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GLANCE STRATEGIES FOR USING AN IN-VEHICLE TOUCH-SCREEN MONITOR

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16. Abstract

In this study, subjects in a driving simulator followed a lead vehicle that continuously changed speed while they also performed a secondary task on a touch-screen monitor that could be located at various positions within the simulator. Subjects were instructed to give priority to the following task. Driving performance in the following task was affected by whether or not the secondary task was required, but was not affected by the location of the monitor. However, consistent with the instructions about priority of tasks, time to complete the secondary task was strongly influenced by monitor position. Farther locations required more time, especially for shorter subjects. Analysis of the number and timing of glances away from the road suggested that subjects coped with the more difficult monitor positions primarily by making more glances to the monitor, while the average duration of individual glances was not much affected. These results suggest that the subjects' partial success in coping with the secondary task was possible because the secondary task could be broken down into partially independent subtasks. This study was part of a modeling effort designed to better understand the combined visual and motor demands of secondary tasks, and how they are affected by the design of controls and displays. Various ways in which this study should be extended to support that modeling effort are reviewed.

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CONTENTS

INTRODUCTION

Background

Increasing numbers of systems for in-vehicle tasks secondary to driving are being installed in motor vehicles. Examples include music players, GPS systems, communication systems, and e-mail readers. The visual, cognitive, and physical requirements of using these systems can result in driver distraction, especially when the displays are placed in non-ideal locations. Driver attention problems are causal factors in many traffic accidents (Blanco et al., 2006). Allocation of the driver's visual resources to in-vehicle tasks and displays is a factor in many crashes (Wierwille & Tijerina, 1996).

Previous studies have examined the effects of display and button position on driving performance. However, most have not studied the combined visual, cognitive, and physical aspects of operating in-vehicle equipment and driving, and no study has adequately addressed the difference between visual difficulty, represented by visual distance from the road scene ahead to the display, and physical difficulty, represented by reach distance from the driver's resting position to the task interface, in terms of the interference between driving and a secondary task. This report discusses the glance behavior of drivers performing in-vehicle tasks using a touch-screen monitor placed in one of four positions with differing levels of visual and physical difficulty.

Goals

The objective of this study was to examine the effect of the position an in-vehicle touch-screen monitor on glance timing while driving. Special emphasis was given to the physical difficulty of the in-vehicle task by adding a significant motor component and manipulating the physical configuration of the touch screen. Previous studies examined primarily the visual characteristics of in-vehicle tasks.

The difficulty of the in-vehicle task was varied by placing the monitor in one of four fixed positions in the area of the center console: near-high, near-low, far-high, and far-low. The near positions were within easy physical reach of the steering wheel, while the far positions required a more difficult physical reach. Shorter subjects had to lean with their torsos to complete the reach. The high positions were at a smaller visual angle from the road ahead, while the low positions were at a greater visual angle.

In this experiment, the difficulty of the driving task was varied by using two simulated weights for the subject's vehicle. In a driving simulator, subjects drove a normal weight vehicle, which responded quickly to desired speed changes, and a heavier vehicle, which was slower to respond.

The following hypotheses were tested:

1. The total task time will be greater when the display is farther from the subject because of increased reach distance and increased time looking away from the task. The total task time and the increase in total task time will be greater for shorter subjects, because the total glance time and the time between glances will be greater.
2. The total glance time will be greater when the display is farther from the subject because of increased reach distance and increased visual distance. The total glance time will be greater for shorter subjects because the reach required to perform the task will be more challenging for them. The increase in total glance time between near and far monitor positions will be greater for shorter subjects because the subjects will need to use more complicated movements that may involve more body parts in order to reach the far monitor positions.
3. The durations of individual glances will increase when the display is farther from the subject because of the increase in movement time needed to reach the monitor.
4. The durations of individual glances will decrease when the subject is driving the heavy vehicle, because this is a more difficult driving task.
5. The time between glances will increase when the display is farther from the subject. The increase in the time between glances between near and far monitor positions will be greater for shorter subjects because the more complicated movements that they must make will require additional motor planning.

6. The number of glances will increase when the display is farther from the subject. There will be a greater cost associated with performing a reach to the monitor in when it is in the far positions, so subjects are likely to perform the reach only when they have plenty of time. However, subjects will want to maintain awareness of the current state of the in-vehicle task, so they will make additional glances, not accompanied by reaches, to the monitor.

Previous Work

This report describes primarily the analysis of the glance data. Detailed analysis of driving performance and task performance is provided in Fuller, Tsimhoni, and Reed (2008). The primary driving performance data from that report are reproduced in Figure 1. The RMS error for the difference between the subject's speed and the lead vehicle's speed was larger for all four monitor positions compared to the condition in which the secondary task was not required. The RMS error was also always greater for the heavy vehicle compared to the light vehicle. However, driving performance did not differ substantially among the four monitor positions. Thus, the requirement to perform the secondary task had a negative effect on driving performance, but that effect was not greater for the farther monitor positions.

