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Field Comparison of Driving Performance Using a Portable Navigation System

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Recent work has revealed that increasing numbers of drivers now receive driving instructions using a portable navigation system. A $2 \times 2 \times 2$ (position × display decrease mode × voice) factorial experiment was executed to compare driving performance when using a portable navigation system (PNS). Thirty-two subjects were paid to participate in this field study, and a smart phone was adopted as the portable navigation device. The results indicated that drivers using the PNS under the conditions *up position* and *with voice instruction* performed better in terms of trip duration, mean speed, and the standard deviation of speed.

KEY WORDS

1. portable navigation system 2. smart phone 3. driving performance 4. car safety.

1. INTRODUCTION. Vehicle navigation systems (VNSs) using global positioning system (GPS) technologies are rapidly becoming commonplace in automobiles. Navigation systems are intended to provide navigational assistance using electronic maps and turn-by-turn directions through audio and visual cues. VNSs typically use 6–10 inch liquid crystal displays (LCDs) as the information display interface, and this is usually positioned in the middle of the car's dashboard. These are commonly referred to as onboard navigation systems. In order to read the display while driving, users must take their eyes off the road ahead. Hence, this type of display system is also called a head-down display (HDD). The use of a HDD would therefore seem to affect driving safety (Liu and Wen, 2004). Zwahlen et al. (1988) pointed out that if a driver's gaze leaves the road for longer than 2 seconds, then the traffic accident risk is significantly increased. French (1990) and Wierwille (1995) indicated that this kind of distraction situation is one of the main factors causing danger on the roads. Green (1999) indicated that drivers could receive information without lowering their gaze, thus avoiding attention gaps that arise from them taking their eyes off the road to look down at the information on a HDD. The number and duration of the driver's sight deviations from the road are reduced using a head-up display (HUD).

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Previously VNSs were costly options. However, a new generation of GPS, portable navigation devices, is poised to make such features more affordable. The devices can evolve from smart phones or personal digital assistants (PDAs) owing to their small size, and become navigation devices when connected to a GPS receiver. These devices offer an advantage over VNSs, giving consumers use of the PDA for other applications. The technology is considered to be more flexible than some existing VNSs, and can be used both inside and outside the vehicle. The cellular phone is the most personal and ubiquitous device yet devised. Furthermore, some smart phones combined with 3G service, Wi-Fi and an operating system make them become ubiquitous and powerful tools. Dornan (2005) pointed out that more than a million consumers use their cellular phones or PDAs as navigation systems. Mobile devices, from cellular phones to PDAs are becoming increasingly powerful and increasingly useful in everyday life. The systems also use voice prompts over the handset's speakerphone. A user enters the driving destination into the phone through voice or keypad; the phone then delivers direction instructions in real time, both graphically on the screen and verbally through the phone's speaker, as the user drives. These kinds of tools can be called portable navigation systems (PNSs).

Owing to their mobile character, PNSs can display navigation information directly about the driver's line of vision and reduce the number and duration of the driver's sight deviations from the road if users place them in a position near the steering wheel, in line of sight with the road ahead. Kiefer (1991) and Kaptein (1994) pointed out that the car controlling performances of drivers using the HUD are better. However, Liu and Wen (2004) revealed that there were no significant differences in car handling. The speed of drivers using a HUD is, on average, faster than that of drivers having to look down at the dashboard (Iino et al., 1988; Kato et al., 1992). However, the researches by Hooey and Gore (1998), Kiefer and Liu and Wen indicated that no significant difference was found in average vehicle speed between the users of HUD and HDD.

Earlier, in 1988, Zwahlen et al. investigated the safety issues of a VNS and examined the visual, safety and performance aspects of operating a simulated CRT (cathode ray tube) touch-panel display while driving at a constant speed along a straight road – keeping a lateral lane position (Zwahlen et al., 1988). Their results revealed that introducing VNSs or controls that require eye fixations of several seconds could raise a serious problem. Lansdown (1997) pointed out that the drivers may experience overload in attention when a VNS that makes exclusive use of the visual modality is introduced into the vehicles because drivers depend largely on the visual modality for driving related information. To compensate for this, drivers tend to drive slowly and more carefully (Walker et al., 1991). Therefore, exclusively visual displays result in slower speeds than other display modalities, e.g. auditory display.

