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TIME-SHARING OF A VISUAL IN-VEHICLE TASK WHILE DRIVING: FINDINGS FROM THE TASK OCCLUSION METHOD

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16. Abstract

What can the task occlusion method reveal about time-sharing of a visual in-vehicle task while driving? To examine this issue, 24 licensed drivers (12 under 30 years, 12 over 65 years) were instructed to plan routes to specified destinations on an electronic map while driving a simulator. Four levels of steering difficulty (parked, straight road, moderate curves, and sharp curves) were examined for two levels of task immediacy (map fixed and map rotating). Subjects also performed the task while parked with the map intermittently occluded. Six combinations of viewing times (1, 1.5, and 2 s) and occlusion times (1 and 3 s) were examined.

When driving, total task time increased significantly from 11.0 s while parked to 15.5 s on straight roads and 19.5 s on sharp curves. Total glance time at the display, however, remained unchanged (M=12.0, SD=0.6 s). As road curvature increased, subjects made shorter glances at the display, longer glances at the road, and more glances overall. As a result, driving performance degraded and error probability increased. During occlusion, total task time increased as viewing time decreased and as occlusion time increased. Total glance time, however, remained unchanged (M=10.4, SD=0.4 s) in all 6 timing combinations, and error probability remained constant.

These results can be explained in light of four key constructs: *time pressure* on sharp curves resulted in short and efficient glances to the display; *interference of concurrent driving* resulted in longer total glance times at fixed maps while driving relative to task occlusion; and *postponed processing* and *the cost of task partitioning* balanced each other to keep total glance time unchanged when viewing time and occlusion time were manipulated.

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INTRODUCTION

General

As telematics devices become more common in vehicles, the problem of driver distraction increases. There is an ongoing attempt to minimize this problem by implementing speech recognition and auditory presentation of information, but some information is most efficiently conveyed visually (e.g., determining spatial location via electronic street maps). The focus of this report is on a subset of such in-vehicle tasks that are visual and require no motor input.

In-vehicle tasks that require long eyes-off-the-road time degrade driving performance (see Green, 1998, for a review). Vehicle crashes, a safety consequence of degraded driving performance, increase when in-vehicle tasks are more visually demanding (Wierwille and Tijerina, 1998). Therefore, understanding the visual demands imposed by in-vehicle tasks is important for the understanding and prediction of driving performance and the consequent driving safety.

A simple method to determine the visual demand of a task is to measure the total task time while driving (or while parked). Some claim, however, that total task time does not tell the full story. Longer in-vehicle tasks may not necessarily impose higher visual demands on the driver. For example, a driver may choose for safety purposes to wait longer between consecutive glances at the display, thus increasing total task time but reducing the negative consequences of the task on driving. Alternatively, a task that affords short glances to the display may also take longer to complete yet impose relatively low visual demand on the driver (e.g., Weir, Chiang, and Brooks, 2003).

This suggests a need to better understand other temporal measures of time-sharing, such as the mean glance time, the total glance time, the number of glances, and the constructs that underlie changes in time-sharing characteristics while driving.

Key Constructs that Affect Time-Sharing while Driving

Four key constructs are considered: (1) time pressure to look back at the road, (2) interference of concurrent driving, (3) postponed processing and planning while looking away from the display, and (4) the cost of task partitioning. Each of these constructs is thought to affect the timing of glances at the in-vehicle display and at the road, as shown in Table 1. As some of the effects predict opposite outcomes, the overall outcome is often hard to foresee. Nevertheless, verification of the effects of each of the constructs is a first step towards understanding the overall outcome.

Table□ Four constructs that affect time-sharing of a visual in-vehicle task while driving (SGDisp=single glance duration to the display, SGRoad=single glance duration to road, TGT=total glance time, TTT=total task time)

			Duration Change			
Construct	Description	Effect on Time Sharing a Visual In-Vehicle Task while Driving	SG Disp	SG Road	TGT	TTT
1. Time pressure to look at the road	After looking away from the road for some time, the driver feels the need to look at the road again	Time pressure to look back at the road results in shorter glances and induces efficiency in performing the in-vehicle task	⇓	⇑		
2. Interference of concurrent driving	When looking away from the road, the driver still processes some driving information	Concurrent processing of driving information interferes with the in-vehicle task			⇑	⇑
3. Postponed processing and planning	When looking at the road, the driver can perform some post processing of what was just seen and plan ahead for the next glance	Post processing and planning of the in-vehicle task while looking at the road reduces total time spent looking at the display			⇓	⇓
4. The costs of task partitioning	Partitioning the in-vehicle task into small parts may degrade performance or require more glances at the display	The cost of task partitioning requires repeating steps and making more glances at the display to complete the in-vehicle task	⇑	⇓		

The first two constructs (time pressure and interference) can be tested by comparing task performance while parked to task performance while driving at fixed levels of visual demand. A controlled increase of the visual demand of driving is likely to increase the time pressure to look back at the road. It is expected that single glances will therefore be shorter and time between glances will be longer. The total glance time may remain constant if the time pressure induces efficiency, and the total task time will either remain constant or slightly increase. Interference of the driving task with in-vehicle task performance is likely to increase with higher visual demand of driving, resulting in degradation of task performance and therefore longer total glance times and longer total task times.

Fixed levels of visual demand can be achieved by conducting the driving experiment on simple roads with long curves of constant curvature. Once the driver has entered the curve, the visual demand of maintaining lateral position within the lane boundaries is a linear function of the curvature of the road (Tsimhoni and Green, 1999). Thus, a controlled increase in the visual demand of driving can be attained.

The latter two constructs (postponed processing and the cost of task partitioning) cannot be tested based on the visual demand of driving without further experimental manipulation. One such manipulation is controlling the duration of glances away from the in-vehicle task. If postponed processing and planning occur between glances at the display, a performance increase will be observed when the time between glances is longer. On the other hand, if pauses between glances at the display are associated with high costs due to forgetting information and the need to reacquire the last point of fixation, performance degradation is likely to be observed.

Controlling the duration of glances to and from the display can be achieved by occluding the display or covering the subject's eyes at fixed intervals. The "task occlusion" methodology has been used in several experiments in recent years. The main purpose of these experiments has been to define a test procedure to detect tasks that are unsafe for driving (Society of Automotive Engineers, 2003). A summary of methodologies and findings from twelve task occlusion experiments appears below. All of these experiments occluded the in-vehicle display to measure task performance as it relates to driving.

Task Occlusion Methodology

Occlusion Goggles vs. LCD Blanking

There are two common methods for occluding the display. The more common method is for the subject to wear goggles with LCDs that rapidly switch on (transparent) or off (opaque) based on a signal from a computer (e.g., Plato visual occlusion spectacles, Translucent Technologies). Another method is to mount a shutter on top of the task display (usually an LCD) or to blank the display using software. Of the 12 reviewed experiments, 8 occluded the display using occlusion goggles and 4 used a shutter on the display or blanked the display using software.

In an experimental comparison of the two methods, Weir, Chiang, and Brooks (2003) found no significant difference in task timing and driving performance between goggles and LCD. They did report, however, a slight preference by subjects for the LCD method. Additionally, the goggles were reported by several researchers as uncomfortable to the wearer after long use and they were limited to subjects who do not wear glasses.

Another comparison of the two methods was performed by Niiya (2000). Niiya found slower response times (200 ms difference) in an object recognition task when using goggles. This difference was attributed to the accommodation time to the display after the goggles were occluded. (As a side note, there was no measurement or mention of the resting point of accommodation of subjects. If one has a resting point of accommodation of 80 cm, there should be no accommodation and therefore no degradation in response time.)

Timing of Occlusion Intervals

A wide range of occlusion intervals has been examined in the reviewed experiments. Figure 1 provides a graphic summary of the combination of viewing time and occlusion time for 12 experiments. In most of these experiments, the rationale for choosing a certain timing scheme was the similarity of glance times to actual driving and the need to interrupt the task. Most of the experiments used glance times between 1 and 2 s and occlusion times between 1 and 5 s Of note are Krems et al. (2000) who chose among other intervals extremely short viewing times (200-400 ms), and Monk, Boehm-Davis, and Trafton (2002) who focused on extremely long viewing and occlusion times (as long as 5 s viewing time and 13 s occlusion time).

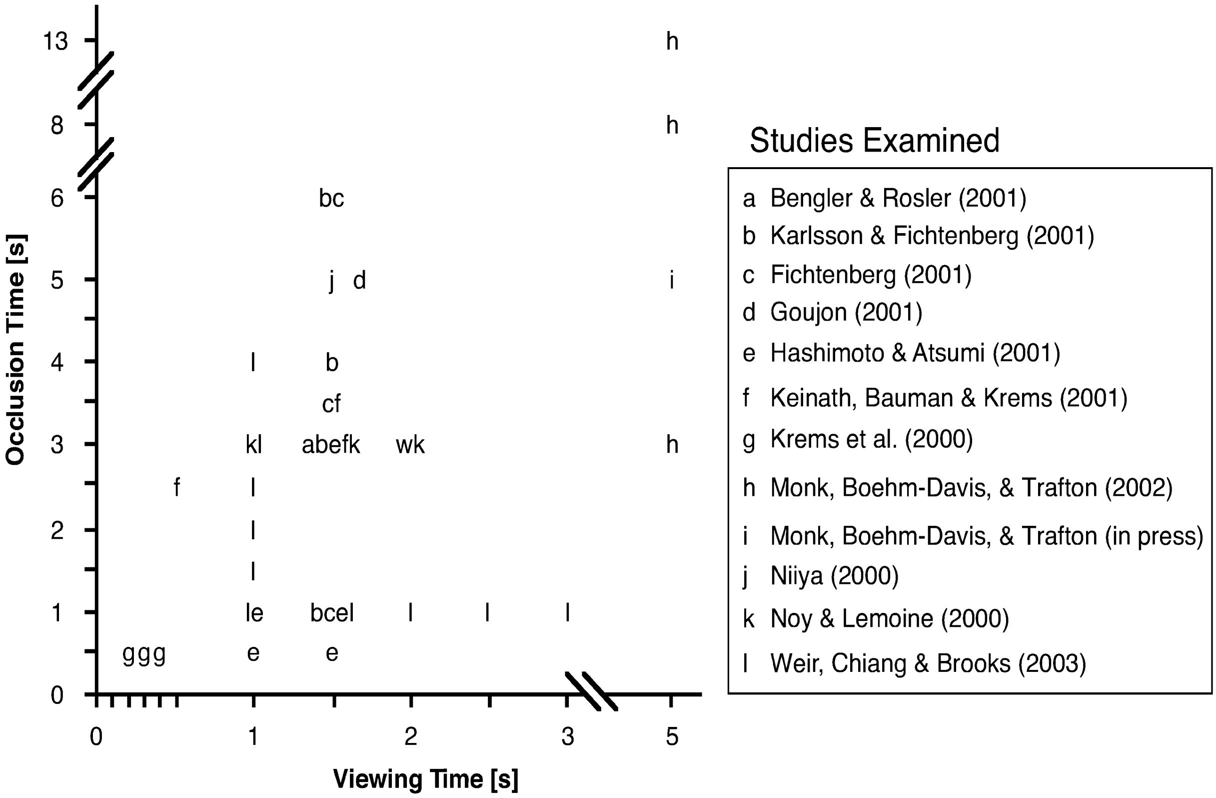

Figure 1. Viewing time and occlusion time in previous occlusion experiments

Findings from Other Task Occlusion Experiments

Total Shutter Open Time

Total shutter open time (TSOT) is a measure of the time the subject views the task, analogous to the total time spent looking at the display while driving. Comparison to the total task time when performing the task continuously (without occlusion while parked) should provide some information about the ability to perform the task while driving. Table 2 shows the ratios between TSOT and TTTstatic, which have been used to predict task partitioning while driving, in some of the reviewed articles. Ratios over 1.0 indicate that there is cost associated with partitioning the task into small parts. Ratios below 1.0 indicate that the task can be partitioned without cost and/or the benefit of delays between glances at the display can be utilized for task completion.