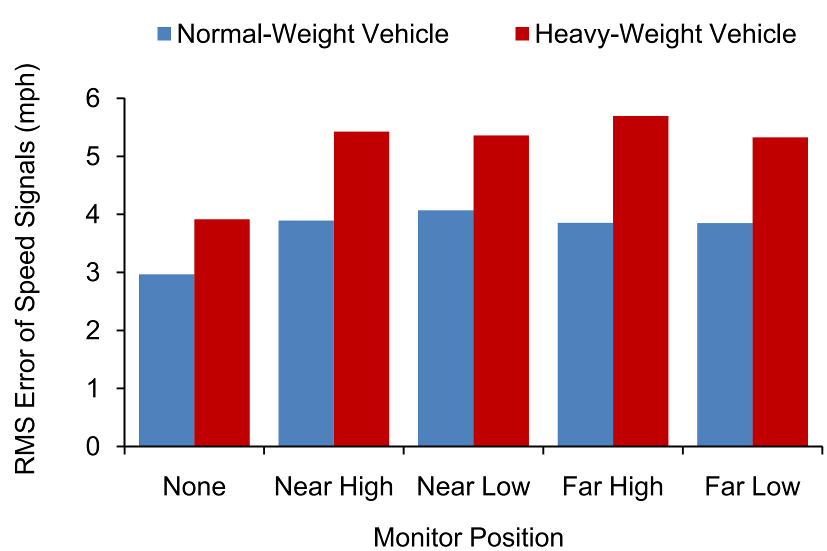

Figure 1. Average RMS error in the speed signals of the lead and subject vehicles for each condition.

METHOD

In this study, subjects drove in the UMTRI driving simulator while performing a secondary in-vehicle task using a touch screen monitor. Independent variables were monitor position and vehicle weight. Dependent variables were delay in following speed changes, error in matching desired speed, secondary task time, and metrics of glance behavior, including average glance duration and time between glances.

Subjects

Fourteen licensed drivers (seven male, seven female) between the ages of 19 and 30 (mean=24.1, SD=4) participated in this study. Written informed consent was obtained, and the study was approved by the University of Michigan's Behavioral Sciences and Health Sciences Institutional Review Boards. Subjects received financial compensation for their time.

Subjects were recruited from the University of Michigan and Ann Arbor communities via newspaper advertisements and flyers. The age range was chosen to be similar to that of military drivers exposed to convoy driving situations. Five of the male subjects were members of the Reserve Officers' Training Corps (ROTC), and one female subject had been discharged from the Army recently. Subjects were required to have a far visual acuity of 20/40 or better and no history of motion sickness. Subjects were selected so that three to four subjects were included in each of four height groups: four short females (59-61 inches, 150-155 cm), three midsize females (63-64 inches, 160-162.5 cm), four midsize males (68-70 inches, 172.7-177.8 cm), and three tall males (72-74 inches, 182.9-188 cm). These heights were chosen to give a range of heights representative of approximately 5th percentile female, 50th percentile female, 50th percentile male, and 95th percentile male, respectively.

Apparatus

Driving Simulator

The study was conducted in UMTRI's driver-interface research simulator. This fixed-based driving simulator consists of a full-size vehicle cab with a projected instrument panel, a torque motor connected to the steering wheel, six video projectors and projection screens (200° forward field of view, 40° rear field of view), and a sound system, including a sub-bass sound system for vertical vibration. The forward screen was 16 to 17 feet (4.9 to 5.2 meters) from the driver's eyes, depending on seat adjustment, requiring drivers to accommodate from the in-vehicle display (at 1-2 diopters) to approximately infinity (<0.25 diopters) whenever they looked at the screen straight ahead. The main simulation functions were controlled by hardware and software provided by DriveSafety (Vection and HyperDrive Authoring Suite, version 1.6.2).

Two vehicle dynamics settings were used. The first setting (normal-weight condition) simulated a typical passenger car, and the second (heavy-weight condition) simulated a vehicle that was 35% heavier and as a result accelerated and decelerated more sluggishly. Subjects drove on a four-lane divided highway as the fourth vehicle in a simulated convoy. There was no other traffic on the road.

Video Collection

Video of the subjects was recorded in the frontal (forward and rear views) and sagittal planes using low light cameras. A quad splitter was used to combine the three camera views with the video from the front screen into a single video file.

In-Vehicle Task Equipment

The experiment used a tablet personal computer with a touch-screen monitor (Lenovo, ThinkPad X60). The monitor was mounted in four different positions within the vehicle (Figure 2). The four display positions were chosen so that they differed in difficulty of physical reach and visual angle. The near-high position was in the center console and had a short reach distance and small visual angle from the road ahead. The near-low position also had a short reach distance, but the visual angle was greater. The far-high position had a large reach distance and a moderate visual angle. The far-low position had a large reach distance and a large visual angle.

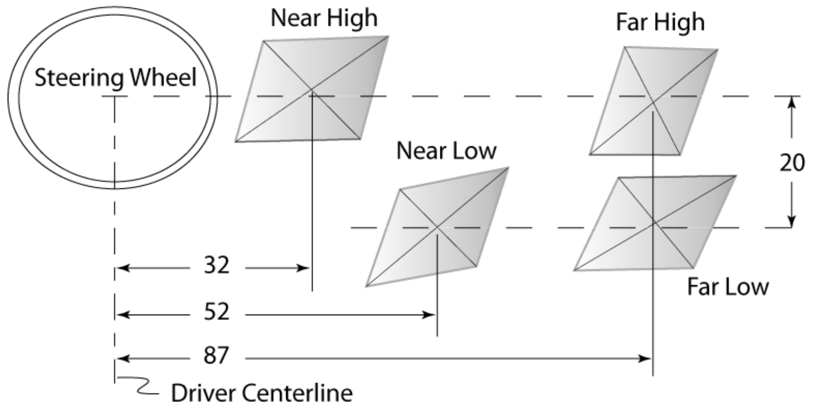

Figure 2. The four monitor positions are shown along with the distances (cm) from the driver's centerline.

To complete the in-vehicle task, the user interacted with a menu-based interface with fixed-location buttons on the touch-screen monitor. The task required the subject to conduct a visual search to locate and match three pairs of "scout" and "target" icons (Figure 3). In each trial, the six icons appeared in different positions on the screen. The program for the in-vehicle task was written using Visual Basic for Applications (Microsoft, 2007).

Figure 3. The front screen of the in-vehicle task is shown. The subjects were required to match the correctly numbered "scout" (gray vehicle) and "target" (orange person) icons. For example, the subject first selected Scout 1 and Target 1, then pressed a button to complete the assignment. This sequence was repeated for the remaining icon pairs.