Walker et al. (1991) carried out a simulator experiment to evaluate seven VNSs that varied in complexity and mode of presentation. They found that drivers using auditory navigation devices of variously low, medium or high complexity make significantly fewer navigation-related errors than those using visual mode devices. In terms of complexity, the participants using complex devices drove more slowly than those using the simpler devices, and high-complexity displays were the least preferable. Parkes and Coleman (1990) found that drivers using an auditory device made fewer driving errors and reduced trip duration and distance.

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Labiale (1990) found that driver workload was reduced when navigation information was presented auditorily, rather than visually, and drivers preferred auditory information. In high driving workload situations, drivers using auditory devices did not reduce their speeds as much as those using visual devices (Walker et al., 1991). Liu (2001) executed a simulator study to compare drivers' rating of workload and performance of navigation under both high- and low-load driving conditions when simple or complex; navigation information was presented visually only, aurally only or by multimodal (visual and auditory) display. The results showed that participants using multimodal display had fewest errors and controlled their vehicle properly. The visual display led to reduced driving safety, apparently because it imposed higher demands on the driver's attention.

On the market, most special portable navigation systems are designed with a horizontal display mode (landscape). However, most designs of PDAs and phones are precisely the opposite, with a portrait format display. Some smart phones can display in either modes (vertical or horizontal). However, the display of navigation systems always show heading-up (track-up), and the vehicle symbol remains pointed towards the top of the screen regardless of the vehicle's heading. In this way, it seems that the portrait display mode can show more relevant route information. Therefore, it is important to check the effect of different display modes when using a PNS.

The navigation systems all have the same purpose of serving as a navigation assistant for the driver. However, they range in functionality and result in differential system safety, efficiency, and usability (Eby and Kostyniuk, 1999). Chae and Kim (2004) suggest that the display of a smart phone is not likely to become much larger because the need for portability will continue to constrain the screen size. Only a small amount of information can be shown on the screen. Hence, for a PNS to be accepted and used by drivers, it depends on the drivers' capability to successfully process the information provided. Therefore, it is important for researchers to devote attention to examining the drivers' needs and limitations in accordance with different driving situations and thus try to ascertain the display mode capable of presenting navigation information to the majority of drivers in an efficient and safe way.

Many researchers (Harms and Patten, 2003, Liu and Wen, 2004, Jamson and Merat, 2005, etc) have discussed the effects of VNS on drivers' performance through simulator experiments. Wickens (2000) reported the principles from human factors as applied to vector map design of navigation systems. May et al. (2005) showed the results of a project that was aimed to undertake study to enable landmarks to be an integral feature of a navigation system. Schager (2008) discussed human errors made by operators and designers of navigation systems. We have carried out an experiment to verify the effects of using a paper map and portable navigation system and the finding were revealed in Lee and Cheng (2008). However, there are few published studies of navigation systems that used portable devices where the experiments were executed in a real driving environment.

In sum, a PNS displays a user's location on a map and uses graphics, text and voice prompts to deliver turn-by-turn driving and walking instructions to a destination. The screens of PNS are small and it may be difficult to read the information presented on them. Since drivers depend largely on the visual modality for driving related information, when a navigation system is used in a vehicle the drivers may experience attention overload – raising a serious safety issue. Hence, PNSs pose a crucial problem: how can the navigation information for driving tasks be presented effectively

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Table 1. Description of the test environments.

Speed limit (km/h)	Number of intersections	Number of turns	Distance of routes (m)
70/50	39	17	18615

and safely? Therefore, the major purpose of this study was to examine how display mode, voice and device position affect a user's driving efficiency and performance in real driving.

2. METHODS.

2.1. *Participants*. This study recruited thirty-two students (18 males and 14 females) to participate in the experiment. All participants held a valid driver's license and their ages ranged from 24 to 41 years old, with an average of 30·1 and standard deviation of 4·44. They were unfamiliar with the roads of the test area, and none had previous experience of using navigation systems. In addition, all subjects reported that they were not prone to motion sickness, and were required to pass a formal vision test and an informal hearing test. Participants had to meet the normal requirements for vision of at least 1·0 (or 1·0 after correction) and be able to hear the voice instruction of the PNS clearly.

