Effects of e-map format and sub-window on navigation performance
and glance behavior

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With the advances in global position system (GPS), automobile manufacturers have begun to produce intelligent transportation systems to assist drivers, such as in-vehicle navigation systems. These navigation systems combine an electronic map (e-map) and permanent roadway signs to inform drivers of their current locations and traffic information visually or aurally. To date, the moving e-map is still the primary medium for navigation or GPS applications; it can’t be completely replaced by voice guidance. An on-road driving experiment was conducted to investigate the effects of e-map format and sub-window on navigation performance and glance behavior while using an in-vehicle navigation system. Twenty participants navigated an urban route using the navigation display under 2D or 3D e-map conditions, and either with a sub-window or not. Driver navigation errors and visual glance data were collected during the trials. Results show that a sub-window reduced navigation errors but increased the time spent glancing to the visual display. There was no difference in performance between the 2D and 3D e-map conditions. However, 3D e-map led to more visual glance behavior to the navigation display than 2D one. The wider implications for the design of navigation visual displays are discussed.

Keywords: Driving performance; Interface design; Navigation display

INTRODUCTION

With the advances in global position system (GPS), automobile manufacturers have begun to produce intelligent transportation systems to assist drivers, such as in-vehicle navigation systems. These navigation systems combine an electronic map (e-map) and permanent roadway signs to inform drivers of their current locations and traffic information visually or aurally. They offer a technological solution to driver navigation in an unfamiliar area. While drivers can benefit from receiving route guidance information and traffic status, they have to face heavier visual loading at the same time. Besides, when receiving related information provided by the navigation system, drivers need to keep their eyes off the road, which may seriously influence driving safety. Distraction from the primary driving task is one of main causes of traffic dangers (Wierwille, 1995). Previous studies have also reported that the increase of visual demand for using a navigation system could bring negative impacts on driving safety and performance (Ross and Burnett, 2001; Toshiaki, et al., 2003; Williams and Helbig, 2006). Therefore, one major requirement for display-based navigation systems is that information must be readable and understandable fast and reliably (Baumann, et al., 2004).

The e-map presentation technique has been developed from two-dimensional (2D) to three-dimensional (3D) formats (Van Orden and Broyles, 2000). As we know, the actual world is spread in the 3D space and thus the 3D format is more like ‘real world’ representation that may imply better human perception and performance. However, previous studies have revealed that 3D displays are not markedly superior to 2D ones for the air combat or air traffic control tasks (Tham and Wickens, 1993; Van Orden and Broyles, 2000). These studies mostly focused on the performance of pilots or air traffic controllers; little research has aimed at evaluating the differences in driving performance between 2D and 3D formats. There is a need to evaluate the effect of e-map format on driving performance and visual demand while using a navigation display.

In recent years, the multi-windows interface technology has made the navigation display capable of simultaneously presenting both a main-window and a sub-window. The sub-window is usually designed to highlight the information of turn direction (i.e. present the region of intersection at large scale next to the main window) when approaching an intersection. Combining a main-window with a sub-window, the navigation display could provide noticeable and redundant route guidance that might result in better navigational performance than a single-window display. But an extra sub-window may impose more visual demand on the users. The effect of sub-window on driving performance is still not fully understood because most navigation-related studies used single window display only (Liu, 2000; Streeter, et al., 1985; Sikanen, et al., 2005; Van Orden and Broyles, 2000). Besides, how sub-window interacts with drivers to affect attention distraction remains to be evaluated.
In many countries, no regulations are being established to keep the use of in-vehicle navigation system as safe as possible. It is important to understand which representation format of the navigation display could safely and efficiently assist drivers, especially driving in a compact city with many intersections. To obtain more reliable evidence of the effects of e-map format and sub-window, the present study conducted a controlled on-road driving experiment instead of a simulated driving trial. The aim of the study was to investigate the extent to which general drivers benefited from the provision of 3D representation and a sub-window within a navigation display. Two key benchmark comparisons were used: (1) the driving performance and glance behavior with and without a sub-window, and (2) the driving performance and glance behavior under 2D e-map format compared with those under 3D format for navigation purposes.

METHOD

Subjects

Subjects consisted of 20 young male adults whose mean age was 26.1 (±3.7) years. They all satisfied the following criteria: clean driving license; regular drivers for least the last three years; were unfamiliar with the area where the study took place; had not previously used an in-vehicle navigation system; had normal (20/20) or corrected to normal visual acuity and normal color vision.

Apparatus

The on-road driving experiment was run using a middle automobile (Ford Telstarr 1800). Two PC cameras (Logitech QuickCam Messenger) were used to collect the drivers’ responses and road circumstances, respectively. Each PC camera could capture 30 frames per second and it was connected with a notebook computer for data processing. The MIO Moov series of navigation systems with the MioMap software were used to provide moving e-map and visual turn instructions for the participants. They can present either the 2D-‘plan’ view or 3D-perspective e-maps. This navigation system had a 3.5-in diagonal TFT-LCD screen with the pixel resolution of 320 horizontally and 240 vertically.