Procedure

Subjects were instructed to remain in the lane and maintain a constant headway to the vehicle directly in front. This lead vehicle changed speed following a sinusoidal pattern with random frequency and amplitude.

This study used a modified version of the coherence technique (Brookhuis, de Waard, & Mulder, 1994; Ward et al., 2003). The lead vehicle changed between a low speed and a high speed at a frequency that ranged between 0.02 and 0.04 Hz. The minimum speed of the lead vehicle ranged between 55 and 60 mph (88 to 97 km/h), while the maximum speed ranged between 70 and 75 mph (112 to 121 km/h). This variation in frequency and amplitude was introduced to make it difficult for the subjects to predict the lead vehicle speed. The speed change trajectory was smoothed by basing the signal profile on a sinusoidal function.

The subject was taught how to perform the in-vehicle task and then practiced the task with the monitor in two of the four positions for a minimum of five minutes. Next, the subject practiced driving in the simulator without performing the in-vehicle task. After at least five minutes, and when the subject reported he or she was comfortable with the driving task, the subject was instructed to add the concurrent in-vehicle task while continuing to maintain a constant distance to the lead vehicle. After the practice drives, the subject completed a total of ten drives. Each drive consisted of multiple interactions with the in-vehicle system. Subject were instructed to complete the in-vehicle task well as they could while feeling comfortable with their driving performance. Consequently, the number of completed trials per drive was not fixed and ranged from 0 to 14, with an average value of 7.5±3.1 trials per drive. Subjects were given sufficient rest between drives to reduce fatigue.

Subjects were instructed to maintain a constant distance to the lead vehicle during each drive. They were told that distance keeping was their primary task and that they should complete the in-vehicle task at a comfortable rate. Subjects were instructed as follows: "Your primary job is to maintain a constant distance between yourself and the lead vehicle, so do not rush to complete the task. You may complete the task in as many stages as you like. You may push several buttons each time you reach to the screen or only one." To encourage subjects to comply with the instructions and to maintain a reasonable distance from the lead vehicle, if the subject was more than 660 feet (200 meters) behind the lead vehicle, the experimental task was paused until the driver caught up and the headway distance was below that threshold.

Task Metrics and Glance Evaluation

Glance data were collected from face video of subjects during the experiment. Glance data were taken from the first two repetitions of the in-vehicle task for each condition. The glance metrics considered were the total glance time, the median glance duration, and the median time between glances.

The start of a glance was defined as the moment a subject's eyes started to move away from the road toward the touch screen monitor, or when the eyelids closed during a preparatory blink. The end of the glance was defined as the moment a subject's eyes started to move away from the monitor and back to the road. The glance duration was defined as the time between the start of a glance and the end of a glance. The median glance duration was the median of the glance durations for each repetition of the task. The total glance time was the sum of all glance durations during one repetition.

The time between glances was defined as the time from the end of one glance to the start of the next glance. The median time between glances was the median of the times between glances for each repetition.

In addition to the glance metrics, another metric used was the total time required to complete the in-vehicle task, from the first touch on the screen to the final touch on the screen. This is referred to as the total task time. The median total task time for each drive was used for the analysis.

Experimental Design and Data Analysis

After the practice drives, each subject completed ten drives for the experiment. The two within-subject factors that were varied were monitor position for in-vehicle task (four levels: near-high, near-low, far-high, and far-low) and vehicle weight (two levels: normal and heavy). Each subject also completed two drives with no in-vehicle task (the baseline condition).

Monitor position order was blocked by vehicle weight so that subjects would have fewer adjustments to make to vehicle performance, but was counterbalanced across subjects. Half of the subjects were assigned to perform all the light vehicle trials first, and the other half were assigned to perform all the heavy vehicle trials first. The monitor position order was determined using a Latin square design. For each subject, the same order was used for both vehicle weights. The baseline condition was the third trial for each weight block. This was done to ensure that all subjects had equal amounts of experience with driving and the in-vehicle task when the baseline data were collected.

Data analyses were performed using linear mixed-effects models. Linear mixed models (LMM) is a maximum-likelihood analysis method that can be used to estimate any number of random and fixed effects (McLean, Sanders, Stroup, 1991). For unbalanced within-subject designs, such as this one, LMM allows for proper estimation of random effects for within-subject F-tests without case-wise deletion of data, as is necessary for general linear models.

Analysis was performed in SAS 9.1.3 (SAS Institute Inc., Cary, NC, USA) using the Satterthwaite method for estimating denominator degrees of freedom. Backwards selection was used to identify effects in the final model. All main effects and interactions were initially included. Random effects included the main effect of subject as well as interactions between subject and each of the included fixed effects.

To examine the effects of reach distance and visual distance from the road ahead, the four-level monitor position variable was reformatted in SAS. The near-high and near-low monitor positions, which both had short reach distances, were grouped and compared to the far-high and far-low positions. Also, the near-high and far-high monitor positions, which were located at a short visual distance from the road ahead, were grouped and compared to the near-low and far-low monitor positions.

Glance Strategies

The median time between glances for each subject and each monitor position was plotted against the median glance duration in order to illustrate and examine how glance strategies varied based on the location of the monitor for the in-vehicle task. This is similar to a technique used by Donmez, Boyle, and Lee (submitted) to examine risk-taking behavior in young drivers.