2.2. *Apparatus*. A GPS PDA phone, A700, produced by Mio-tech was adopted as the PNS and placed in the experimental car (Toyota Corolla). The screen size of this phone is 4·2 (w) × 5·5 (h) cm (2·7 inch diagonal), and the display resolution is 240 (w) × 320 (h) pixels. The navigation software of the PNS is MioMap. This PNS can display with either vertical or horizontal modes. Moreover, the scale of the electronic map is adjustable, and for this study was set to 1:2000 (default value). Other functions of the GPS PDA phone excluding navigation were disabled during the experiment.

2.3. *Driving road descriptions*. This study aimed to survey whether there were significant differences in the drivers' performance under varied conditions when using a portable navigation system. The test area in this experiment included both simple and complicated environments. The starting point and destination were fixed and decided in advance, and the routes were planned by the PNS. Table 1 depicts the descriptions of the test environments. All participants were required to follow the instructions of the navigation system whilst obeying all traffic rules.

2.4. *Experimental designs and tasks*. The experiment consisted of a 2 (up/down position) × 2 (vertical/horizontal display) × 2 (voice on/off) factorial experiment. All participants were randomly assigned to each of the eight experimental conditions with equal numbers. Figure 1 shows the PNS with vertical (portrait) display mode at the up position. It was positioned from 4° to 10° below the drivers' horizontal visual line. The PNS with horizontal (landscape) display mode at the down position is shown in Figure 2 and the angle was 18 to 24° below the drivers' horizontal visual line.

All participants took a test drive of at least 10 km and no more than 12 km to acclimatize to the test car before the formal experiment. An experimental assistant accompanied the participants in the front passenger seat and controlled all equipment. He was not allowed to talk to or disturb the drivers during the test period. The

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Figure 1. The PNS at the up position with vertical (portrait) display mode.

Figure 2. The PNS at the down position with horizontal (landscape) display mode.

starting point and destination were decided in advance, and these two positions were programmed into the PNS. The PNS automatically planned the routes from the starting point to the destination.

All participants followed the experimental assistant's instructions to the start point after finishing the test drive. They were divided into eight groups randomly. The experimental assistant instructed the participants to understand the meanings of the navigation information. All participants were then asked to follow the system's route guidance information. The participants moved off after they had prepared and felt ready. To establish measures of drivers' performance with different conditions, all participants were requested to reach the destination as quickly as possible whilst obeying all traffic regulations. Experiments were executed between September 7 and

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October 11, 2006. The data were recorded from Monday to Friday, 10 am to 12 noon and 2 to 4 pm. The eight conditions were distributed randomly throughout the data collection periods. During the experiment, rush hours were deliberately avoided and congestion did not occur. The weather and road surface conditions were good on days the research was conducted. There was no precipitation or water on the non-slippery road surface. Experimental data were recorded during the trips as follows.

2.5. *Measurement methods.* The drivers' performance data was collected by DriftBox, produced by RACELOGIC (www.driftbox.com). This is a very powerful tool for anybody wanting to accurately measure vehicle or driver performance. DriftBox uses a GPS system with an update rate of 10 samples per second. The GPS system used was a real time kinematic (RTK) system, which gives an accuracy of 0·25 degrees, speed ($\pm$0·1 kmh), cornering g-force ($\pm$0·01 g), acceleration g-force ($\pm$0·01 g), and distance measurement ($\pm$10 cm). In addition, the RTK system allows the units to calculate the relative position to within millimetres.

DriftBox was mounted between the rear-view mirror and windscreen and had been calibrated. An SD flash memory card socket was equipped in DriftBox. Data was logged to the SD flash card when velocity was above 0·5 km/h and can be analyzed in detail using the PC software provided. Although the number of red light stops was not equal for every driver, traffic signals can be regarded as completely random in the experiments and thus the effects of this cause would balance out on average. Hence, the time spent waiting at a red light was not considered.

In Liu (2001), some measures were adopted to be the indicators of performance parameters. They are mean speed, standard deviation (SD) of speed, variance in lateral acceleration and variance in steering wheel position. Liu pointed out that mean vehicle speed is a somewhat face-valid measure of task demands. In addition, speed maintenance is a sensitive index in measuring the amount of attention demanded. Dingus et al. (1997) found that sudden lateral movements are indicative of a vehicle that has come off lane centre track due to driver inattention. McDonald and Hoffmann (1980) showed that changes in driver steering actions occur with changes in driver attention.