Table21 TSOT as a function of TTTstatic in selected experiments

Experiment	Task	TTTstatic [s]	TSOT/TTTstatic
Bengler & Rosler (2001)	Destination entry using handwriting	45-76	0.38 (estimated)
Karlsson & Fichtenberg (2001)	Destination entry	18-25	0.6-1.11
Fichtenberg (2001)	Count A's in text	25	0.8-1.08
Goujon (2001)	Destination entry	23, 67	0.7-0.79
Goujon (2001)	Radio control, phone control	2.4-9	1.05-1.7
Hashimoto & Atsumi (2001)	Destination entry and menu selection	3-15	0.7-0.8
Keinath et al. (2001)	Destination entry	50	0.62-0.68
Noy & Lemoine (2000)	Destination entry, radio, map reading	10-40	1.26-1.69
Weir et al. (2003)	Continuous character entry	1.0 key/s	0.92-1.06

The ratio between TSOT and TTTstatic in these experiments was not consistent. The reported results from Bengler and Rosler (2001) suggest a ratio of 0.38 (estimated). This is most likely because subjects used handwriting and were able to continue writing when the display was occluded. On the other end of the spectrum, the very short tasks of Goujon (2001) and all the tasks of Noy and Lemoine (2000) reported high ratios (1.05-1.07 and 1.26-1.69, respectively). The rest of the experiments reported ratios that were around 1.0 with a tendency to be somewhat lower (0.6-1.11).

Comparison of Task Occlusion to Total Glance Time while Driving

Hashimoto and Atsumi (2001) compared task occlusion performance to glance performance in on-road driving. A comparison between the total shutter open time (TSOT) and the total glance time (TGT) while driving yielded a ratio of 0.9. All the tested combinations of occlusion intervals were slightly lower than TGT.

Similarly, Weir, Chiang, and Brooks (2003) compared task occlusion performance to glance performance in simulator driving. The reported task performance in terms of keys pressed per second did not change significantly from the occlusion condition to the driving condition. When driving, subjects entered 1.0 keys per second. In the task occlusion condition, they entered between 0.92 to 1.06 keys per second. Keying rate had a tendency to decrease when closed times were longer.

Purpose of the Experiment

Task occlusion experiments thus far have demonstrated the application of the method for several in-vehicle tasks at a wide range of timing intervals. None of these experiments, however, used task occlusion to explain the effects of task demands and road demands on task partitioning and driving. There were only a few attempts to validate task occlusion results by comparing them to glance times while driving. Finally, no systematic control of the visual demands of driving and the visual demands of the in-vehicle task has been reported.

To address these issues, the following questions were examined:

How is task partitioning while driving affected by the demand of the task (e.g., static vs. rotating map) as a function of visual demand?

> The type of task and the demands that it imposes on the user are likely to influence how it is partitioned. (E.g., if partitioning the rotating map task into short glances degrades task performance, the driver will probably try to make longer glances to the display.)

In the task-occlusion paradigm, how does limiting the glance duration and the duration of occlusion affect task performance?

> Forcing shorter glances is likely to interfere with the natural partitioning of the task and therefore will increase the number of glances. Longer occlusion durations are likely to cause forgetting of information but on the other hand they might allow planning and post processing. Since these two effects can negate each other, the outcome of the combined effect is uncertain.

How can the results of the task occlusion method explain task partitioning while driving?

> It is expected that subjects will vary the timing of glances at the display and at the road as a function of the visual demands of the road and the task. The occlusion technique will simulate these timing variations by changing the length of viewing times and occlusion times. The resulting total shutter open times and error rates will serve to explain the choice of glance timing when performing the task on the road.

Do subjects partition the task differently while driving? Are these differences correlated with age or gender?

> Older subjects are expected to make shorter glances at the display and longer glances at the road. As a result, their total task times are expected to be longer than of younger subjects.

TEST PLAN

To examine time-sharing of a visual in-vehicle task while driving, subjects were instructed to plan routes on electronic maps in a driving simulator in two experimental conditions: while driving on long curves of several radii with the map displayed and while parked with the map intermittently occluded.

Test Participants

Twenty-four licensed drivers participated in this experiment, 12 younger (ages 20 to 28, mean of 23) and 12 older (ages 65 to 71, mean of 68). Within each age bracket there were 6 men and 6 women. Subjects were recruited from a list of people who had participated in previous UMTRI experiments. All were paid $40 for their efforts.

Subjects' vision was tested (using an Optec 2000 from Stereo Optical Inc.) for far visual acuity and mid-range visual acuity (at a simulated distance of 80 cm). All had far visual acuity of 20/40 or better as required by state law for driving (for day and night driving). All had mid-range visual acuity of 20/50 or better.

Subjects reported driving 2,500 to 30,000 miles per year. On average they drove just about the mean for U.S. drivers (11,000 miles per year). No subject had a professional driving license. Seven younger and 2 older subjects reported being in an accident within a 5-year period prior to the study. Six younger and 3 older subjects had used an in-vehicle navigation system before, but only 1 (younger) subject had used it more than a few times.

Test Materials and Equipment

Driving Simulator

The experiment was conducted in the second generation UMTRI Driver Interface Research Simulator (software version 7.2.4), a low-cost driving simulator based on a network of Macintosh computers (Olson and Green, 1997). The simulator (Appendix E) consisted of an A-to-B pillar mockup of a car, a projection screen, a torque motor connected to the steering wheel, a sound system (to provide engine, drive train, tire, and wind noise), a sub-bass sound system (to provide vertical vibration), a computer system to project images of an instrument panel, and other hardware. The projection screen, offering a horizontal field of view of 33 degrees and a vertical field of view of 23 degrees, was 6 m (20 ft) in front of the driver, effectively at optical infinity. The simulator collected driving data at 30 samples per second. For this experiment, lateral position and steering wheel angle were collected. An additional column, indicating when the subject performed the in-vehicle task, was added to the data file (a software change for this experiment).

Simulated Roads

The simulated roads were designed to impose three levels of workload by manipulation of road curvature (straight sections, moderate curves, and sharp curves) (Table 3). These curve radii were chosen based on results from previous studies (Tsimhoni and Green, 1999; Tsimhoni, Yoo, and Green, 1999), in which the visual demand of these curves was quantified. (Visual demand was defined as the fraction of time the road was viewed). A linear increase in visual demand was found as curvature increased. Additionally, the visual demand at the beginning of curves was higher and decreased to a steady state after approximately 150 m. Therefore, to avoid drastic changes in visual demand within conditions, curves in this experiment were designed to be long enough to maintain constant visual demand values. Furthermore, the map viewing task was presented 200 m after the start of the curves to avoid the peak demand experienced at the beginning of the curve.

Table 3. Road characteristics

Road Section	Degrees of Curvature	Radius [m]	Visual Demand
Straight	0	-	0.25
Moderate curve	4.5	388	0.34
Sharp curve	9	194	0.44

The single lane road was 3.66 m (12 feet) wide. The simulated vehicle was put in automatic cruise control mode at 72.5 kph (45 mph) for the entire experiment. These parameters were chosen to simplify the driving task and to avoid unnecessary lane departures to the left lane (which were very common in a previous simulator experiment with two lanes and no oncoming traffic).

Map Display

An LCD monitor (Elotouch 1225L, 30.7 cm [12.1 in] diagonal), located in the center console of the vehicle, was used to simulate a navigation map display. To reduce the active area to a size more likely for a production vehicle, a 17.8 cm (7 in) diagonal rectangular opening (4:3 horizontal to vertical ratio) was cut into a black cardboard cover. Maps (11.2 cm horizontal by 8.4 cm vertical) were displayed in the center of this rectangle. The center of the display was 23±2 degrees below the horizontal line of sight and 30±2 degrees to the right of the center at a distance of about 80 cm (Figures 2 and 3). Street names appeared in Helvetica 16 pt font at 3.5 mm height, which translated to a visual angle of 0.0044 radians.

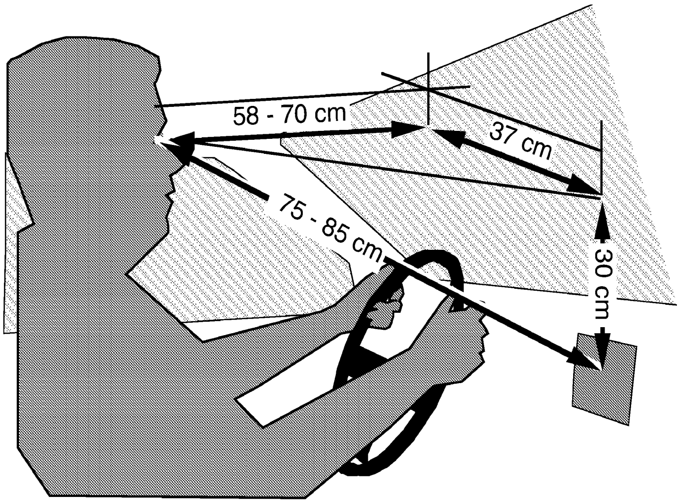

Figure 2. The location of the in-vehicle displays

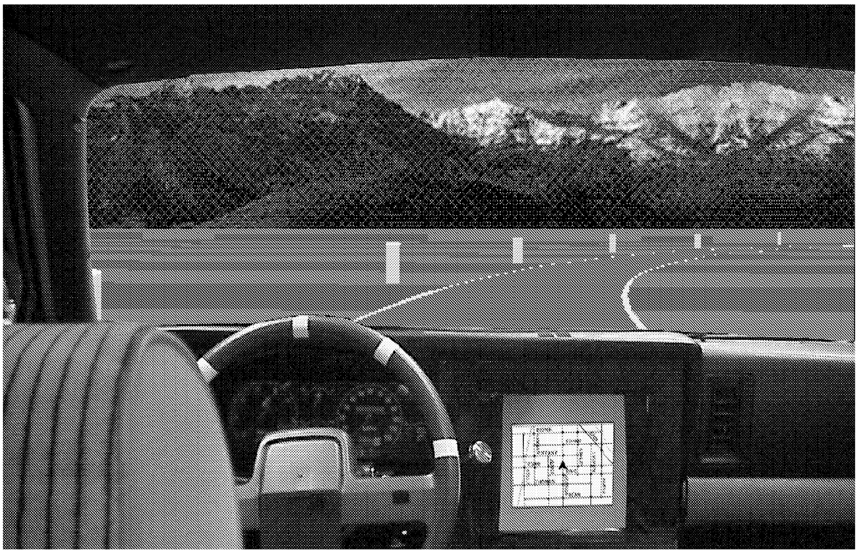

Figure 3. Driver's view of the single-lane road and map display
(Note: The map display and road scene were enhanced in this image for clarity)

Control Program

A custom REALbasic program (REALbasic ver. 3.5.1, REAL Software Inc.), running on a Power Macintosh 9500/120, was used to control the presentation of the maps on the in-vehicle display and to record the start and end times by timing switch presses on a device mounted on the subject's index finger.