RESULTS

Total Task Time

Subjects took significantly longer overall to perform the in-vehicle task when the monitor was in the farther positions, $F(3,28.5) = 13.3$, $p < 0.0001$ (Figure 4). The task time increased by 79.0% from the near-high monitor position to the far-low position. Shorter subjects took significantly longer than taller subjects to complete the in-vehicle task, $F(3,9.83) = 5.44$, $p < 0.05$. Vehicle weight did not significantly affect task completion time, $F(1,52.1) = 1.61$. The increase in in-vehicle task time for far and low monitor positions was significantly greater for short females and midsize females compared to midsize males and tall males, $F(9,28.5) = 2.46$, $p < 0.05$ (Figure 5).

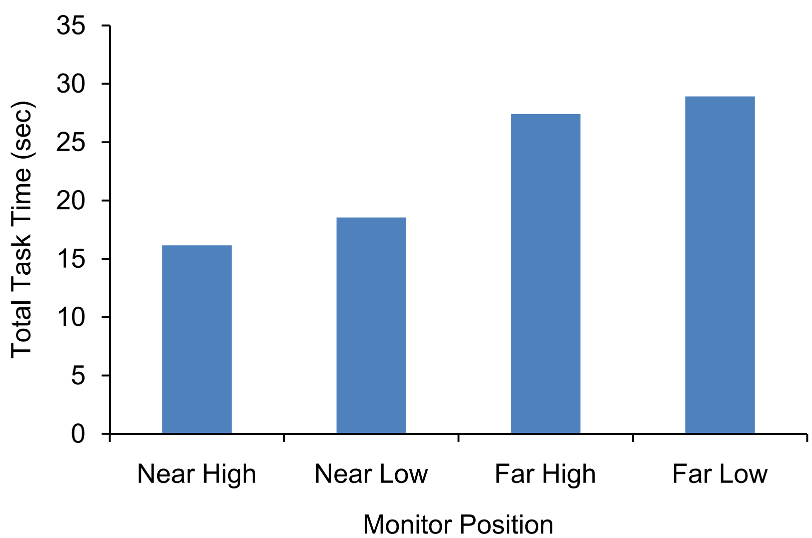

Figure 4. Mean total task time (seconds) for all subjects for each monitor position.

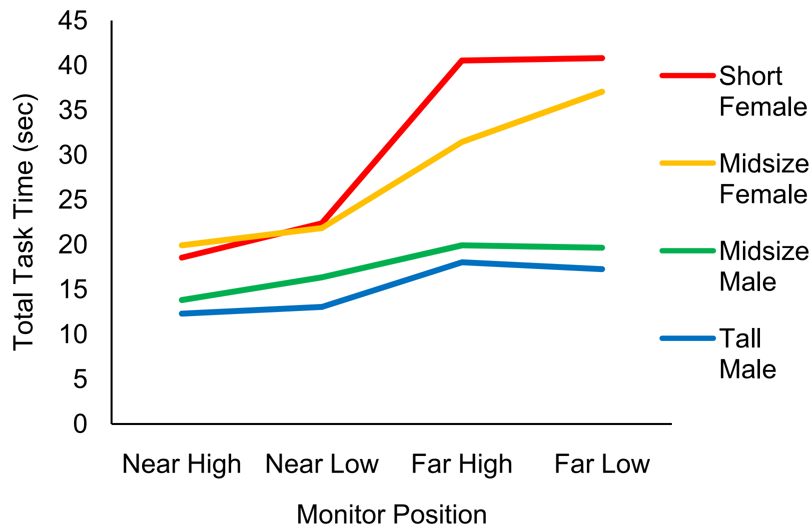

Figure 5. Mean total task time (seconds) for each monitor position and each stature group.

Further analysis of monitor position showed a significant increase in total task time from near to far monitor positions, $F(1,9.96) = 38.2$, $p < 0.0001$, but no significant change from high to low positions, $F(1,92.8) = 1.08$. The interaction between stature and monitor reach distance was also significant, $F(3,9.97) = 6.57$, $p < 0.01$, with the drivers in the two shorter stature groups displaying a larger increase in total task time between near and far monitor locations than the drivers in the two tall stature groups.

Total Glance Time

The total glance time for a trial increased significantly with far and low monitor positions, $F(3,15.7) = 10.1$, $p < 0.001$ (Figure 6). The total glance time was 11.0 seconds for the near-high monitor position, 12.9 seconds for the near-low position, 14.4 seconds for the far-high position, and 15.7 seconds for the far-low position.

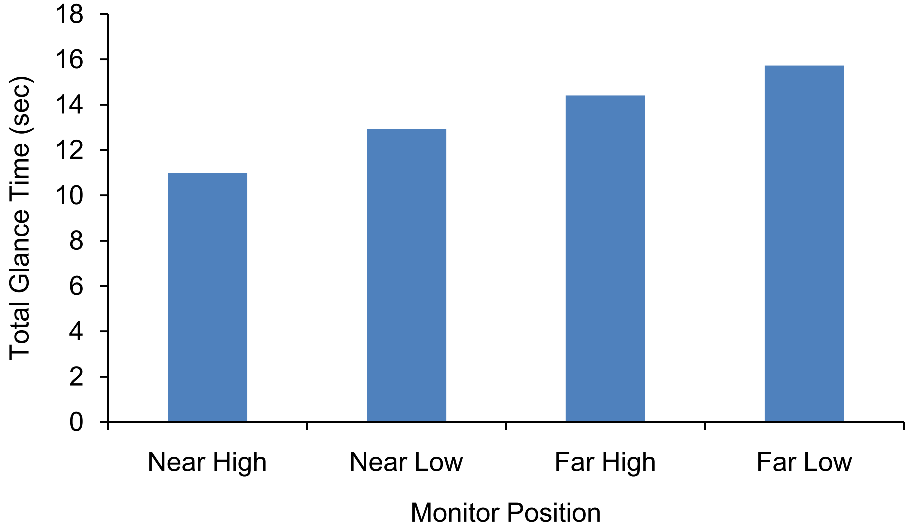

Figure 6. Average total glance time (seconds) for each monitor position.

