Comparisons of driver distraction from in-vehicle device use: rotary controllers and touch screens

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Abstract
Recently, various kinds of interaction types have been widely utilized in numerous application devices. Especially in automobiles, rotary controllers and touch screens have been most prevalently adopted in controlling many functions of in-vehicle information systems (IVIS) while driving. In-vehicle devices should be much more carefully considered due to the dual task properties. Though many studies on the usability across interaction types of controllers have been conducted, the researches on comparison of differences in driver’s distraction between rotary controllers and touch screens for controlling the in-vehicle devices has been absent yet. The aim of this study is to analyze the driver’s distraction across the two interaction types under driving situations. In this end, a user experiment was conducted in a driving simulator environment, to examine driver’s distraction. The primary driving performance, secondary task performance, and visual distraction were measured and evaluated. Based on the results, the distraction level of each interaction type was scrutinized. This study could be helpful in comprehension of which interaction types are more suitable in terms of safety and usefulness for in-vehicle devices under the driving situation.

Keywords: in-vehicle navigation systems, interaction, distraction, touch screen, rotary controller

Introduction
In-vehicle GPS navigation systems have become one of the essential devices in automobiles. The in-vehicle GPS navigation systems are controlled by touch screens or rotary controllers, while touch screens are prevalently used as smart devices (smart phones or tablets) utilized as alternative navigation systems [1, 2]. The market of GPS navigation systems have been showing annual average growth rate of 13% globally from 2008 to 2010, with a remarkable growth rate of 491.5% from 2009 to 2010 in South Korea [3]. Hence numerous researchers have studied the in-vehicle GPS navigation systems.

The in-vehicle GPS navigation system cannot avoid the dilemma of dual tasks while driving, which must be indispensably considered as it is under the category of an in-vehicle device. According to the study of Horrey and Wickens [4], not only visual tasks disaggregating attention, but also non-visual tasks using voice recognition or hands-free devices induce average reaction time delays of 130ms in case of unforeseen dispersion of driver’s attention [5-7].

Cognitive abilities primarily required by a driving task are visual recognition and attention resource for detecting both a car driving in front and possible risk factors on the road. Moreover, drivers may be distracted by watching speedometers or maps, listening to radio or music, or sharing some conversation with passengers. Previous studies in substantial numbers also accentuated the risks of adrift gaze - off from a road in front and dispersion of driver’s attention [5-7].

The interaction types between the driver and in-vehicle information systems may be represented in two groups. One is a traditional or prevalent type such as physical button/switch, touch screen, or rotary controller while the other is a nascent type such as speech recognition and gestures. As of a traditional type of in-vehicle information systems, most of the navigation systems also possess touch screen controller. Also, smartphones and tablets with touch screens may often substitute for in-vehicle navigation systems [1, 2], thereby controlling the navigation system via touch screens have become more habitual. Device controls through touch screens incur non-rigorous forward concentration while driving and unstable driving postures which eventually threatens drivers’ safety [8]. To overcome such disadvantages of touch screens and fully utilize many of in-vehicle functions, automobile manufacturers have conducted studies on development of multifunctional interface which allows drivers to manipulate various functions without the risk of safety through the minimization of the drivers’ gaze being away from road. Subsequently, some navigation systems applied the rotary controllers as an alternative [9]. ‘i-drive’ of BMW, ‘MMI’ of Audi, ‘COMAND APS’ of Mercedes-Benz, or DIS controller of HMC are the representative examples and they all utilize the in-vehicle functions by rotary controllers.

Nevertheless, there has been no clear studies about the attention dispersion of drivers in respect to two different control types: touch screen and rotary controller. Harvey et al. [10] conducted a comparative study on the difference between the touch screen and rotary controller during the in-vehicle information system manipulation. Yet the corresponding study was conducted in the Great Britain where the right hand dominant participants were bound to manipulate the devices with their left hand, under the right-hand drive vehicle situation. Thus, the result of the study may not be fully applicable for countries where drivers are under the left-hand drive
vehicle situation such as the United States, China, and South Korea. Furthermore, adequate number of tasks could not be performed for the navigation system because the study embraced the in-vehicle information systems in general rather than the in-vehicle GPS navigation system solely.

This study concentrated on the comparison of driver’s attention dispersion in respect to two different control types: touch screen and rotary controller, while driving and using a navigation device. A driving simulator and eye tracker were utilized to measure and juxtapose the driver’s attention dispersion in two different driving environments.

**Methods**

**Participants**

Total eight graduate students (five males, three females) from Seoul National University within an age group ranging from 25 to 34 years old (mean = 27.63, SD = 3.07) were recruited for the experiment. Every participant held driving licenses and had more than one year of driving experience in left-hand driving countries. Participants were all right-hand dominants. All of the participants were with either normal or corrected normal vision, and without any color recognition problems [11]. To check the basic cognitive ability, MMSE(Mini Mental Status Exam) was performed [12], and all subjects acquired more than a passing score (27/30 points). Every subject had normal level of attention capability.

**Apparatus**

In this study, we used automotive simulation software UC-win/Road version 10.0 of Forum8 and a driving simulator developed by the Department of Industrial Engineering, Seoul National University, South Korea. The simulator used in this study is shown in Figure 1. Subject’s eye gaze was measured by using eye-tracker produced by Dikablis (Dikablis Essential) and eye-tracking data was analyzed by using Dikablis’ D-Lab 3.0 software. The driving behaviors of the subjects were recorded by Sony’s NEX-6 camera.