In-Vehicle Task

Subjects were asked to plan a route on an electronic map from an icon representing their current location at the center of the map to a specified intersection. After hearing a recorded street name (voiced by a semi-professional announcer and played through 2 speakers in the car), the subjects pressed the finger switch to view the map. Their task was to find where the street dead-ended into another street and plan a route to that intersection. The maps were planned so that there was always exactly one such intersection. Subjects planned the route from an arrow indicating their current location to the specified intersection according to predetermined rules they practiced before the experiment (Appendix F). These rules made it possible to plan the route at each intersection without the need to compare alternative routes. When subjects had planned the route and counted the number of intersections, they pressed the finger switch again, indicating that they had completed the task, and then said the number of intersections.

The maps presented in the experiment were all based on a common template (e.g., Figure 4) but differed from one another in the relative orientation of streets and the selection of street names. Street names were taken from a list of 100 popular first names in the U.S. so that subjects would be familiar with their pronunciation and spelling. Each map consisted of 12 T-intersections and a varying number of 4-way intersections. The target T-intersection and corresponding street name that were presented to the subject were counterbalanced within each block of 8 maps. This was done to minimize anticipation of the location of the intersection (located in one of four quadrants), orientation of the street (vertical or horizontal), direction of the intersection from the street name (left/right, up/down), and number of intersections counted (5-8). Maps were repeated across the two parts of the experiment (on the road versus intermittent occlusion).

In half of the trials, the map rotated clockwise similar to what occurs in real navigation systems on curves and when turning at intersections. The map rotated at a rate of 2 deg/s with a screen refresh of 2 frames per second (every 1 deg). The rotation was programmed to slow down when the map rotation exceeded 85 deg and stop at 90 deg to avoid having to read upside down.

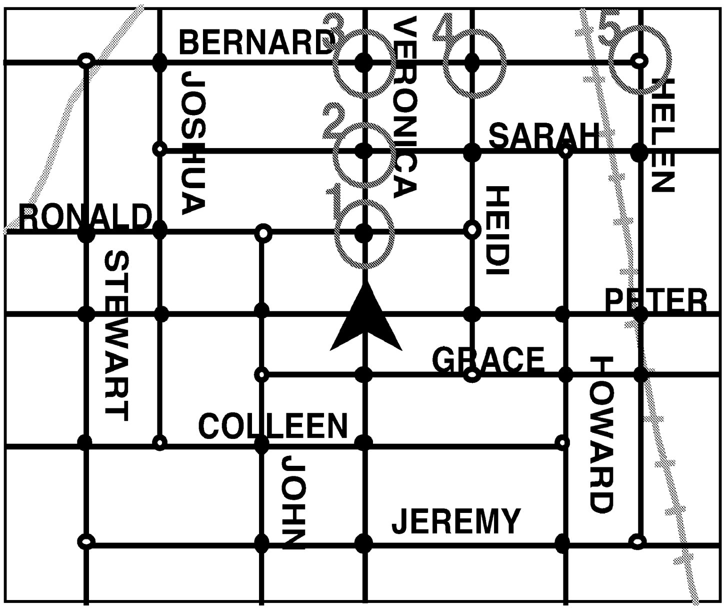

Figure 4. Sample map (numbered circles indicate counting of the intersections)

Figure 5 illustrates a possible collection of steps for completing the in-vehicle task.

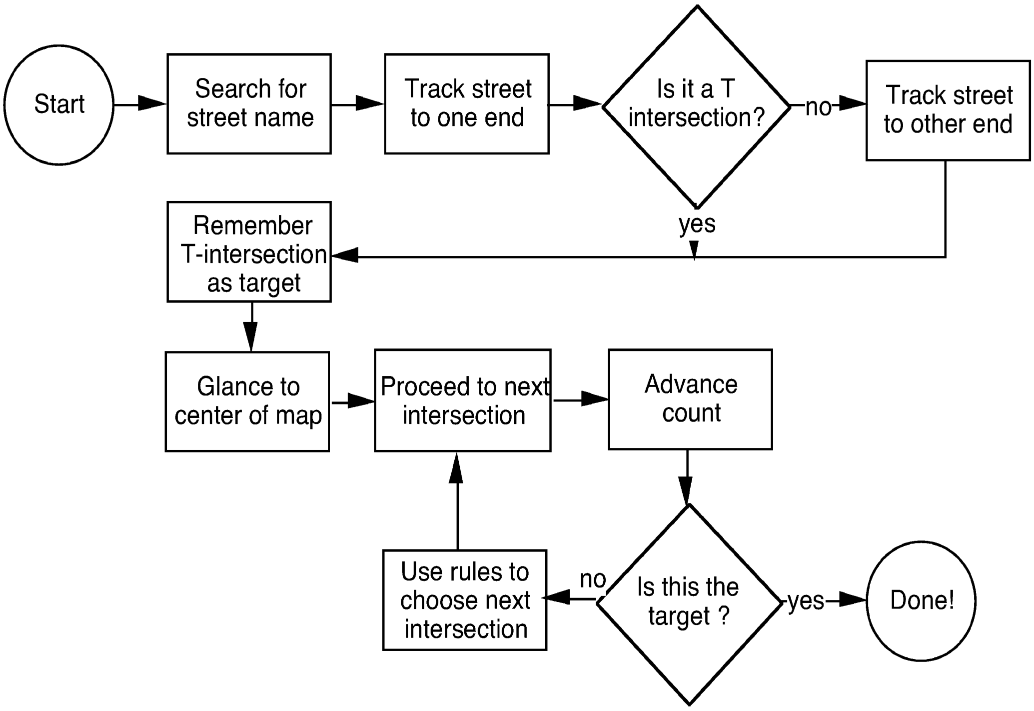

Figure 5. Steps performed for completion of the in-vehicle task

Occlusion Procedure

The occlusion technique implemented in this experiment was intended to simulate in-vehicle task performance where drivers glance at the display intermittently. Because it was important to explore several timing schemes, forced occlusion, in which the subject had no control over timing, was chosen. To help subjects time their glances, their attention was drawn to the display by a short beep prior to the end of the occlusion interval (after which the map was visible).

Subjects were instructed to look away from the display during the occlusion interval so that the task would be more similar to when performed while driving. First, it prevented subjects from keeping their eyes fixated on a certain point on the display in preparation for the next viewing interval. Second, it forced reaccommodation of the eyes from the road (simulator screen at 6 m) to the in-vehicle display (at 0.8 m). Third, it required eye and head movements similar to those performed while driving.

Although looking away from the display added possible validity to the task occlusion method, it was more complicated to perform than without head movements and required more practice. Therefore, clear instructions followed by several practice trials were given. The experimenter provided feedback to subjects who forgot to look away from the display. In a few cases, a black-and-white checkerboard image was displayed as soon as the display was occluded to remind the subject to look away. This procedure was only necessary a few times, and proved very effective.

The timing of map display and occlusion intervals are shown in Figure 6. Total task time (TTT) was measured from the first switch press to show the map until the second switch press to stop showing the map. Total shutter open time (TSOT) was the total duration the map was visible to the subject (i.e., the number of viewing intervals multiplied by the duration of a single viewing interval). If the switch was pressed in the middle of a viewing interval, the map was hidden immediately, and TSOT was adjusted accordingly.

When applying the task occlusion method, TTT is a direct function of TSOT and the timing of viewing intervals and occlusion intervals (Equation 1). TSOT reflects a simulation of the time drivers would divert their eyes from the road scene and total task time reflects the overall time they would be engaged in the secondary task. If TSOT is constant, TTT increases when occlusion intervals are longer and when viewing times are shorter.

$$\text{TTT} = \text{TSOT} + (\text{TSOT} / \text{Single Viewing Time}) \times \text{Single Occlusion Time} \tag{1}$$

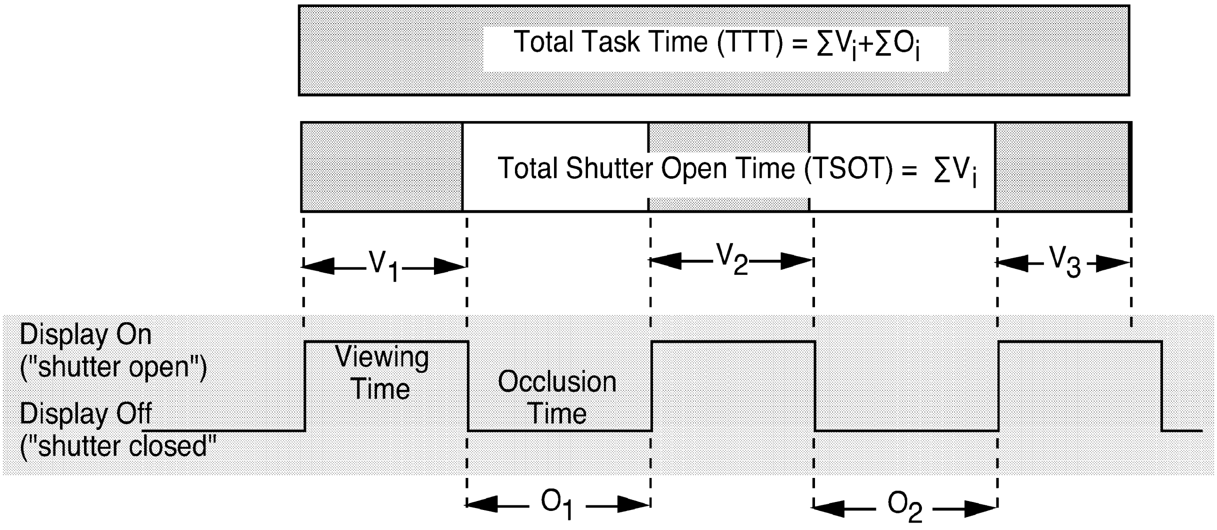

Figure 6. Diagram of timing measures

Experimental Design

The experiment consisted of two parts. In the first part, the subjects performed an in-vehicle task while operating a driving simulator with four levels of driving workload (parked, straight road, moderate curve, and sharp curve). The order of road presentation was counterbalanced between subjects of the same age and gender subgroup. The three road curvature conditions were performed in all six possible order combinations (Table 4). The parked condition was always performed at the beginning and the end of the experiment.