Total glance time decreased significantly with increasing subject stature, $F(3,3.81) = 6.14$, $p < 0.1$ (Figure 7). The average total glance time was 16.6 seconds for short females, 13.2 seconds for midsize females, 12.2 seconds for midsize males, and 11.6 seconds for tall males. No interactions were significant.

Figure 7. Average total glance time (seconds) for each stature group.

Dividing monitor position into reach distance and visual distance provided additional information about the effects of monitor location. Total glance time to the far monitor position was 26.0% longer than to the near position, $F(1,214) = 34.7$, $p < 0.0001$. Placing the monitors in the low positions resulted in a 12.8% increase in total glance time compared to the high positions, $F(1,214) = 7.91$, $p < 0.01$.

Median Glance Duration

The median glance duration was affected by the combination of subject gender and stature, with the female subjects generally making shorter glances to the monitor (Figure 8). Although the effect was very small, it was significant, $F(3,118) = 7.74$, $p < 0.0001$. The median glance duration was 1.50 seconds for short females, 1.33 seconds for midsize females, 1.64 seconds for midsize males, and 1.47 seconds for tall males. The median glance duration was not affected by monitor position, $F(3,211) = 1.64$, or vehicle weight, $F(1,211) = 0.02$.

Figure 8. Median glance duration (seconds) for each stature group.

The effect of reach distance to the monitor on the median glance duration was not significant, $F(1,215) = 1.41$, nor was the effect of visual distance, $F(1,215) = 2.54$.

Time Between Glances

The effect of monitor position on the time between glances was significant, $F(3,2.31) = 7.49$, $p < 0.1$ (Figure 9). The median time between glances increased from 0.526 seconds for the near-high monitor position to 0.670 seconds for the near-low position to 1.16 seconds for the far-high position. It decreased slightly to 0.885 seconds for the far-low position.

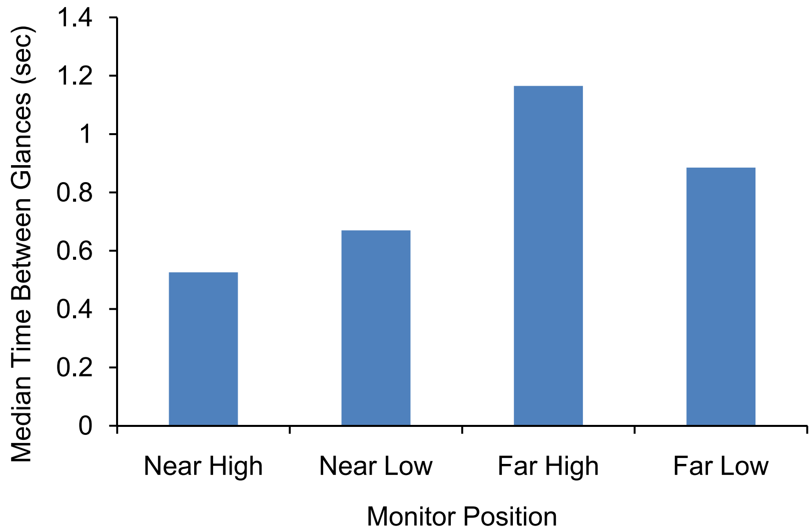

Figure 9. Median time between glances (seconds) for each monitor position.

Subject stature also had a significant effect on time between glances, $F(3,5.79) = 4.83$, $p < 0.1$ (Figure 10). Midsize females had the greatest median time between glances (1.12 seconds), followed by short females (0.802 seconds), midsize males (0.699 seconds), and tall males (0.652 seconds).

Figure 10. Median time between glances (seconds) for each monitor position.

The effect of vehicle weight was not quite significant effect, $F(1,4.46) = 3.61$, $p = 0.12$. The median time between glances was 15.6% longer for drives in normal-weight vehicles compared to heavy vehicles. No interactions were significant.

The results were slightly different when monitor position was analyzed by reach distance and visual distance. Subjects looked at the road for 71.4% longer when the monitor was in one of the far positions than when it was in one of the near positions, $F(1,16.2) = 17.41$, $p < 0.001$. However, visual distance did not have a significant effect on time between glances, $F(1,216) = 0.54$.

Time Between Glances vs. Glance Duration

The median time between glances was plotted against the median glance duration for each subject and each monitor position (Figure 11). Each point represents one subject's median time between glances and median glance duration across all trials for the given monitor position and vehicle weight. The spread of the glance durations was approximately the same for each position. The time between glances, however, was more variable for the far monitor positions.