There are many measured parameters that can be recorded automatically by DriftBox. However, not all parameters are related to the driving performance. In this study the objective measurements included T1 (trip duration; sec), T2 (trip distance; m), T3 (mean speed; km/hr), T4 (SD of speed; km/hr), T5 (variance in lateral acceleration; g), T6 (variance in longitudinal acceleration; g), T7 (mean yaw rate; deg/s) and T8 (standard deviation of yaw rate; deg/s).

2.6. *Statistical Analyses.* The data analysis was performed using SPSS software (version 12.0, SPSS, Inc., Chicago, IL). Multivariate analysis of variance (MANOVA) was used to simultaneously test the differences of eight measures, the mean vector for each factor and all the interactions of three factors. The three factors were:

- A. up/down position; level 1: up, level 2: down,
- B. vertical/horizontal display; level 1: vertical, level 2: horizontal and
- C. voice on/off; level 1: on, level 2: off.

When the factor effect was significant using Wilk's lambda method in MANOVA, it represented at least one measurement was significant in eight measures. Meanwhile, univariate analysis of variance (ANOVA) was used to find the significant measures

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Table 2. The descriptive statistics of eight measures under different levels of each factor.

Factors	Up position	Down position	Vertical display	Horizontal display	Voice on	Voice off
Time (sec)	1680·4	1758·3	1691·0	1747·6	1678·6	1759·9
	(101·7)	(98·8)	(106·0)	(101·9)	(99·1)	(99·9)
Distance (m)	18986·9	18976·1	18900·9	19062·0	19033·6	18929·3
	(294·3)	(287·5)	(321·4)	(228·4)	(315·0)	(253·5)
Mean speed (km/hr)	40·6	38·9	40·2	39·4	40·8	38·8
	(2·49)	(2·25)	(2·60)	(2·38)	(2·46)	(2·14)
SD of speed (km/hr)	15·9	15·1	15·9	15·2	15·9	15·1
	(1·50)	(1·02)	(1·47)	(1·12)	(1·63)	(0·80)
Variance in lateral acceleration (g)	0·117	0·114	0·114	0·117	0·115	0·116
	(0·012)	(0·008)	(0·009)	(0·011)	(0·010)	(0·011)
Variance in longitudinal acceleration (g)	0·101	0·102	0·103	0·100	0·101	0·102
	(0·010)	(0·010)	(0·011)	(0·009)	(0·009)	(0·011)
Mean yaw rate (deg/s)	1·52	1·57	1·53	1·56	1·49	1·60
	(0·28)	(0·25)	(0·26)	(0·28)	(0·25)	(0·28)
SD of yaw rate (deg/s)	0·65	0·67	0·65	0·66	0·64	0·68
	(0·11)	(0·09)	(0·09)	(0·11)	(0·09)	(0·11)

The values in brackets are the standard deviations of the measures in each group.

and to determine whether they had a factor effect. If 3-way interaction did not exist, the comparisons of the marginal means were evaluated on significant main effects and 2-way interactions by one-way ANOVA and post-hoc tests. The p value $<0{\cdot}05$ was considered to be significant.

3. RESULTS. The descriptive statistics of eight measures are presented as means and standard deviation (SD) in Table 2. The values in brackets are SDs of the measures in each group.

The MANOVA and ANOVA were the main methods of this study. The determination of sample size for a factor effect was complicated in ANOVA because it needed to specify the effect size using all of the treatment means to calculate observed power. For simplification, the effect sizes were not shown, just the observed powers. The p values and observed powers of factor effects in MANOVA were shown in the first row and the brackets of Table 3. The results of ANOVA were shown after the second row of Table 3. Although parts of observed powers were small such that interactions did not exist, 2-way interaction $A \times C$ of factor A and factor C was significant in MANOVA. The ANOVA results revealed that the $A \times C$ existed in the SD of speed and variance in longitudinal acceleration, but did not exist in the time, distance and so on. In addition, the results revealed that the main effects of factor A and C were significant in time and mean speed. Hence, the model including main effects of factor A and C was used to fit them. However, all of the factor effects did not exist in distance, variance in lateral acceleration, mean yaw rate and SD of yaw rate.