Table 4 Order of road curvature presentation

	Road Curvature [degree of curvature] (P=parked, 0=straight, 4.5=moderate curve, 9=sharp curve)					
	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6
First	P	P	P	P	P	P
Second	0	4.5	9	0	4.5	9
Third	4.5	9	0	9	0	4.5
Fourth	9	0	4.5	4.5	9	0
Fifth	P	P	P	P	P	P

In the second part of the experiment, the in-vehicle task was performed while parked, with the display intermittently occluded at each of 6 combinations of timing (A – F in Table 5). The order of presentation of these conditions was counterbalanced between subjects in each age and gender subgroup based on a 6x6 Latin square design (Table 6).

Table 5 Task occlusion conditions

		Map Viewing Interval			
		1.0 s	1.5 s	2.0 s	No limit
Map Occlusion Interval	1.0 s	A	B	C	▨
	3.0 s	D	E	F	▨
	No occlusion	▨	▨	▨	Baseline

Table 6 Task occlusion order

	Task Occlusion Condition (refer to Table 5)					
	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6
First	A	B	C	D	E	F
Second	B	C	A	F	D	E
Third	C	A	B	E	F	D
Fourth	D	E	F	A	B	C
Fifth	E	F	D	C	A	B
Sixth	F	D	E	B	C	A

Test Activities and Sequence

The subjects began the experiment by completing a consent form (Appendix A) and a biographical form (Appendix B), followed by performing a vision test and a paper and pencil tutorial of the map task until the experimenter felt the subject understood the task adequately. They were then seated in the driving simulator (Table 7 – activity 1).

After a short introduction to the experimental protocol, subjects practiced driving for 5 minutes on a road that consisted of straight sections, moderate curves, and sharp curves (as mentioned in Table 3 earlier). They then drove a similar road, for which baseline driving data were collected. Prior to driving each segment, subjects were instructed to drive as they would normally and do their best to remain in their lane.

The map task was then described and shown on the in-vehicle display. After confirming that the subject could read the street labels clearly, instructions on performing the map reading task were given. The subject then performed the task while the vehicle was parked.

Subsequently, subjects performed the task while driving on the practice road. The tasks were presented manually by the experimenter at a convenient pace to each subject. Special care was given to instruct subjects to "perform the task only if you think you can remain in the lane," and "remember your first priority is to stay on the road." Subjects then drove on 3 roads while performing 8 trials in each road, followed by a 5-minute break.

The simulator was “parked” for the occlusion conditions that followed. Subjects were given instructions on how to perform the task. Subjects performed the in-vehicle task while the display was intermittently occluded for six combinations of interval durations (as described previously in Table 5). For each of six conditions, the first four trials were practice for the new timing scheme, followed by eight test trials.

Two test conditions followed. In the first, subjects searched for a given street name, found the intersection where that street dead ended, and pressed the finger switch. In the second, subjects searched for a given street name and pressed the finger switch as soon as the street was found. In several of these trials, subjects identified the quadrant in which the street name or intersection had appeared. This was done to verify that the subject was indeed performing the task and not pressing the switch randomly.

Finally, because of the duration of the experiment and concerns about confounding practice effects, an additional set of 8 baseline trials (without occlusion) was performed. Subjects then completed a post-test form (Appendix C) and a payment form. They were all paid $40 for their efforts.

Table□ Summary of activities and their sequence

Step	Task	Order of Blocks	Example of Alternative Order	Number of Trials (Maps)	Time (Min)
1	Pre experiment: Introduction, biographical, and consent forms. Pretest DA measurement (Appendix G)				10
2	Simulator practice (all curvatures)				6
3	Baseline driving (all curvatures)				6
4	Task practice: no driving			8	8
5	Task baseline: no driving			8	4
6	Task while driving - practice			8	6
7	Task while driving 1 - straight (0)	0	9	8	6
8	Task while driving 2 - moderate curve (4.5)	4.5	4.5	8	8
9	Task while driving 3 - sharp curve (9)	9	0	8	10
	Break Post-test DA measurement (Appendix G)			0	10
10	Task occlusion - practice			4	4
11	Task occlusion - 1 condition A	A	F	4+8	6
12	Task occlusion - 2 condition B	B	E	4+8	6
13	Task occlusion - 3 condition C	C	D	4+8	6
14	Task occlusion - 4 condition D	D	C	4+8	7
15	Task occlusion - 5 condition E	E	B	4+8	7
16	Task occlusion - 6 condition F	F	A	4+8	7
17	Task baseline search for intersection only			24	5
18	Task baseline search for street name only			24	4
19	Task baseline 2			8	4
20	Post-experiment debriefing				5
Total				180	135

Data Analysis

Data for each dependent variable were analyzed using repeated measures ANOVA with age and gender as between-subject variables. In the driving part of the experiment, road curvature and map rotation were treated as within-subject variables. In the occlusion part of the experiment, occlusion time, viewing time, and map rotation were treated as within-subject variables.

RESULTS

Task Occlusion

Total Shutter Open Time (TSOT)

Total shutter open time did not change with the manipulation of viewing time and occlusion time in the explored range (Figure [illegible]). The effect of viewing time on TSOT was not significant but the effect of occlusion time was near significant (F[1,19]=0.2), F[1,19]=3.7, p<0.10, respectively). Overall, when occlusion time increased from 1 to 3 s, the mean TSOT decreased from 10.6 to 10.2 s.

When the map rotated, TSOT increased significantly (F[1,19]=214, p<0.0001) from 8.4 to 12.3 s (46%), which confirms that rotating the maps made the task more demanding. The interaction of map rotation with occlusion time and viewing time was significant (F[2,38]=13.8, p<0.0001). As seen in Figure [illegible] (bottom left), when viewing time increased from 1 to 1.5 s, TSOT of static maps increased from 7.4 to 8.7 s and TSOT of rotating maps decreased from 13.0 to 12.0 s. As seen in Figure [illegible] (bottom right) when occlusion time increased from 1 s to 3 s, TSOT of static maps decreased from 9.0 to 7.9 s and increased slightly for rotating maps from 12.2 to 12.5 s (F[2,38]=12.2, p<0.01). Long occlusion times reduced TSOT when the map was static, but not when rotating.

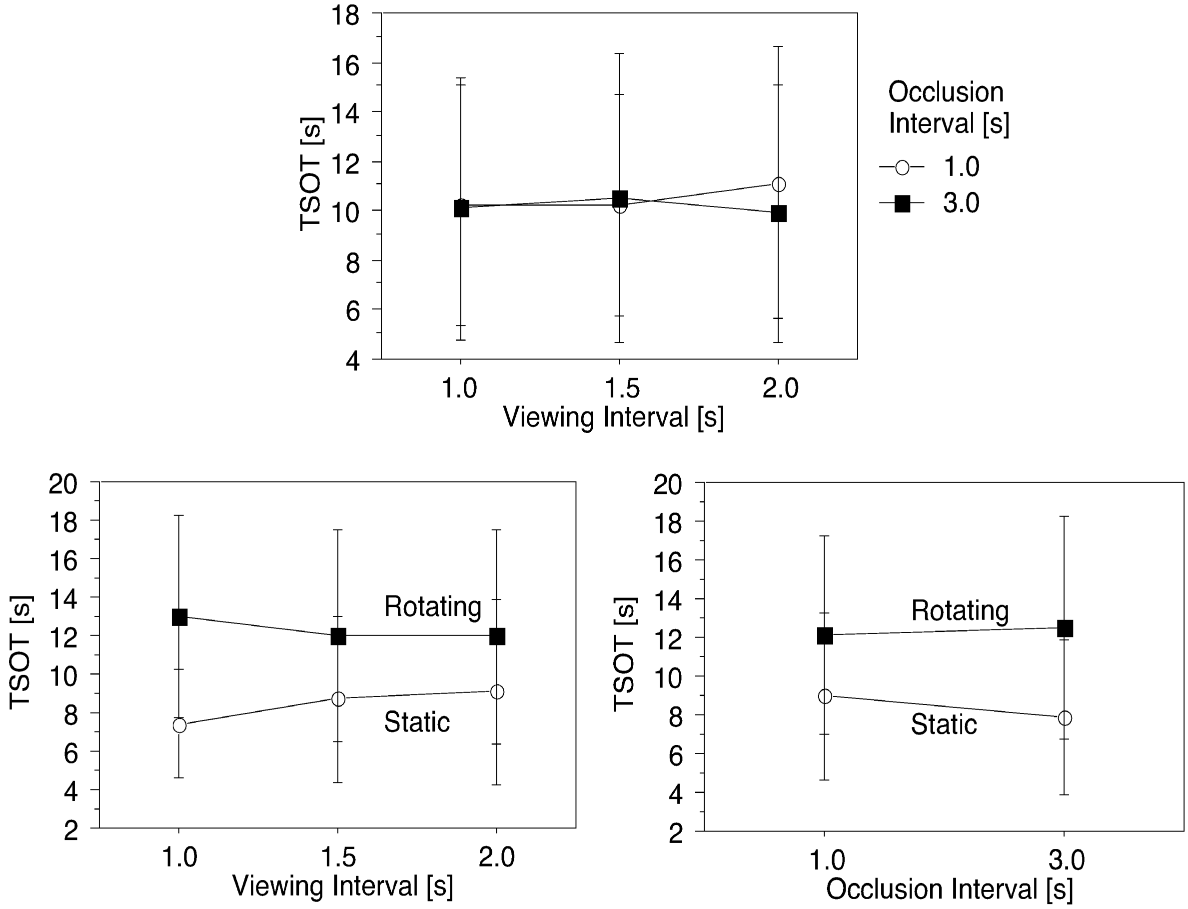

Figure [illegible]. The effect of viewing interval and occlusion interval on total shutter open time

Older subjects looked at the display longer than did younger subjects (F[1,19]=11.3, p<0.01). Younger subjects had a TSOT of 9.0 s and older subjects had a TSOT of 11.8 s (a 31% increase). No other higher order interactions with age were significant, suggesting that the patterns described above were similar across age.