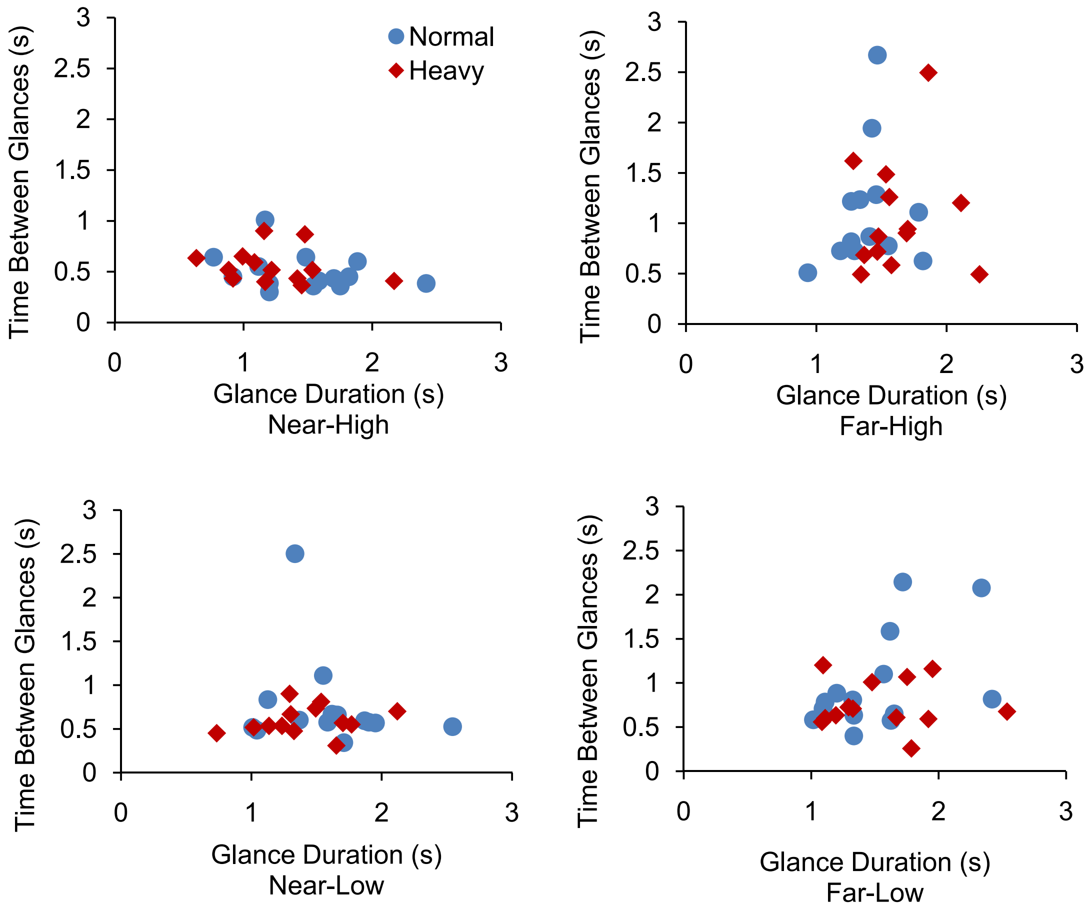

Figure 11. The median time between glances for each subject is plotted against the median glance duration for each monitor position, with a distinction made between trials involving normal-weight and heavy vehicles.

Number of Glances

Shorter subjects made significantly more glances to the monitor for the in-vehicle task than did tall subjects, $F(3,175) = 10.00$, $p < 0.0001$ (Figure 12). The mean number of glances was 11.8 for short females, 9.98 for midsize females, 8.19 for midsize males, and 7.81 for tall males.

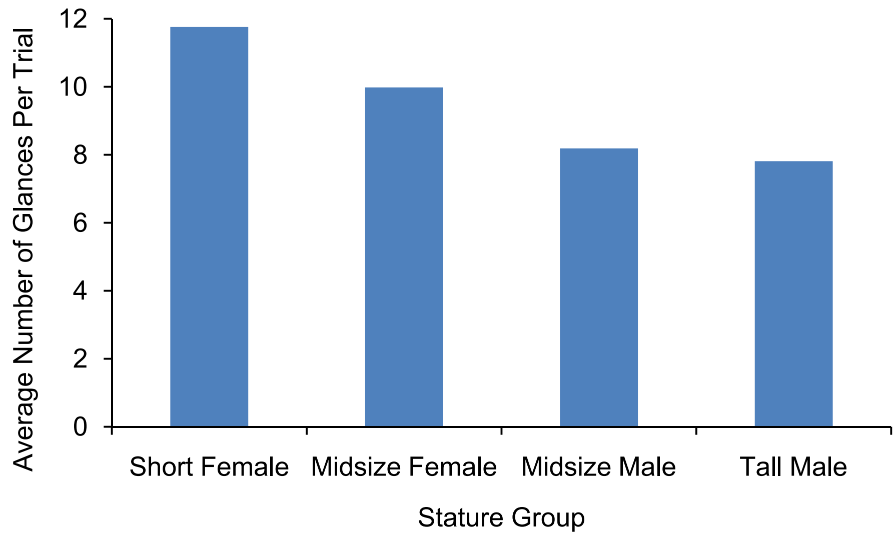

Figure 12. Average number of glances per trial for each stature group.

The number of glances also increased as the monitor was moved farther from the subject and the road, $F(3,214) = 5.00$, $p < 0.005$ (Figure 13). No interactions were significant.

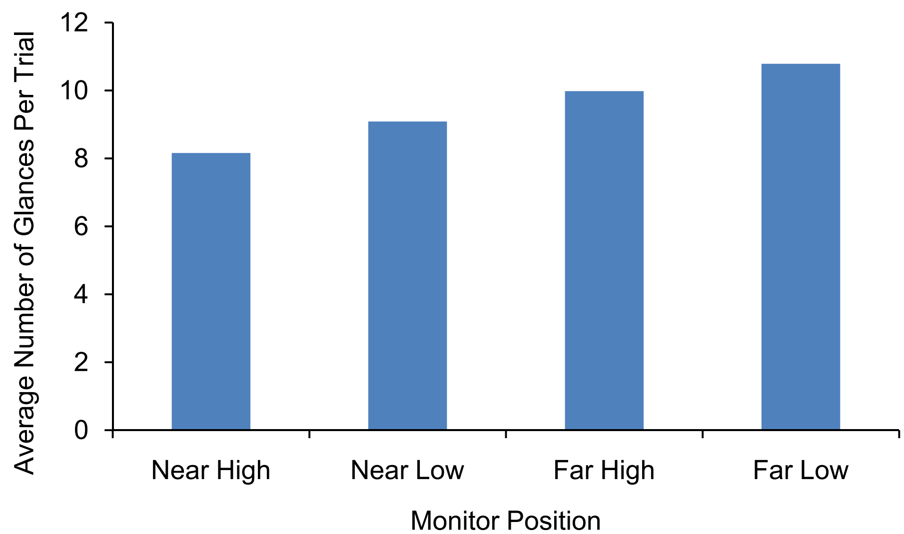

Figure 13. Number of glances per in-vehicle task iteration for each monitor position.