An iPad mini (A1489) was used as a representative navigation system with touch screen and the device for a rotary controller condition was self-developed. Positions of the rotary controller along with the display in the simulation environment were the same as those of commercialized passenger cars.

Statistical results were obtained and analyzed by using the SPSS 22.0 and Noldus’ the Observer XT 8.0 software.

**Experimental Design and Procedure**

Each subject participated in two experimental conditions: touch screen condition and rotary controller condition. In both experimental conditions, subjects were placed in driving situations and instructed to perform secondary tasks with the navigation system while driving. To prevent learning effects, the order of conditions for subjects was counter balanced.

Subjects wore an eye tracker and were instructed to sit down on the simulator to drive along the designated road (5.0 km) with a combination of curved and straight sections. While driving, subjects should maintain their driving speeds at 70 kilometers per hour and the lane they are driving on as well. They were asked to do three secondary tasks, and these secondary tasks consisted of “text-input” task, “list search” task, and “map zoom in/out” task. The "text-input" task was entering the destination name into the navigation system, and the "list search" task was finding the desired destination in the list of recent destinations (scroll adjustments). The "map zoom in/out" task was adjusting the scale of the map under the driving situation (scale zoom in/out).

In addition to the second tasks, subjects should respond to the change of the colors of LED light sources presented in near vision zone [13]. Color changes of the light source was indicated six times in total when driving, three times under a primary driving situation only while the other three were under each secondary tasks.

The objective of this experiment was to find out that which interaction type (touch screen or rotary controller) for navigation systems is better considering driver attention distraction. For this objective, we measured various factors; primary driving performance secondary task performance and visual distraction.

**Results**

**Primary driving performance**

We measured and compared the driving performance while driving on the simulated track and performing the secondary tasks. Primary driving performance was compared in the two sides of the longitudinal control and lateral control. The longitudinal control analysis was performed to compare how well the subjects maintained their driving speeds at the given value of 70 kilometers per hour; the initial speed changes before reaching the criterion were neglected but only afterward variations were considered. First, the independent two samples t-test was performed to compare the mean of the two conditions and calculate the variance. The homogeneity of variance were compared by using Levene’s test. As a result, dispersions caused by each conditions: rotary controller and touch screen, are not homogeneous. Overall, the case of rotary controller showed more well-kept speed than the case of touch screen (t(35831.845) =
Longitudinal control performance across the two interaction types is shown in the box plots in Figure 2.

In the Lateral control analysis, we compared how well subjects maintained a given lane. We calculated the lane number and the proportion of neighboring lane invasion during driving. By performing paired t-test for calculated value, we compared two conditions. The result showed that there is no significant difference between two conditions ($t(7) = -0.155$, $p = 0.882$). Lateral control performance across the two interaction types is shown in the box plots in Figure 3.

Secondary task performance was for the purpose of analyzing whether drivers performed a given task efficiently and effectively or not, thus, we computed the completion time of each task. By using the calculated value, paired t-test was conducted to compare the performance under two different conditions. The result showed that there is no significant difference under two conditions ($t(23) = 1.441$, $p = 0.163$). However, when considering average completion time for each condition, the one of rotary controller usage condition is longer than the one of using touch screen ($\text{Mean}_{\text{rotary}} = 25.76$, $\text{Mean}_{\text{touch}} = 18.44$). Secondary task performance across the two interaction types is shown in the box plot in Figure 4.

Visual distraction
To measure visual distraction, the subjects were examined how many times their gaze was dispersed away from the frontal area. The main criterion was the ratio of front road gaze time respect to the navigation display gaze time. Paired t-test was performed comparing the difference across the two conditions. Overall, the result showed that the rotary controller condition cause more gaze dispersion ($t(7) = 2.940$, $p = 0.022$) rather than the touch screen condition does. Visual attention off-the-road across the two interaction types is shown in the box plot in Figure 5.

There was no significant difference in the success rate of color change detection across two conditions ($t(7) = 0.629$, $p = 0.549$). But there was relatively higher score in rotary controller condition than in touch screen condition ($\text{Mean}_{\text{rotary}} = 0.6042$, $\text{Mean}_{\text{touch}} = 0.5417$). Peripheral visual distraction across the two interaction types is shown in the box plot in Figure 6.
Conclusions

This study tried to find more appropriate interaction type among rotary controllers and touch screens for controlling in-vehicle navigation systems. For this purpose, eight drivers’ distraction including visual distraction were measured and analyzed. To measure drivers’ distraction, primary driving performance, secondary task performance, and visual distraction was calculated.

The primary driving performance was analyzed, separated by longitudinal control and lateral control. In longitudinal control, rotary controllers were better than touch screens in terms of speed maintenance. In lateral control, there was no statistically significant difference between touch screens and rotary controllers. The small sample size might be the cause of this insignificance.

For analyzing the secondary tasks performance, task completion time across the interaction type was compared, and statistically significant difference between two conditions was not observed.

Finally, visual attention on the navigation systems and LED signals detection performance were measured for analyzing the driver’s visual distraction. We calculated the ratio between time for which eye gaze stare front road and time for which eye gaze stare navigation display. Overall, the result showed that there were more gaze dispersion in rotary controller condition than in touch screen condition. On the other hand, there was no significant difference in the success rate of color change detection between two conditions.

The results of this study could be applied to choose the appropriate interaction type for controlling in-vehicle navigation systems.

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