Total Task Time during Task Occlusion

The main effects of viewing time, occlusion time, and the interaction between them on TTT were all statistically significant (p<0.0001) (F[1,19]=189, F[1,19]=54, and F[2,38]=25, respectively) (Figure 8). When occlusion time was 3 s and the viewing interval was reduced from 2 to 1 s, total task time increased from 22.4 to 37.5 s (+67%). A smaller increase was observed when viewing time was cut from 2 to 1 s and occlusion time was 1 s per interval (from 15.9 to 19.7 s, +24%). Given that total shutter open time remained constant, the above increases were expected, as they merely reflected the added occlusion time (Eq. 2). For example, at an occlusion time of 3 s, decreasing viewing time from 2 to 1 s decreased the cycle time from 5 to 4 s. Since twice as many views were required, total task time was expected to increase by about 60% (2 x 4 / 5=1.6). Similarly, the expected increase for an occlusion time of 1 s was 33%.

$$\text{TTT} = \text{Number of Glances} \times (\text{Viewing Time} + \text{Occlusion Time}) \qquad (2)$$

Total task time increased significantly (F[1,19]=175, p<0.001) from 17.9 to 29.1 s when the map rotated. The interaction between viewing time and rotation (Figure 8, bottom left) was also significant (F[2,38]=25, p<0.0001). When viewing intervals were 2 s, total task time for rotating maps increased from 15.8 to 22.5 s (+42%). With shorter viewing times (and consequently longer total task times), there was a greater increase due to the rotation of the map (at 1.5 s, from 18.2 to 27.4 s, +50% and at 1 s, from 19.7 to 37.5, +90%). The interaction between occlusion time and rotation (Figure 8, bottom right) was significant (F[2,38]=53, p<0.0001). When occlusion was 1 s, total task time for rotating maps increased from 14.2 to 20.4 s (+43%). When occlusion time was 3 s, however, the increase was greater (from 21.5 to 37.7 s, +75%).

The effect of age on total task time was significant (F[1,19]=9.2, p<0.01). Older subjects performed the task with the static map in 21.4 s and with the rotating map in 32.2 s. Younger subjects performed the tasks in 14.5 and 26.0 s, respectively. The overall task time increase due to age was 32%.

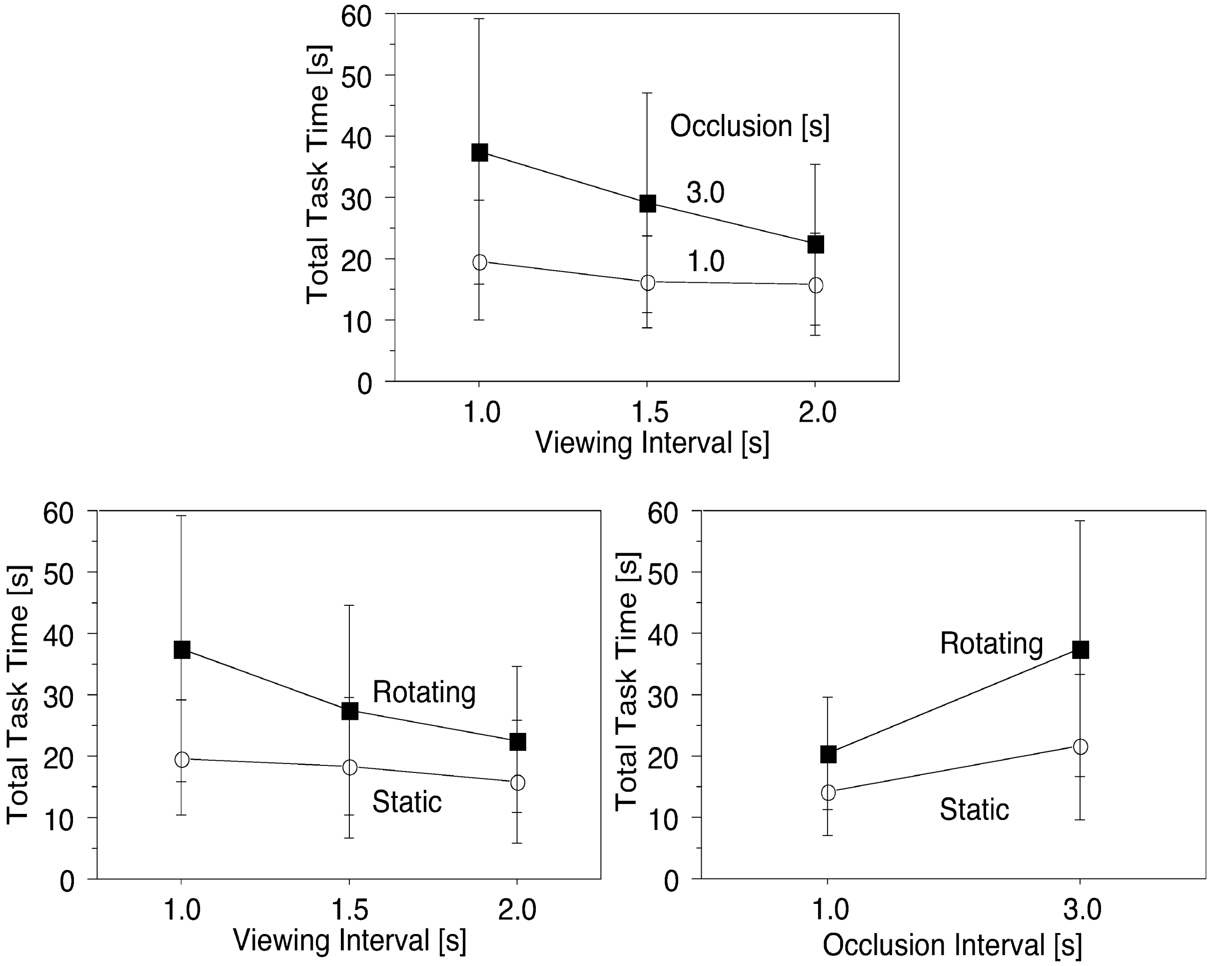

Figure 8. The effect of viewing and occlusion intervals on total task time

Error Rate during Task Occlusion

Although there was a substantial amount of errors (0.2), no significant difference in error rate was found as a function of the occlusion timing (Figure 9).

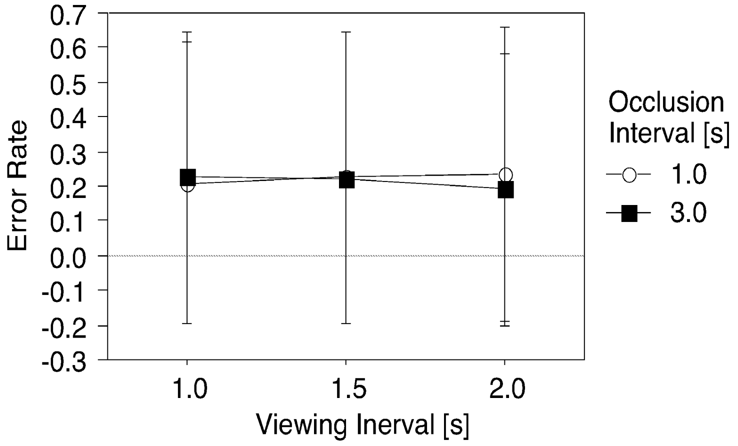

Figure 9. The effect of viewing and occlusion intervals on error rate

Task Performance while Driving

Total task time (TTT) was measured from the switch press to show the map until the switch press to stop showing the map. Total glance time (TGT) was measured from glance timings reduced from videotape recording of the subject's face and a close-up of the left eye.

Total Glance Time while Driving

Neither road curvature nor map rotation had a significant effect on total glance time while driving (F[2,32]=0.9, F[1,16]=0.9, respectively) (Figure 10). When the map was static, total glance time remained unchanged at 12.0 s, a slight increase from 11.0 s when parked. When the map rotated, greater variability between conditions was noted but the differences were not statistically significant and did not follow a consistent trend. As mentioned previously in Table 3, the visual demand associated with the driving sections was 0.25, 0.34, and 0.44. Greater differences between curves might have led to different results.

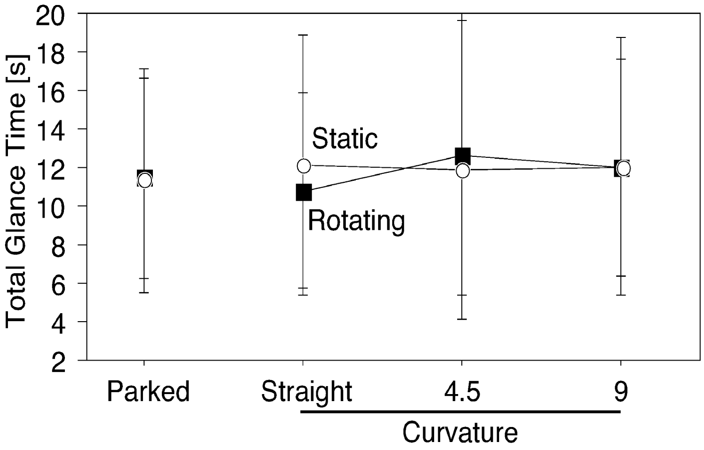

Figure 10. The effect of curvature and map rotation on total glance time while driving

Overall, older subjects looked at the display longer (13.9 s) than did younger subjects (10.1 s) (F[1,16]=4.7, p<0.05).

Total Task Time while Driving

Figure 11 shows a significant increase in total task time from 11.0 s while parked to 15.5 s on a straight road to 16.5 and 19.3 s on a moderate and sharp curve, respectively (F[2,32]=11.7, p<0.001). Map rotation resulted in a near significant decrease of about 2 s (F[1,16]=4.3, p<0.10). The interaction between curvature and map rotation was not significant (F[2,32]=0.5).

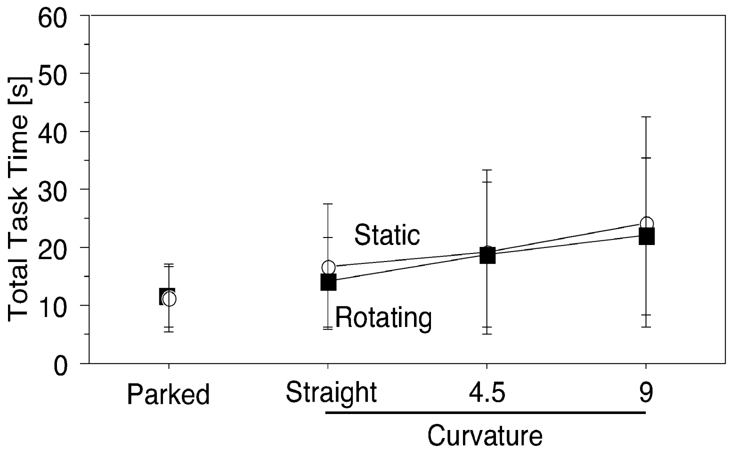

Figure 11 . The effect of road curvature and map rotation on total task time while driving

Age had a significant effect on total task time while driving (F[1,16]=6.5, p<0.05). Map rotation had a near significant effect (F[1,16]=4.3, p<0.10) and the interaction between age and map rotation was significant (F[1,16]=4.9, p<0.05). Younger subjects had a mean total task time of 14.3 s with static maps and 14.8 s with a rotating map. Older subjects had higher total task times that were affected significantly by the rotation of the map (25.9 s and 21.9 s, correspondingly). Although a near typical increase of 81% in total task time was noted for the static map condition, when the map rotated, the increase was only 48%, less than the typical performance degradation due to age.