When the effect of the reach distance to the monitor was considered separately from the visual distance, reach distance had a significant effect on the number of glances, $F(1,215) = 12.28$, $p < 0.001$, with subjects making an average of 1.76 additional glances per trial to the far monitor positions, but visual distance did not, $F(1,216) = 2.75$. In addition, the interaction between reach distance and vehicle weight was significant, $F(1,215) = 3.04$, $p < 0.1$, with a greater increase in number of glances to far monitor positions for the normal-weight vehicle, compared to the heavy vehicle.

DISCUSSION

Monitor Position

It was predicted that total task time would be greater when the display was farther away from the driver because of increased reach distance and increased time looking away from the task to the road. The results show that task time increased for far monitor locations compared to near, though there was no significant difference between low and high monitor positions.

It would be tempting to conclude that reach distance from the steering wheel is a more important factor in the design of in-vehicle systems than the visual angle from the road. However, this finding may not extend to monitor positions that are very different from those that were tested here. It is more conservative to state that a horizontal increase in reach distance of 35 to 55 cm (the distances between the near and far monitors for the low and high positions, respectively) has a greater effect on glance behavior than a vertical increase in visual distance of 20 cm.

The total glance time and number of glances also increased for far monitor positions compared to near, as was predicted. In addition, total glance time and number of glances increased for low monitor positions compared to high positions. There are at least two possible explanations for these findings. First, the glance time includes the time to move the eyes from the road to the monitor. Sometimes, it also included the time to reach from the steering wheel to the monitor, because the reach usually was made while the subject was looking at the monitor. Therefore, the increase in total glance time may reflect, in part, the greater time required for the eye and hand movements needed to complete the in-vehicle task. Second, it may have been more difficult for the subjects to perform the in-vehicle task when the monitor was in the far and low positions because of greater difficulty in seeing the icons on the screen and greater difficulty in achieving the manual precision required to press the icons correctly. This greater difficulty could have resulted in the subjects spending more time on the in-vehicle task.

It was hypothesized that glance duration might increase for far monitor positions because of increased movement time, but in fact, monitor position had no effect on the duration of individual glances. The increase in the total glance time was a result of more glances of the same duration rather than longer glances. It is possible that in some cases subjects started to move their hands towards the monitor prior to starting a glance. In the video from the experiment, subjects sometimes left their hands near the monitor between glances rather than withdrawing them to the steering wheel. In addition, subjects could have broken the in-vehicle task into more subtasks in order to avoid an increase in glance duration. Therefore, even though the inclusion of eye and hand movements in the glances would have resulted in longer glances, subjects instead decided to complete a smaller portion of the task during each glance so that the duration of each glance away from the road remained approximately the same.

The far monitor locations also resulted in an increase in time between glances, as was predicted. Performing the in-vehicle task with the monitor in the far locations was more difficult than with the monitor in the near locations, so more attention was likely diverted from the concurrent driving task. The greater time between glances for the far monitor positions could reflect the need for more recovery time between working on the in-vehicle task (perhaps to regain the desired headway or to center the vehicle in the lane) and more preparation time before each glance away from the road (perhaps to stabilize the vehicle before moving the hand, head, and in some cases torso).

The number of glances subjects needed to complete the in-vehicle task increased for far monitor positions, as was expected. This, together with the increase in total glance time and no change in glance duration suggests that most subjects were making similar glances regardless of monitor position, but they required more glances and more time to complete the in-vehicle task when the monitor was in the far positions.

Stature

The total task time, the total glance time, and the time between glances were longest for the short females and midsize females, and shortest for the midsize males and tall males. This could indicate that the shorter subjects performed the reach using more complicated movements. The videos show some subjects in the shorter stature groups leaning with their torsos in order to reach some of the monitor positions, while the subjects in the taller stature groups could generally perform the reach using arm movements alone. The motor control literature suggests that more complicated motor actions require additional time for planning (Schmidt & Lee, 1999). Thus, the greater time between glances for short subjects could be attributable to the need for a longer planning stage during which the subjects began to prepare for the movement while still looking at the road. The greater total glance time for short subjects could include additional preparation time for the movement, when the subjects are looking at the monitor prior to making a reaching movement, as well as the greater time required to perform the more complicated movement.

Female subjects also made shorter glances to the monitor and more of them. This suggests that these subjects did not feel comfortable taking their eyes off the road for very long. It is possible that these subjects were grouping the button presses into smaller chunks when performing the task, which required them to look at and reach to the monitor more times. Alternatively, they may have completed the same number of reaches to the monitor, but with longer periods of time between reaches to prepare or recover. In order to keep track of where they were in the task, they may have made additional glances to the monitor, unaccompanied by reaches.

All the subjects in the two shorter stature groups were female and all the subjects in the two taller stature groups were male. Therefore, it was impossible to distinguish between gender effect and stature effect. This confounding represents the reality of stature differences between the genders, so the observations from this study are likely representative of what would be found in a larger population.

Vehicle Weight

Vehicle weight had little if any effect on glance behavior. It was thought that glance duration would decrease for the heavy vehicle, because driving the heavy vehicle should be more difficult than driving the normal-weight vehicle, similar to driving on sharp curves in Tsimhoni and Green (2003). Thus, subjects should feel constrained to take their eyes off the road for shorter amounts of time. However, there was no change in glance duration. The cost of short glances while trying to maintain lane position on a sharp curve is critical and immediate. In contrast, the cost of short glances while trying to maintain headway to a lead vehicle in a heavy vehicle is cumulative. Furthermore, the heavy vehicle was perhaps more predictable, thus requiring shorter glances to the road.