Experiment design

This study evaluates two independent variables: e-map format and sub-window. E-map format was a between-subjects factor, including 2D and 3D e-maps for representing navigation route on the display. Sub-window was also a between-subjects factor with two levels, no sub-windows and one sub-window. Four experimental conditions (2 × 2) comprised the combination of the e-map format and sub-window. Due to the constraints of driving an actual route with a real navigation system, each subject was assigned to one driving trial for preventing from the learning effect. The test navigation system could be set to display each experimental condition. Fig. 1 shows an example of 3D e-map with a sub-window. The navigation display was set on the stationary position (just above the mid-console) during all the experimental trials.

Experimental route and procedure

The experimental route was explicitly designed to have five driver decision points within its 2.3 km length. A driver decision point was defined as a location where a driver had more than one navigation choice and was not following a main artery. These were locations where unawareness of navigation instructions could lead to a navigation error from a driver. The route took about 9 min to drive, the speed limit on the route being 50 kph.

The subjects took place in the driver’s seat. To familiarize subjects with the vehicle controls, they were asked to freely drive the car for approximately 20 min, without use of the navigation system. Each subject was then asked to drive from a starting position to arrive at a pre-identified destination using a navigation system with the given tested condition. The navigation system provided subjects with correct turning information as they approached each decision point. In the driving route, each subject was required to make five turns to reach the destination. The participants were asked to obey all traffic signs and follow navigation aiding information in their driving. The experimenter, sitting in the front passenger seat, observed and recorded the number of navigation errors made by the driver. When the driver made an error at a decision point, the experimenter would immediately ask him to return to that decision point and then to continue performing the trial. All reactions of the driver were videotaped during the experimental trial. All driving trials took place mid morning or mid afternoon.

Dependent variables

The dependent variables were number of navigation errors, mean glance duration, and number of glances toward the navigation display during the driving trial. The number of navigation errors was the summation of missed turns and wrong turns the subject made in following the directional advice of a navigation system during the trial. Of interest was the possibility that different experimental conditions influenced the amount of navigation errors subjects made during the driving trials.

Visual glance behavior was measured with a digital video...
camera in order to determine the mean duration and number of glances to the in-vehicle visual display during the driving trial. Each duration of glance was estimated by replaying the recorded video through Windows Media Player 9.0. The replay speed was set as 1/30 of the normal speed. The experimenter carefully watched the slow-motion video and recorded all the glance durations for every subject.

The number of glances was defined as the total number of glances to the in-vehicle display during the driving trial. A greater glance duration and number of glances for a driver watching at the in-vehicle display are assumed to indicate higher distraction that may affect driving safety.

**Data analysis**

Descriptive statistics included analyzing means and standard deviations for every dependent measure. Analysis of variance (ANOVA) method was applied to identify whether the e-map format and sub-window had any impacts on the dependent variables ($\alpha = 0.05$). If the responded data distribution was not normality, Mann-Whitney procedure (non-parametric counterpart of the two-sample t-test) was used to evaluate the studied main effects ($\alpha = 0.05$)

**RESULTS**

Fig. 2 shows the results of the number of navigation errors for the 2D and 3D e-map conditions, using either a sub-window or not. Due to the between-subjects design, each bar represents the average navigation errors made from N = 5 subjects. Overall the navigation errors made by the subjects using the 2D e-map was 2.3 (SD= 1.6). Under the no sub-windows condition the number of navigation errors was 3.2 (SD= 1.5), while under the one sub-window condition the number of navigation errors dropped to 1.4 (SD= 1.3). A similar result was found for the 3D e-map format. The overall navigation errors made by the subjects using the 3D e-map was 2.1 (SD= 1.5). Under the no sub-windows condition the number of navigation errors was 2.8 (SD= 1.9), while under the one sub-window condition the number of navigation errors dropped to 1.4 (SD= 0.5).

![Fig. 2. The number of navigation errors made by the subjects in each experimental condition, according to e-map format and sub-window.](image)

A two-factorial ANOVA with e-map format (2D or 3D) and sub-window (with or without sub-window) revealed that the difference in the number of navigation errors between conditions with and without a sub-window was significant, F(1, 16)= 6.4, p= 0.022. However, the difference in the number of navigation errors between the 2D and 3D e-map conditions was not significant, F(1, 16)= 0.1, p= 0.756. The interaction between the e-map format and sub-window factor was also not significant, F(1, 16)= 0.1, p= 0.756.

