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The effect of touch-key size on the usability of In-Vehicle Information Systems and driving safety during simulated driving

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ABSTRACT

Investigating the effect of touch-key size on usability of In-Vehicle Information Systems (IVISs) is one of the most important research issues since it is closely related to safety issues besides its usability. This study investigated the effects of the touch-key size of IVISs with respect to safety issues (the standard deviation of lane position, the speed variation, the total glance time, the mean glance time, the mean time between glances, and the mean number of glances) and the usability of IVISs (the task completion time, error rate, subjective preference, and NASA-TLX) through a driving simulation. A total of 30 drivers participated in the task of entering 5-digit numbers with various touch-key sizes while performing simulated driving. The size of the touch-key was 7.5 mm, 12.5 mm, 17.5 mm, 22.5 mm and 27.5 mm, and the speed of driving was set to 0 km/h (stationary state), 50 km/h and 100 km/h. As a result, both the driving safety and the usability of the IVISs increased as the touch-key size increased up to a certain size (17.5 mm in this study), at which they reached asymptotes. We performed Fitts' law analysis of our data, and this revealed that the data from the dual task experiment did not follow Fitts' law.

1. Introduction

In-Vehicle Information Systems (IVISs) have gained in popularity for drivers over the last few years. In general, IVISs include navigation systems, entertainment systems such as music/video players and satellite broadcasting receivers, and various car management systems. IVISs are operated mainly by virtual controls on touch-screen interfaces, by physical controls such as knobs and buttons, or by voice recognition systems. Among these methods, especially for aftermarket products, touch-screen interfaces are the most prevailing methods for operating IVISs. A touch-screen interface is one of the most natural and intuitive interfaces, and typical input is a natural pointing gesture; as a result, training is minimized (Greenstein, 1997; Scott and Conzola, 1997). In addition, they require no additional input devices such as physical keys or a mouse; therefore, the dimension of a device can be minimized (Holzinger, 2003; Scott and Conzola, 1997). Furthermore, the interface design is very flexible; the layout, dimensions and number of touch-keys are limited only by the dimension of the touch-screen size.

In most cases, touch-screen interfaces, especially for IVISs, are manipulated by fingers. For finger interactions, Pfauth and Priest (1981) identified that the touch-key size is the main factor in the design of the touch-screen interfaces. As the touch-key size decreases below a certain level, usability measurements such as the task completion time, accuracy, and subjective ratings are significantly degraded compared to physical keys. This degradation could be attributed to a lack of tactile feedback (there is no engraved surface between neighboring keys) and visual feedback (the target is occluded by the fingers). Many studies that focus on touch-key sizes have been conducted on relatively large touch-screen interfaces such as kiosks and ATM machines, which are mainly manipulated by the index finger (Bender, 1999; Beringer, 1990; Colle and Hiszem, 2004; Hall et al., 1988; Scott and Conzola, 1997; Sears, 1991), and on small interfaces such as PDAs and mobile phones, which focus on one-handed thumb uses (Parhi et al., 2006; Park and Han, 2010; Perry and Hourcade, 2008). However, as far as the authors are aware, there is no published study of touch-key sizes that focuses on IVISs.

The purpose of the previous studies on the touch-key size was mostly to investigate the effect of the touch-key size on the usability of the touch-screen interfaces and to, thereby, determine

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the proper touch-key sizes for specific touch-screen devices. However, a study on the touch-key size for IVISs needs to focus on the driving safety together with the usability of the IVISs. Interacting with IVISs is often a secondary task that is performed while conducting a primary task, which is driving. According to the multiple-resource theory of attention, humans have only a limited amount of attention that is available at any given time (Navon and Gopher, 1979; Wickens, 1984). When users perform a secondary task while conducting a primary task, the amount of attention to the primary task is reduced, and the performance of both the primary and secondary task is decreased (Sanders and McComick, 1993; Vollrath and Trotzke, 2000). The performance degradation in the secondary task becomes larger as the demand for resources made by the primary task increases (Sanders and McComick, 1993). The result of Tsimhoni et al. (2004) is an example, of how the secondary task performance (in terms of task completion time for entering address into a navigation system) decreased as the primary task workload of driving (in terms of road curvature) increased. The performance degradation in dual tasks was found to be amplified when both the primary and secondary tasks required the same human resources (Brookhuis et al., 1991; Lee, 2007; Schweitzer and Green, 2007; Sodnik et al., 2008; Tsimhoni et al., 2004). Lee (2007) showed that text messaging while driving could interfere with driving much more than conversing on a mobile phone. Brookhuis et al. (1991) empirically showed that manual input while driving causes more interference on driving than conversing on a mobile phone. Sodnik et al. (2008) experimentally showed that the visual interface of text messaging and calling causes more interference with driving and also causes a higher workload for the users compared with an auditory interface. Tsimhoni et al. (2004) showed that, when drivers use a touchscreen keyboard to enter addresses while driving, the lateral deviation and the number of lane crossings was higher than when a voice recognition system was used. Interacting with IVISs while driving is definitely a case in which the primary and secondary tasks are performed simultaneously and require the same human resources, such as visual processing, cognitive processing and motor control. In line with the above fact, many studies have reported that driving performance decreased and safety risks increased when the participants were interacting with IVISs while driving (Alm and Nilsson, 1995; Glcukman et al., 1988; Gopher, 1990; Horrey et al., 2006; Hosking et al., 2009; Janelle et al., 1999; Salvucci, 2001; Salvucci et al., 2007). In such a risky case, an improper touch-key size could increase the level of difficulty of interacting with IVISs and could lead to a further increase in interference to driving. In turn, improper touch-key sizes could not only decrease the usability of IVISs but also increase the safety risks. Strictly speaking, it might be most desirable not to use IVISs while driving. However, considering the current trend of private vehicles becoming mobile offices, using the IVISs while driving is inevitable in spite of the safety risks (Sodnik et al., 2008).