Single Glance Duration while Driving

Glances down to the display were shorter on sharper curves and when the map was rotating (F[2,32]=39.2, p<0.0001 and F[1,16]=5.9, p<0.05, respectively) (Figure 12, left). The interaction between road curvature and map rotation was not significant (F[1,16]=1.5). On straight roads, the mean duration of a glance to the display was 2.5 s for rotating maps and 2.0 s for static maps; on moderate curves, 1.7 and 1.4 s; and on sharp curves, 1.3 and 1.2 s, respectively. Age effects were not significant.

The duration of glances up to the road (between glances down to the display) increased with road curvature (F[2,32]=6.7, p<0.01) (Figure 12, right). On straight roads, the mean glance duration was 0.75 s, on moderate curves it was 0.85, and on sharp curves 1.0 s. The effects of map rotation and age were not significant.

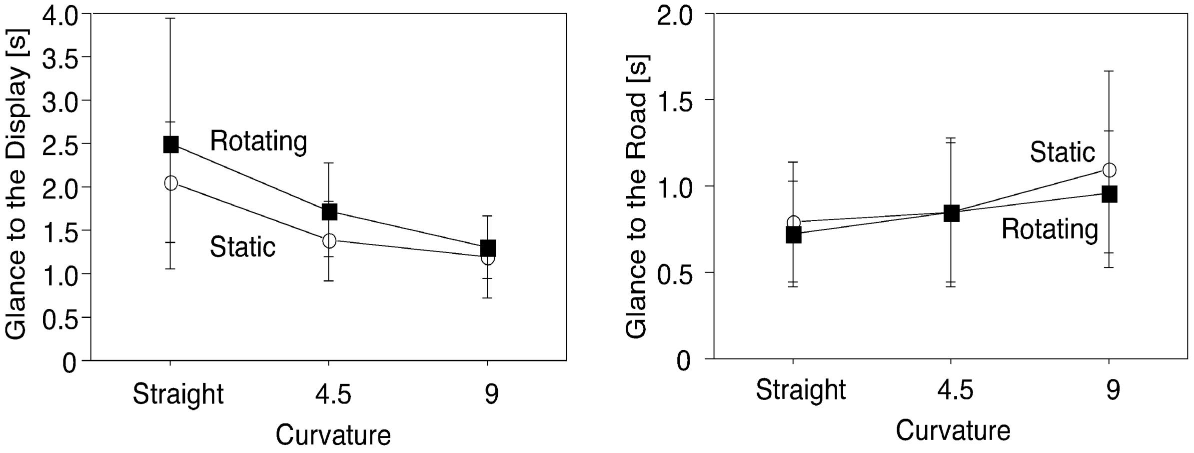

Figure 12 . The effect of road curvature and map rotation on duration of glances to the display (left) and glances at the road (right) while driving

The duration ratio between glances to the road and glances to the display decreased significantly with increasing road curvature (F[2,32]=19.1, p<0.0001). On average, this ratio ranged from 3.4 on straight roads to 1.5 on sharp curves (Table 8 and Figure 13). As roads became more demanding, glances at the road were longer and more frequent. In turn, glances away from the road were shorter and less frequent. Similarly, when the in-vehicle task was more demanding (when the map rotated), glances at the in-vehicle display were longer and more frequent. The tradeoff of glance duration between the road and the in-vehicle display was at a 1:3 ratio. A 0.3 s increase in the duration of glances at the road was associated with a 1.0 s decrease in the duration of glances at the in-vehicle display.

Table 8. The duration ratio between glances to the display and glances to the road

	Duration Ratio between Glances to the Display and Glances to the Road	
Curvature	Map Static	Map Rotating
Straight Road	3.1±1.7	3.8±2.8
Moderate Curve	2.0±1.3	2.5±1.4
Sharp Curve	1.4±1.0	1.6±0.9

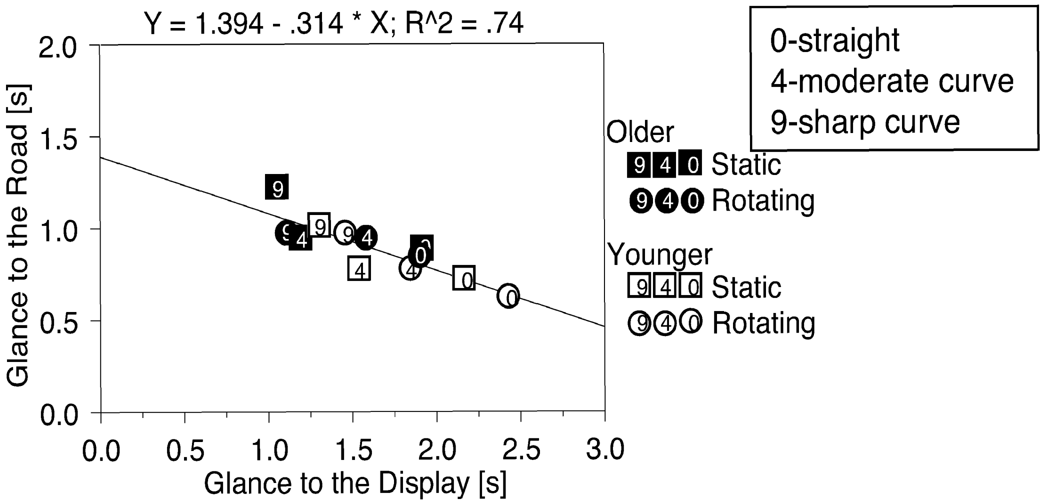

Figure 13. The effect of curvature and map rotation on the relationship between glances to the road and glances to the display. Each point in the figure represents the mean of two trials per 12 subjects.

Error Rates while Driving

Error rates increased with increasing curvature from 0.13 while parked to 0.20 on straight roads, 0.28 on moderate curves, and 0.29 on sharp curves (F[3,51]=7.9, p<0.001) (Figure 14). Older subjects made more errors (0.32) than did younger subjects (0.13) (F[1,17]=15, p<0.01).

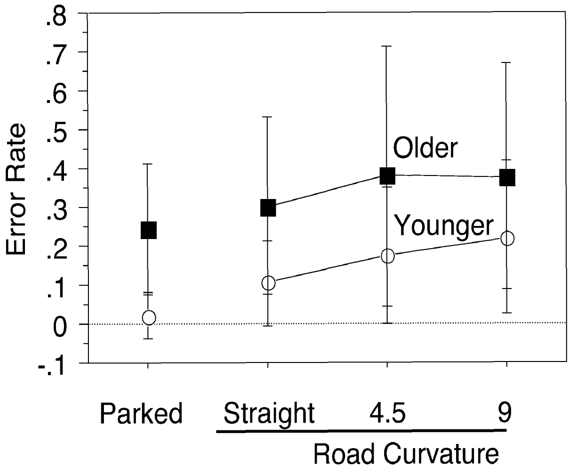

Figure 14. The effect of curvature and age on error rate

Glance Time Comparison between Task Occlusion and Driving

Total time viewing the display during task occlusion (TSOT), while parked (TTTstatic), and while driving (TGT) were similar (10.6, 11.1, and 12.0 s respectively) (Figure 15) (F[2,38]=2.7, p<0.1). There was a significant interaction between test condition and map rotation (F[2,38]=55.6, p<0.0001). When the map was static, TSOT was shorter than the total time spent looking at the display in the other two test conditions. When the map rotated, the effect was reversed. This interaction was caused by a decrease in

TSOT for static maps and an increase for rotating maps. The decrease in TSOT for static maps was likely a result of efficiency due to time pressure and the ability to plan ahead during the occluded intervals. This was further supported by the fact that TSOT for static maps was even lower when the viewing interval was 1.0 s and the occlusion interval was 3.0 s (Figure 7). The increase in TSOT for rotating maps was likely a result of the cost of task partitioning.

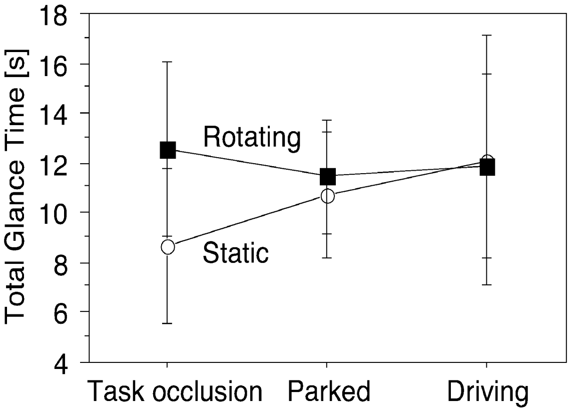

Figure 15. The effect of task on total glance time

Partial Task Times

In two separate blocks of 24 trials each while parked, subjects began the task normally but stopped after finding the street name or after finding the intersection associated with it. The duration of these partial tasks provides a sense of their relative length while performed during the full task. Searching for the intersection was about 1.0 s longer than searching for the street name only (Figure 16). Completing the entire task was about 7.2 s longer than searching for the intersection. Although map rotation added about 1.5 s to search times, it added only 0.5 s to the complete task. This interaction suggests that route planning, from the moment the target intersection was found until the route was planned and intersections counted, did not take longer (and possibly even shorter) when the map rotated.

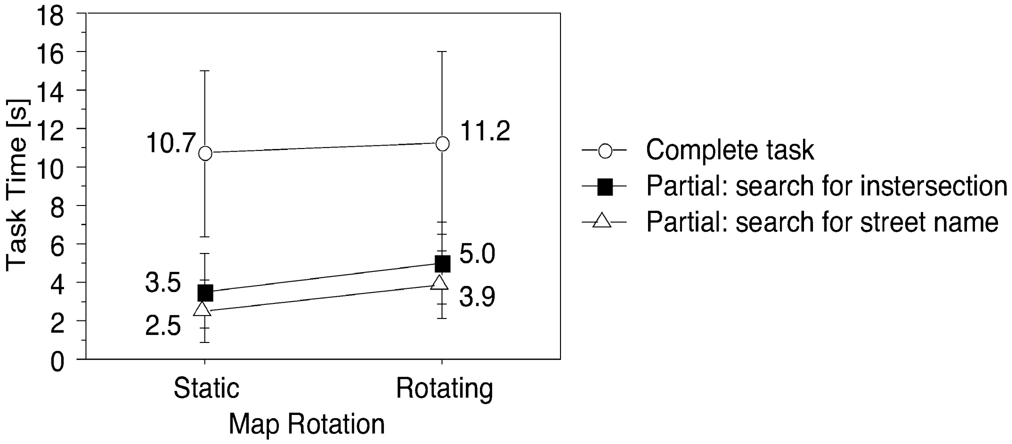

Figure 16. Partial task times

Driving Performance

Driving performance was significantly degraded by the addition of the in-vehicle task. The standard deviation of lateral lane position increased with road curvature (F[2,36]=34.3, p<0.0001) and with task (F[2,36]]=40.9, p<0.0001) (Figure 7, top left). Similarly, the standard deviation of steering wheel angle increased with road curvature (F[2,36]=45.7, p<0.0001) and with task (F[2,36]=53.3, p<0.0001) (Figure 7, top right). The fraction of trials with at least one lane departure increased with curvature and with task (Figure 7 , bottom).

