND CONCLUSIONS**

Before starting the analysis, each driver’s behavior was observed under each of the three secondary tasks. First, glancing at the screen for Voice was the dominant driver behavior during each run. The combination of glancing at the screen and tapping the screen was the dominant driver behavior for Touch and tapping was the dominant driver behavior for Tap. The glancing time for Tap totaled for the 13 tests was approximately 0 s, and the tapping time for Voice totaled for the 13 tests was approximately 0 s. These results could indicate that Voice minimized the effects of manual task loading and Tap minimized the effects of visual task loading.

Second, the interference associated with the three secondary tasks was evaluated in terms of its effect on speed, headway distance, and lateral distance. The three secondary task conditions had different effects on the three vehicle motions. Voice and Touch showed significantly less consistent headway distance than that of Tap. Lateral distance for Touch was significantly less consistent than that for Voice and Tap. Touch resulted in the least consistent lateral distance among the three secondary tasks. However, the screen position condition showed no significant effect on any of the three vehicle motions. It is thought that the combination of visual and cognitive task loadings has a greater effect on the driving performance indicator of longitudinal control, whereas the combination of visual, manual, and cognitive task loadings has a greater effect on the driving performance indicator of lateral control. Manual task loading alone had less effect on longitudinal control than the combinations of task loadings. In addition, from the point of view of the driver’s behavior, glances at the touch screen, including visual task loading, mainly interfered with the driver’s visual scanning of the leading vehicle; glances with tapping interfered not only with the driver’s scanning but also with the driver’s actions used to control the vehicle laterally.

Third, the human-machine interface was addressed toward finding measures to minimize the effect of task loadings caused by operating the touch screen display. Multiple regression analysis was conducted with the absolute value of headway and lateral differences in distance as the dependent variables. The study proposed six linear models as a function of the three secondary tasks and two independent variables. Increases were found in the absolute value of the difference in headway distance with increases in duration for a single glance and a single combination of glance and tap. The absolute value of the difference in lateral distance increased with increases in the duration of a single glance and a single combination of glance and tap. Measures that would be effective for maintaining driving performance would be to decrease the duration per single glance and per single combination of glance and tap. In addition, the model shows that headway and lateral differences in distance significantly depend on each driver’s individual driving style.

Based on these results, it might be concluded that by far the largest effects observed on driving-relevant metrics were on the combination of visual, manual, and cognitive task loadings. Under these conditions, the simultaneous occurrence of a glance and tapping on the screen interfered not only with the driver’s scanning to follow the leading vehicle but also with the driver’s actions to control the vehicle laterally. To maintain driving performance, it would be effective to decrease the duration of each secondary behavior and to reduce the variety of task loadings and their combinations. However, this study did not clearly address the effects of cognitive task loadings on driving performance. A future study is planned to evaluate how cognitive task loading affects driving performance. Another consideration is that drivers on a test track may spend a greater amount of time glancing away from the road than they would on a road and this could influence the secondary task and driving performance. Ranney noted that the real-world risk associated with a secondary task relates to the priority given by the driver to that task and the driving situations in which the driver is willing to engage in the task (12). Thus, the findings of this study should be confirmed under real driving conditions.

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