The marginal means of measures with significant main effects or interaction and the p values of means comparison are shown in Table 4. The estimated marginal means of the time, mean speed, the SD of speed and variance in longitudinal acceleration are

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Table 3. The *p* values of factor effects of MANOVA and ANOVA.
(factor A: position; factor B: display; factor C: voice).

Effect	A	B	C	A × B	A × C	B × C	A × B × C
p value[a]	0·498	0·141	0·582	0·065	0·003**	0·874	0·867
	(0·31)[b]	(0·57)	(0·27)	(0·71)	(0·97)	(0·15)	(0·16)
p value[c] for							
Time (sec)	0·029*	0·103	0·023*	0·887	0·647	0·864	0·394
	(0·61)	(0·37)	(0·65)	(0·05)	(0·07)	(0·05)	(0·13)
Distance (m)	0·911	0·106	0·288	0·079	0·151	0·461	0·582
	(0·05)	(0·36)	(0·18)	(0·42)	(0·30)	(0·11)	(0·08)
Mean speed (km/hr)	0·043*	0·317	0·019*	0·597	0·398	0·706	0·393
	(0·54)	(0·17)	(0·67)	(0·08)	(0·13)	(0·07)	(0·13)
SD of speed (km/hr)	0·041*	0·085	0·041*	0·203	0·016*	0·893	0·671
	(0·55)	(0·41)	(0·55)	(0·24)	(0·70)	(0·05)	(0·07)
Variance in lateral acceleration (g)	0·515	0·473	0·854	0·360	0·559	0·907	0·163
	(0·10)	(0·11)	(0·05)	(0·15)	(0·09)	(0·05)	(0·28)
Variance in longitudinal acceleration (g)	0·757	0·423	0·695	0·524	0·001**	0·357	0·885
	(0·06)	(0·12)	(0·07)	(0·10)	(0·96)	(0·15)	(0·05)
Mean yaw rate (deg/s)	0·561	0·741	0·283	0·223	0·542	0·818	0·210
	(0·09)	(0·06)	(0·18)	(0·23)	(0·09)	(0·06)	(0·24)
SD of yaw rate (deg/s)	0·595	0·667	0·275	0·188	0·537	0·710	0·160
	(0·08)	(0·07)	(0·19)	(0·26)	(0·09)	(0·07)	(0·29)

(*: *p* value $<0{\cdot}05$, **: *p* value $<0{\cdot}01$)

a: using MANOVA

b: the values in brackets are the observed powers of the factor effects

c: using 3-way ANOVA

shown in Figure 3. As shown, the time of using the PNS with up position is shorter than with down position (1680.4 sec vs. 1758.3 sec, *p* value = 0·024) and with voice on is shorter than voice off (1678.6 sec vs. 1759.9 sec, *p* value = 0·019). The mean speed of using the PNS with up position is higher than with down position (40·6 km/hr vs. 38·9 km/hr, *p* value = 0·035) and with voice on is higher than voice off (40·8 km/hr vs. 38·8 km/hr, *p* value = 0·014).

From the results of post hoc tests in Table 4, the speed SD of using the PNS with up position and with voice on (level 1: A1 × C1) is significantly higher than other three combinations of factor levels. The variance in longitudinal acceleration of using the PNS with up position and with voice on (level 1: A1 × C1) had no significant difference with that of using the PNS with down position and with voice off (level 4: A2 × C2), but they were significantly higher than that of other two cases.

4. DISCUSSION.

The DriftBox was used in the study to examine the performance of drivers in a real environment. In order to reduce the cost of experiment control, experimental design is always a trade-off between experimental control and ecological validity (Engstrom et al., 2005). In particular, it can be argued that the traffic may influence the performance of the drivers in field experiments. Driving simulators can be used for the collection of driver behaviour and reach perfect experiment control. However, the discrepancies between real and virtual worlds may influence a subject's perception and behaviour. For example, virtual driving environments are safer and result in lower risk perception. A further study could

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Table 4. The marginal means of measures with significant main effects or interaction. (A1: up position, A2: down position; C1: voice on, C2: voice off).