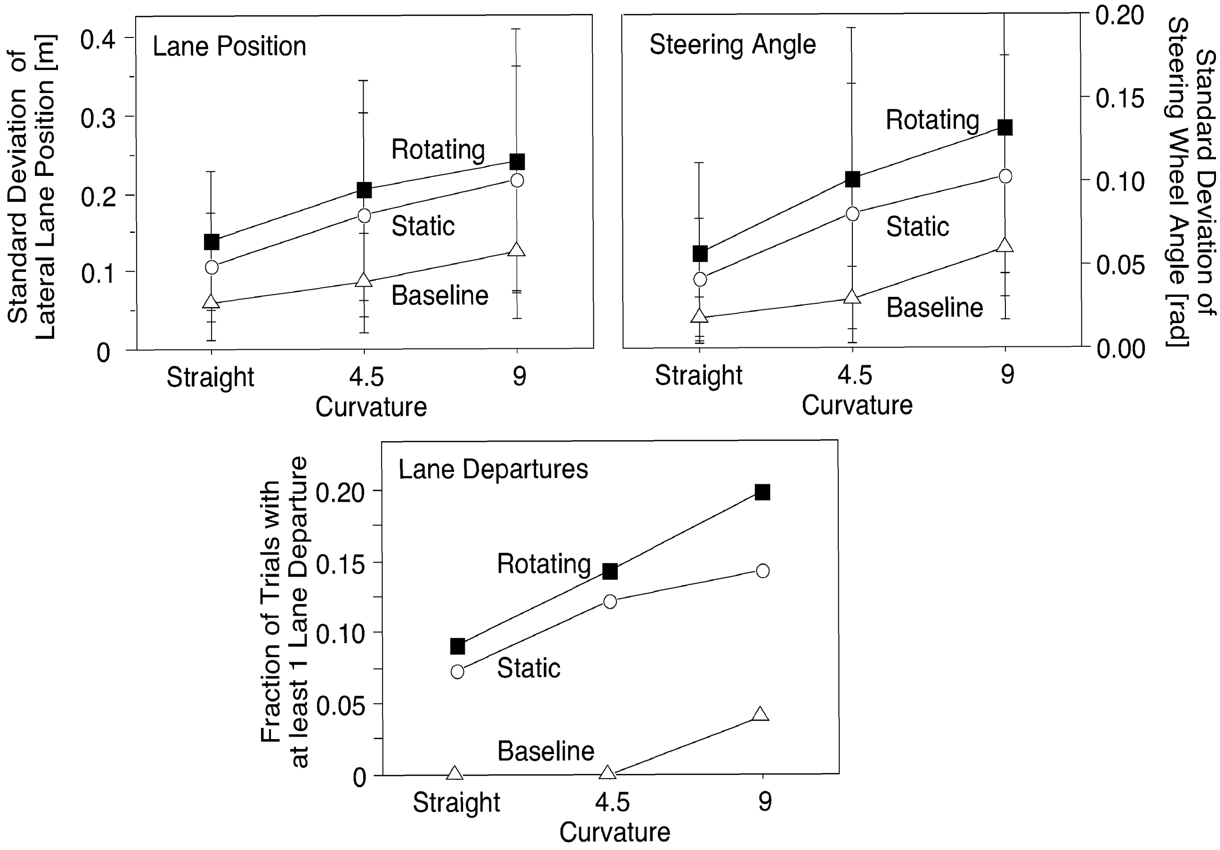

Figure 7 . The effect of curvature and task on lateral vehicle control

A graphical examination of the between-subject tradeoff of total task time and the lateral position variability revealed that younger subjects tended to have similar task times but varied in how well they kept their lane position (Figure 8). Older subjects had poorer performance in both measures.

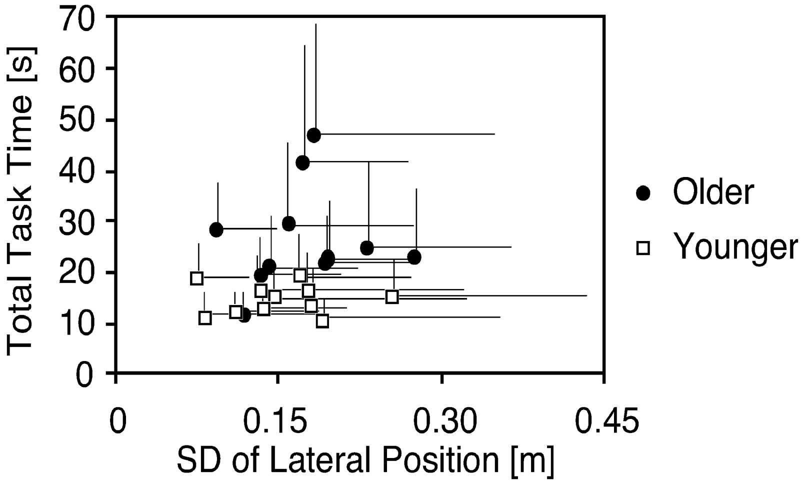

Figure 18 . The tradeoff between total task time and standard deviation of lane control (Each point and line represent mean and 1 SD of one subject's trials)

Subjective Ratings

Subjects rated the difficulty of each of six occlusion blocks immediately after they completed them. Tasks were rated more difficult when viewing time decreased (F[2,36]=32, p<0.0001) and when occlusion time increased (F[1,18]=9.3, p<0.01) (Figure 19, top left). The difference between the two longer viewing times (1.5 s and 2.0 s) was not significant.

Difficulty ratings while driving increased significantly as a function of road curvature from 4.8 on straight sections to 5.8 on moderate, and 6.8 on sharp curves (F[2,30]=92, p<0.0001) (Figure 19, top right). When the task was performed while parked (without occlusion), the difficulty ratings were lowest (3.3 for rotating and 2.6 for static maps). Map rotation raised the rating consistently by about 1 point. (Mean post-test ratings were similar to ratings while driving, but the range was wider: 4.0, 5.7, and 7.6, respectively).

The difficulty of task occlusion conditions was perceived similar to that of driving on a straight road and significantly greater than performing the task while parked without occlusion (Figure 19, bottom).

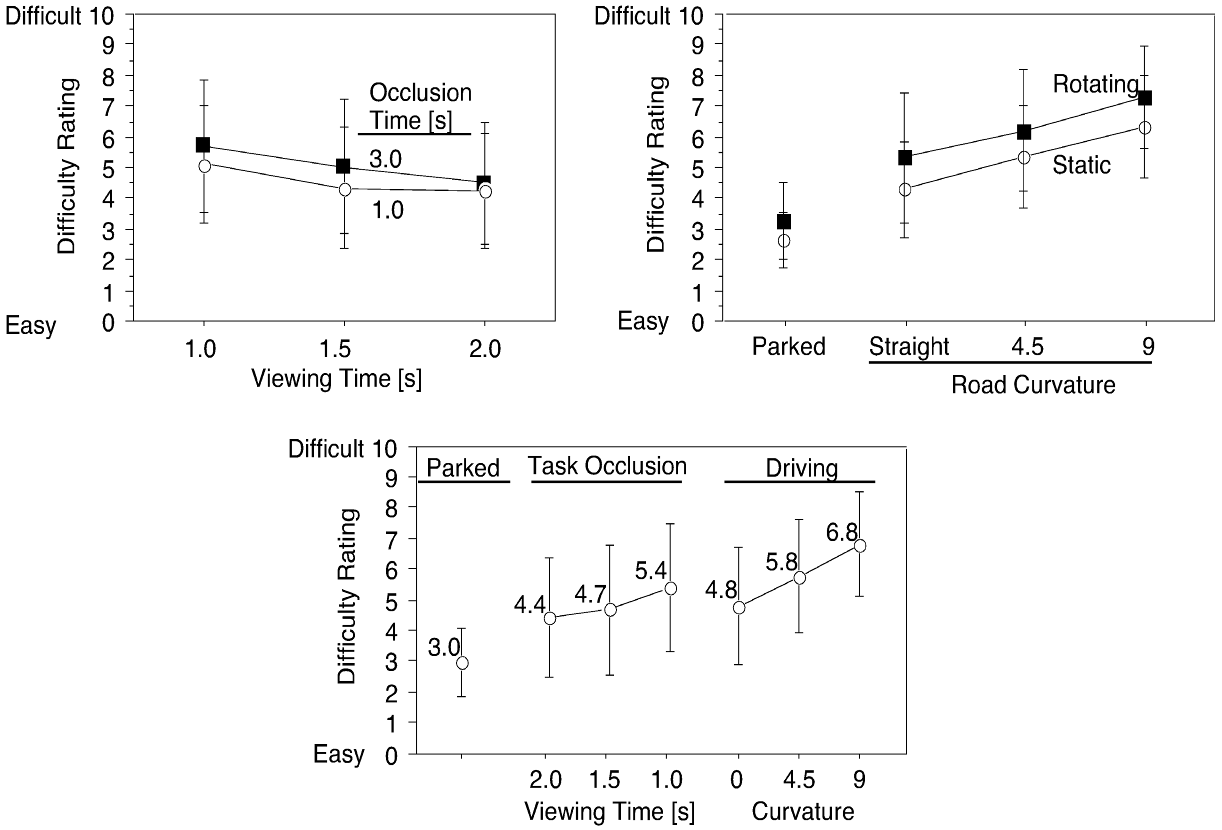

Figure 19. Subjective difficulty ratings of task occlusion (top left), driving (top right), and a side-by-side comparison (bottom)

Post-test ranking of the six timing conditions (Table 9) showed similar results but with some individual differences. Although most subjects (18 of 24) ranked long viewing time with short occlusion time as their first choice, 5 subjects (4 younger) preferred long viewing time with long occlusion time. Similarly, although most subjects (17) ranked short viewing time and long occlusion time as most difficult, 7 subjects (4 younger) ranked short viewing time with short occlusion as most difficult. Subjects justified their choice of rank order by referring to either the difficulty to concentrate and remember what was on the map when forced to look away for 3 s, or conversely the ability to plan and think during that time. All but one older subject stated memory as the main motivation for their ranking order. In contrast, half of the younger subjects stated planning as their motivation.