![Fig. 3. The visual glance behavior responded to the display during the trial, according to e-map format and sub-window. Results of mean duration of glances are shown in the upper plot (a), and those of number of glances in the lower plot (b).](image)

![Fig. 3(a) illustrates the differences in the mean duration of glances for the 2D and 3D e-map conditions, using either a sub-window or not. It can be seen that the subjects took an overall mean duration of glances of 1.2 sec (SD= 0.5 sec) to the 2D e-map display. Under the no sub-windows condition the mean duration of glances was 0.8 sec (SD= 0.2 sec), while under the one sub-window condition the mean duration of glances raised to 1.6 sec (SD= 0.2 sec). A similar result was found concerning the 3D e-map format. Overall mean duration of glances was 1.4 sec (SD= 0.6). The no sub-windows condition led to a mean duration of glances of 0.9 (SD= 0.3), while under the one sub-window condition the mean duration of glances raised to 1.9 (SD= 0.2).](image)

A two-factorial ANOVA with e-map format (2D or 3D) and sub-window (with or without sub-window) indicated that the difference in the mean duration of glances between no sub-windows and one sub-window condition was highly...
significant, $F(1, 16)= 78.83$, $p< 0.001$. Also the difference in the mean duration of glances between the 2D and 3D e-map condition was significant, $F(1, 16)= 6.04$, $p= 0.026$. The interaction between the e-map format and sub-window factor was not significant, $F(1, 16)= 1.21$, $p= 0.287$.

The results of the number of glances are shown in Fig. 3(b). For both 2D and 3D e-map condition, a markedly greater number of glances (about twofold) made by the participants resulted from using a sub-window (as opposed to no sub-windows). Besides, the number of glances in the 3D condition (Mean= 30.4, SD= 17.0) tended to be greater than that of the 2D condition (Mean= 21.3, SD= 10.3). These findings are similar with those of Fig. 3(a).

A two-factorial ANOVA confirmed that the difference in the number of glances between no sub-windows and one sub-window condition was highly significant, $F(1, 16)= 33.79$, $p<0.001$. Also the difference in the number of glances between the 2D and 3D e-map condition was significant, $F(1, 16)= 6.29$, $p= 0.023$. The interaction between the e-map format and sub-window factor was not significant, $F(1, 16)= 4.04$, $p= 0.061$.

**DISCUSSION**

In this study, the same route and navigation system was used under 2D and 3D e-map formats. The results show that there was no difference in the driving performance between 2D and 3D e-map formats. This finding of the present study is congruent with findings by Van Orden and Broyles (2000) and other studies (Tham and Wickens, 1993; Ellis, et al., 1991), that for many tasks, there are no differences in performance between 2D and 3D displays. The 3D display technology might be best suited for use in tasks such as local air traffic control, the planning and control of military operations occurring in complex naval amphibious (Van Orden and Broyles, 2000).

The results reveal that both the mean glance duration and the number of glances were significantly greater under 3D e-map format than those of the 2D one. This is because of that the 3D e-map had more complex colors and background objects than 2D e-map format. It has been believed that a visual display with high graphical complexity is hard to interpret quickly and correctly (Evans and Stevens, 1997). This can be considered as the reason why the 3D e-map format resulted in markedly more diversion of the driver’s attention, as compared with 2D e-map format. Because no difference in the driving performance was found between the 2D and 3D e-map formats, the 2D e-map, with a lower graphical complexity, is suggested to be more adequate to the car-driving tasks. This finding could offer in-vehicle navigation designers new thinking direction in the improvement of 2D e-maps instead of developing more appealing 3D e-maps.

A significantly less navigation errors resulted from using a sub-window (as opposed to no sub-windows) was found in the present study. This result suggests that a sub-window markedly ease display legibility and interpretation by providing noticeable and clear turning information while the driver approaches each decision point. In consequently, the incorporation of sub-window instruction could increase the effectiveness of the navigation system.

In addition, the navigation display with a sub-window tended to cause significantly more distraction (1.75 sec of the mean glance time; 32.1 of the number of glances) than those without a sub-window (0.85 sec of the mean glance time; 15.3 of the number of glances). This is due to that the participants were considerably attracted by a sub-window and consequently paid significantly more time and more often to watch the navigation display. Although using the sub-window could increase navigation performance, it has an adverse impact on visual demand. A trade-off therefore still exists between the two objectives of navigation performance and visual demand.

**CONCLUSION**

This study examined the impacts of e-map format and sub-window of the in-vehicle navigation display on navigation performance and visual glance behavior by an on-road test experiment. The present study confirmed that significantly fewer navigation errors were committed and more visual glance behavior was made when navigation the route using a sub-window (as opposed to no sub-windows). It should be noted that the number of navigation errors made by the driver is much more impacted by the function of a sub-window, than by the format of e-map. Since no difference in the navigation performance was found between the 2D and 3D e-map formats, the 2D e-map is suggested to be used for the sake of its simplicity. In order to enhance navigation performance, we recommend the driver to switch the sub-window on merely under the 2D e-map condition. These findings could provide helpful information concerning how to design an adequate navigation display for the manufacturers, as well as how to select and adjust the format of a navigation system for the drivers.

**ACKNOWLEDGMENTS**

The authors thank all of the participants for their great assistance.

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