Another interesting issue that is related to pointing tasks is Fitts' law (Fitts, 1954). Fitts' law has been widely used in the field of Human–Computer Interaction to quantify the performance of human pointing tasks by logarithmically relating the movement time, the target width and the movement amplitude. Fitts' law works well for a variety of user interfaces in which various body parts are used to interact with different input devices and targets (Mackenzie, 1992). There are also several studies that investigated Fitts' law specifically in touch-screen devices (Bender, 1999; Colle and Hiszem, 2004; Mackenzie and Zhang, 2001; Parhi et al., 2006; Sears, 1991; Sears and Shneiderman, 1991; Sears and Zha, 2003). Bender (1999) investigated target acquisition tasks that used a numeric keypad with touch-key sizes of 10 × 10 mm and 30 × 30 mm and performed Fitts' law analysis. The results were consistent with the predictions of Fitts' law. Mackenzie and Zhang (2001) investigated typing tasks that used a touch-keypad with key-sizes of 6.4 × 6.4 mm and 10 × 10 mm. The results from the analysis of the entry speed and key-size were also consistent with the Fitts' law prediction. Parhi et al. (2006) explored single-target pointing tasks on small touchscreen devices, and the results are consistent with Fitts' law. While the results of these studies were consistent with Fitts' law, there were few studies of touch-key pointing tasks that were not consistent with Fitts' law (Colle and Hiszem, 2004; Sears, 1991; Sears and Shneiderman, 1991; Sears and Zha, 2003). This inconsistency could arise because cursor pointing with a touch-screen is inherently different than pointing with most other devices (Sears and Shneiderman, 1991). In other words, when compared to traditional pointing tasks, touch-key pointing tasks required choice (visual scanning) and motor programming processes in addition to movement (Colle and Hiszem, 2004). All of these studies were performed in the context of the single task of pointing to touch-keys, although the results of the previous studies were dissimilar; however, there were no studies that investigated it in the context of dual tasks, especially for interacting with IVISs while driving. Under dual task conditions, humans cannot fully concentrate on the secondary task (interacting with IVISs) because their attention is allocated to both the primary task and the secondary task. The time that is required to achieve the secondary task is limited because they must drive safely simultaneously. For this reason, the results from the dual tasks are not expected to be in line with Fitts' law. Fitts' law analysis of our data was performed in the discussion section.

In this study, the effects of the touch-key size on driving safety together with the usability of IVISs were experimentally investigated through driving simulation. Specifically, the standard deviation of the lane position, speed variation, and glance behavior were investigated with respect to driving safety, and the task completion time, error rate, subjective preference and workload (NASA-TLX) were measured with respect to the usability of IVISs. Additionally, we performed Fitts' law analysis on our data.

2. Methods

2.1. Participants

A total of thirty participants (graduate and undergraduate students of Pohang University of Science and Technology, 7 females and 23 males) with legal driving licenses voluntarily participated in the experiment. All of the participants had at least a half year of driving experience (range: 1–15 years, mean: 4.7 years, standard deviation: 3.7 years), and their ages were between 22 and 38 years (mean: 28 years, standard deviation: 3.6 years). All of the participants had normal (or corrected to normal) vision without any motor impairments.

2.2. Apparatus

The experiment was conducted with a desktop computer that was equipped with the Windows XP Professional OS, a 17-inch LCD touch-screen monitor (dwcom17s, Digital Window Communication) with a resolution of 1280 × 1024 and a dot pitch of 0.264 mm, a beam projector (SONY), a 1.9 m × 1.4 m screen, a driving wheel and pedal (Logitech Wingman Formula Force GP, Fig. 2) and a camcorder (Samsung vm-hmx 10a). The experimental environment was composed of the simulated driving software and the IVIS prototype, which was developed using Microsoft Visual Studio 2005 (Fig. 1).

The simulated driving environment was projected onto the 1.9 m × 1.4 m screen by using a beam projector. The simulated road