Significant main effect or interaction	Time (sec)	Mean speed (km/hr)	SD of speed (km/hr)	Variance in longitudinal acceleration (g)
A1	1680·4 (1633·1, 1727·7)[a]	40·6 (39·5, 41·7)	—	—
A2	1758·3 (1710·8, 1805·5)	38·9 (37·8, 40·0)	—	—
p value of A effect[b]	0·024*	0·035*	—	—
C1	1678·6 (1631·3, 1726·0)	40·8 (39·7, 41·9)	—	—
C2	1759·9 (1712·6, 1807·3)	38·8 (37·7, 39·9)	—	—
p value of C effect[b]	0·019*	0·014*	—	—
A1 × C1	—	—	16·9 (16·0, 17·7)	0·106 (0·100, 0·112)
A1 × C2	—	—	15·0 (14·2, 15·8)	0·096 (0·090, 0·102)
A2 × C1	—	—	15·0 (14·2, 15·8)	0·095 (0·089, 0·101)
A2 × C2	—	—	15·2 (14·4, 16·0)	0·108 (0·102, 0·114)
p value of A × C[c]	—	—	0·017* {3,2,4}{1}[d]	<0·001*** {3,2}{1,4}[d]

(*: *p* value <0·05, ***: *p* value <0·001)

a: the values in brackets are the 95% confidence limits based on ANOVA model.

b: use ANOVA model intercept + A + C.

c: use ANOVA model intercept + A + C + A × C.

d: use Duncan post hoc Test, the levels in the same subsets representing group means are homogeneous, level 1: A1 × C1, level 2: A1 × C2, level 3: A2 × C1, level 4: A2 × C2

investigate the driving performance in different experiment environments (real and virtual).

In terms of trip duration, the best (up position, vertical/portrait display mode and voice on) and the worst (down position, horizontal/landscape display mode and voice off) groups spent 1583.9 and 1828.6 seconds respectively. The significant factors were position and voice on/off. If a driver missed a turn or made a wrong turn, the trip duration and distance would increase. Parkes and Coleman (1990) pointed out that drivers with auditory navigation devices made fewer driving errors and reduced trip duration and distance. However, the results of this study do not fully support the finding by Parkes and Coleman (1990). From Table 3, the trip distance was not significantly different using the PNS under different conditions. Position, display mode and voice on/off do not influence the trip distance in this study. In sum, using the PNS under the condition (up position or voice on) may allow drivers to reach the destination more quickly. In other words, it may save time when using a PNS set up in the condition when driving.

The significant driving behaviour measurements were mean speed and the standard deviation of speed. The significant factors were position and voice on/off. Iino et al. (1988) and Kato et al. (1992) revealed that the speed of drivers using a HUD is faster

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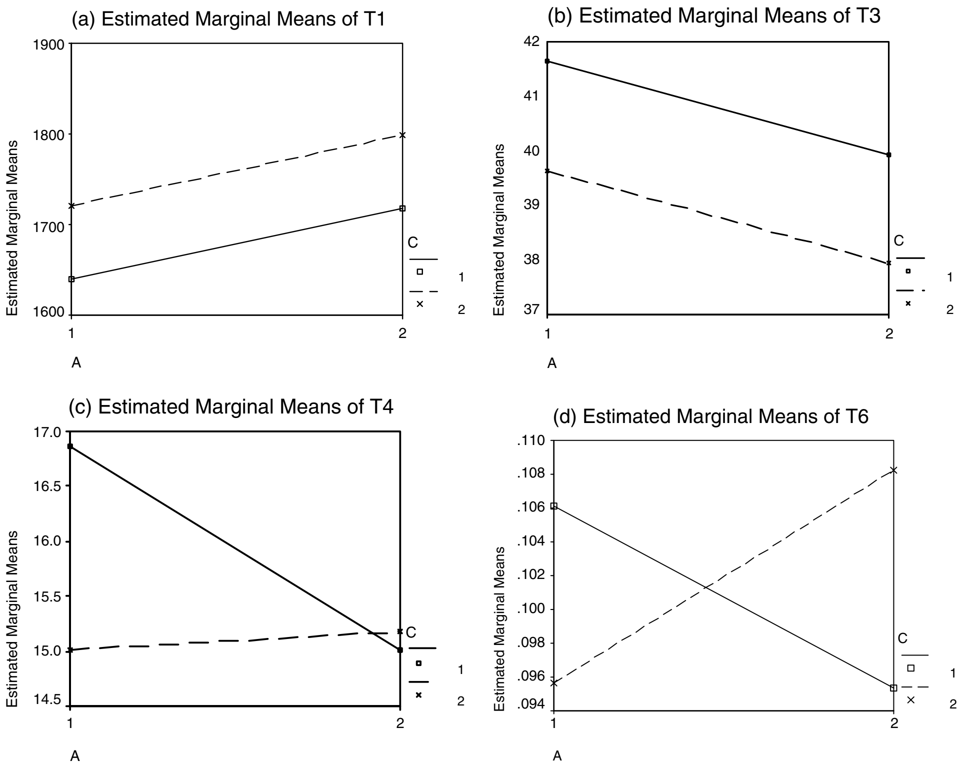