The time between glances was actually shorter for the heavy vehicle compared to the normal-weight vehicle, and subjects made slightly fewer glances to the monitor. This could indicate that subjects were rushing through the in-vehicle task in order to return to the driving task and perhaps caring less about their driving performance when the driving task was more difficult.

Interactions

The increase in total task time from near to far monitor locations was greater for shorter subjects, as was predicted. This is likely because the shorter subjects had more trouble than the taller subjects in reaching to the far monitor locations. It was hypothesized that shorter subjects would show a greater increase in total glance time and time between glances with the far monitor positions, but there were no significant interactions. It is possible that the short subjects were using different glance strategies to compensate for the greater difficulty they had in performing the task with the monitor in the far positions.

Strategies

The dual task scenario created in this experiment required subjects to decide how to share resources such as vision and information processing between two tasks: driving and the in-vehicle matching task. This research makes it possible to investigate whether glance strategies used by drivers vary as a function of the monitor position. This information could aid in the design of future in-vehicle systems, especially with regard to the need for adjustability.

The plots of time between glances against glance duration show some possible differences in glance strategy based on the monitor location. The plots for the two near monitor locations are very similar, with a wide range of glance duration and a narrow range of time between glances across subjects. Based on these plots, subjects can be divided into two behavioral categories: short time between glances with short glance duration and short time between glances with long glance duration. The second strategy is the more risky of these two, because long glances away from the road may increase the likelihood of collision. Long glance durations could indicate that the subject is engaged in cognitive tunneling, in which a subject presented with a secondary task in a simulator concentrates on this task to the exclusion of the primary driving task.

The two far monitor locations have glance duration spreads that are similar to those of the near monitors, but the range of values for time between glances is much larger. Thus, the far monitor locations show four categories of glance behavior: the two identified for the near monitor locations, long time between glances with moderate glance duration, and long time between glances with long glance duration. The third strategy indicates more time is being spent on the driving task than on the secondary task. The last strategy shows that equal time is spent on the two tasks, but the subject switched between the tasks infrequently. This strategy could be displayed by a subject who forgets to shift attention between the tasks or whose attention is captured by one of the tasks. Cognitive capture can cause a driver to focus on a secondary task to the exclusion of the more important driving task (Weintraub, 1987).

In the exit interviews, subjects were asked about how they chose to perform the dual tasks assigned in the experiment. Many subjects indicated that they avoided performing the in-vehicle task when driving around a curve, especially for the far monitor positions. This is consistent with the findings from Tsimhoni and Green (2003) that showed subjects made shorter glances to the display and longer glances to the road with increased road curvature.

All the subjects agreed that the far monitor positions were more difficult, but subjects varied in how they chose to manage the tasks. Some stated that they tried to complete the in-vehicle task as quickly as possible, while others felt that they took more breaks from the in-vehicle task while performing the task with the far monitor positions than when the monitor was at a shorter reach distance. Future work could examine how subject characteristics such as age, risk-taking behavior, and motivation contribute to changes in glance strategy.

CONCLUSIONS

The results of this study demonstrate both strengths and limitations of drivers' abilities to cope with secondary tasks while driving. The instructions that subjects were given emphasized that they should assign the most priority to the simulated driving task and perform the secondary task as well as possible within that context. In terms of overall performance of both tasks, they were partly successful in following those instructions. On the positive side, the effect of far (difficult) monitor positions was limited to performance on the secondary task, while performance on the driving task was virtually unchanged. However, driving performance for all monitor positions was somewhat reduced relative to the control condition in which the secondary task was not required. It is not immediately obvious how to explain the fact that, although driving performance was not entirely independent of the secondary task, it was unaffected by substantial changes in the difficulty of the secondary task (as influenced by monitor position). One possibility is that the mere presence of the secondary task interfered with some general, executive-level process. Alternatively, the results could be explained in terms of the internal performance criteria that were adopted by the subjects. It may be that the reduced level of driving performance that was observed for all monitor positions corresponded to what the subjects considered a minimum (but nevertheless acceptable) level. The higher driving performance that they achieved when they were not performing the secondary task may thus have been considered, in their explicit or implicit strategic calculations, higher than actually required.

At a more detailed level, it appears that the coping strategies used by these subjects involved performing the secondary task in discrete subtasks. Thus, the increased difficulty caused by more distant monitor positions resulted in more glances to the monitor rather than longer glances. Secondary tasks presumably vary in how easily they can be divided into manageable subtasks. The secondary task used here may have been particularly easy to divide, since it consisted of a series of similar components involving locating and identifying icons and matching them by pressing the corresponding locations on the touch screen.

In order to make practical recommendations for equipment and procedures to be used in a range of secondary tasks, it is necessary to consider various aspects of the demands of the secondary tasks. Among these are the extent to which various secondary tasks can be divided into subtasks, as well as the fundamental perceptual, cognitive, and motor requirements of the tasks. Ideally, a comprehensive model should be developed to integrate information about the demands of secondary tasks from this study and from various possible extensions. Important ways in which the current results could be extended include: (1) Use of other measures of driving performance. For example, even within the context of a vehicle-following task, the frequency and abruptness of changes in lead-vehicle speed could be continuously varied so that the task could range from being a relatively predictable tracking task to one in which subjects had to detect unpredictable, heavy braking events. (2) The effects of monitor location on perceptual and motor demands could be separated by varying the monitor's visual characteristics (e.g., size or level of detail in the icons) and motor characteristics (e.g., size of touch-sensitive areas, level of force, or duration of continuous contact required for a response). (3) Instructions to the subject about the strategic importance of the secondary task relative to driving could be varied.

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