Figure 3. The estimated marginal means of measures under different levels of factor A (up/down position; level 1: up, level 2: down) and factor C (voice on/off; level 1: on, level 2: off) for the trip duration (T1), mean speed (T3), the standard deviation of speed (T4) and variance in longitudinal acceleration (T6).

than that of drivers having to look down at the dashboard. However, the research by Kiefer (1991), Hooey and Gore (1998), and Liu and Wen (2004) indicated that no significant difference was found in mean speed between the users of HUD and HDD. The results of this study show that position has a significant effect on mean speed. Walker et al. (1991) indicated that drivers tend to drive slowly and more carefully to compensate for the overload in attention caused by navigation systems. The results show that the drivers slowed down to acquire the information offered by the PNS and this supports Walker et al. (1991). This conclusion also corresponds with the findings of driving efficiency (trip duration and distance).

Variance in lateral acceleration, yaw rate and standard deviation of yaw rate were used as the main car controlling performance measures when drivers were under different navigation modes. Yaw rate is calculated from the heading angle of the car. A lower value of variance in lateral acceleration and yaw rate means that the car is more stable and is being handled better. A high value of variance in lateral acceleration and yaw rate is associated with many course corrections and such a result can be an indication of reduced safety. The results show that there are no significant differences between different groups. Therefore, different conditions had similar effects on car control. Kiefer (1991) and Kaptein (1994) pointed out that the car controlling performances of drivers using the HUD are better. However, Liu and Wen

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(2004) indicated that there were no significant differences in car control. The findings of this study support the latter.

In this experiment, position had significant effects on trip duration, mean speed and standard deviation of speed. Drivers predominantly use their vision to obtain driving related information. Although the screen of a GPS PDA phone is generally quite small, its portable character means the user can place it in an optimum viewing position. This will decrease the visual load greatly, by not requiring the driver to lower their line of sight, and thus allow greater attention to be paid to the traffic conditions. Furthermore, drivers can concentrate their attention on the traffic and easily maintain high speed. Our results appear to support this conclusion.

Overall, the portrait display mode had better performance. This is because the display of the PNS always shows travel direction as up and a vertical display mode can show more of the followed road information on the small screen. However, there was no significant difference in all items of measurements under different display mode. The scale of the electronic map was 1:2000 (default value) in this study. Different scales of the electronic map may have different results. In addition, some navigation systems provide 2D and 3D map-viewing modes. A further study could investigate the effects of different map-viewing modes.

Voice significantly affected the items of trip duration, mean speed and standard deviation of speed. Liu (2001) showed that drivers using multimodal display (visual and auditory) had better driving performance. The results of this study tend to support the findings of Liu. Voice instructions play an important role in navigation systems and make smaller attention demands. The drivers can pay more attention to the traffic conditions and have no need to notice constantly the navigation information on the PNS.

5. CONCLUSION.

This study conducted real-time driving experiments and adopted a suitable tool to record driving performance. The aim of the study was to verify the effects of using a PNS under different conditions. The results revealed that the driver using a portable navigation system under the condition – up position or with audio instruction drove quicker and reached the destination earlier than the others. Therefore, the finding of this study suggests that a user should place a PNS near the steering wheel and activate the voice instructions when driving.

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