Table 9. Difficulty rank order of occlusion conditions

		Map Viewing Interval		
		1.0 s	1.5 s	2.0 s
Map Occlusion Interval	1.0 s	5.1	2.8	1.3
	3.0 s	5.7	4.0	2.2

SUMMARY

Task Partitioning while Driving

> *How is task partitioning while driving affected by the demand of the task (e.g., static vs. rotating map) as a function of driving workload?*

Total task time increased significantly from 11.0 s while parked to 15.5 s on straight roads and 19.5 s on sharp curves. This was not a result, however, of more time spent looking at the display -- total glance time at the display remained unchanged (12.0±0.6 s). As road curvature increased, subjects made shorter glances at the display. The mean glance duration at static maps on straight roads was 2.0 s and on sharp curves 1.2 s, a decrease of 40%. Accordingly, they made longer glances at the road. The mean glance duration at the road was 0.75 s on straight roads and 1.0 s on sharp curves, an increase of 33%. A similar trend was detected when the map rotated. Glances at rotating maps on straight roads lasted 2.5 s and on sharp curves 1.3 s, a decrease of almost 50%. The ratio between glance duration to the display and glance duration to the road ranged from 3.8 on straight roads with the map rotating to 1.4 on sharp curves when the map was static.

Subjects demonstrated flexibility in how they partitioned tasks when there were changes in the demands of the driving task and the in-vehicle task. They adjusted their behavior to the demands, but the adjustment was not enough, and not without cost. Driving performance (e.g., lane departures) degraded significantly more on sharp curves than it did on straight roads, and more so for rotating maps. In addition, more errors were made in the in-vehicle task.

The time pressure imposed by driving resulted in shorter glances at the display, but subjects maintained constant total glance time. Interference from concurrent driving was not significant enough to negate this effect.

Task Performance in Task Occlusion

> *In the task occlusion paradigm, how does limiting the glance duration and the duration of occlusion affect task performance?*

When viewing time decreased from 2 to 1 s, and with occlusion time of 1 s, total task time increased from 15.9 to 19.7 s. With occlusion time of 3 s, total task time increased from 22.4 to 37.5 s. Total glance time, however, remained unchanged (10.4±0.4 s) in all six timing combinations and error probability remained constant (0.2).

The robustness of total glance time to the manipulation of viewing time and occlusion time in this visual task suggests that the costs of task partitioning and the benefits of postponed processing were small or cancelled one another.

Task Occlusion as a Predictor for Task Performance while Driving

> *How can the results of the task occlusion method explain task partitioning while driving?*

A comparison of the occlusion and viewing times with actual glance times while driving (in the simulator) showed that the 1.0 s occlusion interval was similar to actual glance times at the road, but the 3.0 s interval was much longer. As a result, total task times with the 1.0 s occlusion interval were similar to those while driving and total task times with the 3.0 s occlusion interval were unrealistically long.

Total shutter open time was lower than total glance time for fixed maps in the driving condition, but similar to total glance time when the map rotated. Overall, it predicted total glance time and total task time reasonably well, but not better than total task time while parked.

The Effects of the Suggested Constructs

Time pressure. Time pressure (caused by the need to look at the road more frequently on demanding roads) forced subjects to partition the task into smaller chunks, but total glance time while driving remained unchanged for this task. TSOT of static maps, however, decreased with viewing time, implying greater efficiency due to time pressure.

Interference of concurrent driving. Overall, total glance time did not increase with increasing levels of driving visual demand. Total glance time while driving was substantially higher than TSOT of static maps, demonstrating time cost due to interference.

Postponed processing. Postponed processing and planning ahead while looking away from the display should reduce total glance time. Accordingly, in the task occlusion part of the experiment, there was a slight decrease in TSOT from 11 s at baseline to 10.2 s when subjects were required to wait longer between glances (3 s occlusion). In practice, however, task performance while driving was not improved by this effect because glances at the road were always short (on the order of 1 s).

Cost of task partitioning. Total glance time did not increase as the task was partitioned into smaller chunks. This remained true even when the map rotated and thereby increased the cost of looking away from the display. This lack of apparent cost of task partitioning is possibly due to negation by other factors.

Differences between Subjects

> *Do subjects partition the task differently while driving? Are these differences correlated with age or gender?*

Older subjects spent about 35% more time looking at the display and had more errors than did younger subjects in both test conditions (occlusion and driving). Their total task time in task occlusion for static maps and rotating maps increased by 48% and

24%, correspondingly. When driving, their total task time increased by 81% and 48%, correspondingly. For older subjects, total glance time for rotating maps was 4 s lower than static maps, most likely due to the sense of immediacy of the rotating map task.

All subjects made longer glances to the display when the map rotated and when the driving task was less demanding. As a result, their driving performance and error rates were higher.

Future Research

A possible shortcoming of this experiment is that the effects of the four suggested constructs were not independent and in some cases negated one another. The insensitivity of TSOT to the manipulation of viewing times and occlusion times further masked the effects of these constructs. Insofar as it is feasible, it is recommended to continue this line of research with tasks that are insensitive to the manipulation of viewing time and occlusion time. Several researchers have already reported task occlusion experiments in which TSOT did not change much as a function of the timing of glances (Karlsson and Fichtenberg, 2001; Fichtenberg, 2001; Hashimoto and Atsumi, 2001; Weir, Chiang, and Brooks, 2003). It is therefore desirable to test tasks that may suffer or benefit from the task occlusion task more significantly. As an example, it is proposed to compare three types of tasks: (1) a task that can clearly be continued even when the display is occluded (e.g., Bengler and Rosler, 2001), (2) a task that is not readily "chunkable" (e.g., Fichtenberg, 2001), and (3) a task that lends itself to fitting well within any given viewing time (e.g., Weir, Chiang, and Brooks). Additionally, the tasks need to be realistic, similar in length, and error rates have to be controlled or eliminated such that tradeoffs do not affect the timing results.

Application to Automotive Standards

This experiment was not set up to confirm or dispute the validity of the proposed task occlusion standard for testing in-vehicle interfaces (Society of Automotive Engineers, 2003). Nevertheless, it is relevant to those standards. Objective results from this experiment do not exclude any of the six interval combinations. Subjects, however, preferred longer viewing times and shorter occlusion times.

SAE (2003) proposes that an in-vehicle task will be accepted if it can be performed within 15 s or, using the occlusion technique, with a TSOT of under 20 s. The current experiment brings to light a possible logical flaw in that argument. If a driver can perform an in-vehicle task at viewing times of 1.5 s and forced occlusion times of 1-2 s, he or she will not necessarily perform the task that way. Results from this experiment clearly show that subjects chose viewing times far greater than 2 s and glances away from the road less than 1 s even though they were able to perform the task at 1.5 s glances. If the purpose of the standard were to rule out tasks that cannot be performed with viewing times shorter than 1.5 s, then the standard's proposal would be justified.

Moreover, it is hard to find a reasonable task that cannot be performed in 1.5 s glances. In this experiment, for example, even when 1.0 s glances were forced, and even though it was expected that it would be hard to perform the task, there was almost no degradation in performance. Usually if a task requires unreasonably long glances, it is eliminated in the design process and never implemented. As an example, continuously scrolling text and maps are normally not implemented in vehicles because they would require unreasonably long glances.

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APPENDIX A. CONSENT FORM

UMTRI
University of Michigan
Transportation Research Institute
2901 Baxter Road, Ann Arbor, MI 48109-2150

Using Task Occlusion to Predict Task Demands

Investigator: Omer Tsimhoni (763 2498)

The purpose of this study is to gain insight into how drivers perform complex tasks, mainly visual, while driving a vehicle. You will drive the simulator while reading a map displayed on the center console of the simulated vehicle.

You will start with a practice session in which you will drive the simulator. There is a small risk of some motion discomfort while driving the simulator. If you feel discomfort of any significance, please let the experimenter know, so the study can be stopped. After the driving practice, you will practice reading an electronic map while parked and then read it a few times while driving. After a 5 minute break, you will perform the same task while parked, with the map appearing intermittently.

For some drivers, these tasks are quite difficult. Regardless of the difficulty, it is important to try to do your best on both tasks.

Your driving will be videotaped for future reference to your data entry performance, driving performance, and reactions overall. This study is not intended to be a test of your skill, but rather how well the system has been designed to suit you.

The study should take about two and a half hours, with a five-minute break scheduled in the middle. You will be paid $40 for your time. You may withdraw from this study at any time without penalty.

I specifically agree to be videotaped in this study and understand that selected segments from the tapes may be used in presentations to explain the results. My name will not be disclosed with the tape. The raw tapes will be erased 10 years after the project is completed.

Sign your name ________________________

I HAVE READ AND UNDERSTAND THE INFORMATION PRESENTED ABOVE. MY PARTICIPATION IN THIS STUDY IS ENTIRELY VOLUNTARY.

________________________ Print your name	________________________ Date	
________________________ Sign your name	________________________ Witness (experimenter)	Participant number:

APPENDIX B. BIOGRAPHICAL FORM

Date: ________ Participant number: ________

Biographical Form

Personal Details

Name ____________________________

Born (month / day / yr) ___ / ___ / ___ in (city / state) ________________

Handedness (circle one) left right

Occupation: ________________ if retired: previous occupation: ______________

Education

(circle highest level completed, fill in blank)

high school

some college/major :_________________

college degree :_________________

graduate school: major _______________

Driving

What motor vehicle do you drive most often?

Year: _________________ Make: _______________ Model: _______________

How many miles do you drive per year? ____________

How much time do you spend on an average day driving (not as a passenger?)

__________ hours

Have you driven more than 30,000 miles in your lifetime? Yes No

Do you have any special driving licenses (e.g. heavy truck) and if so, what kind?

No Yes: explain -> _________________

How many accidents have you been involved in during the past 5 years? _____

In-Vehicle Navigation

Have you ever used an in-vehicle navigation system? No Yes

If yes: Once A few times Many times I own/owned a system

Vision Circle what vision correction you use

When driving: no-correction contacts glasses (multifocal, bifocal, reading, far-vision)

When reading: no-correction contacts glasses (multifocal, bifocal, reading, far-vision)

For the experimenter only

12526616

Far Acuity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	T	R	R	L	T	B	L	R	L	B	R	B	T	R
	20/200	100	70	50	40	35	30	25	22	20	18	17	15	13

Near Acuity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	T	R	R	L	T	B	L	R	L	B	R	B	T	R
	20/200	100	70	50	40	35	30	25	22	20	18	17	15	13

APPENDIX C. POST-TEST EVALUATION FORM

Date: ________ Participant number: ________

Post-Test Evaluation Form

1. Rate the difficulty of performing the navigation task in the following scenarios:
(1=extremely easy, 10=extremely difficult)

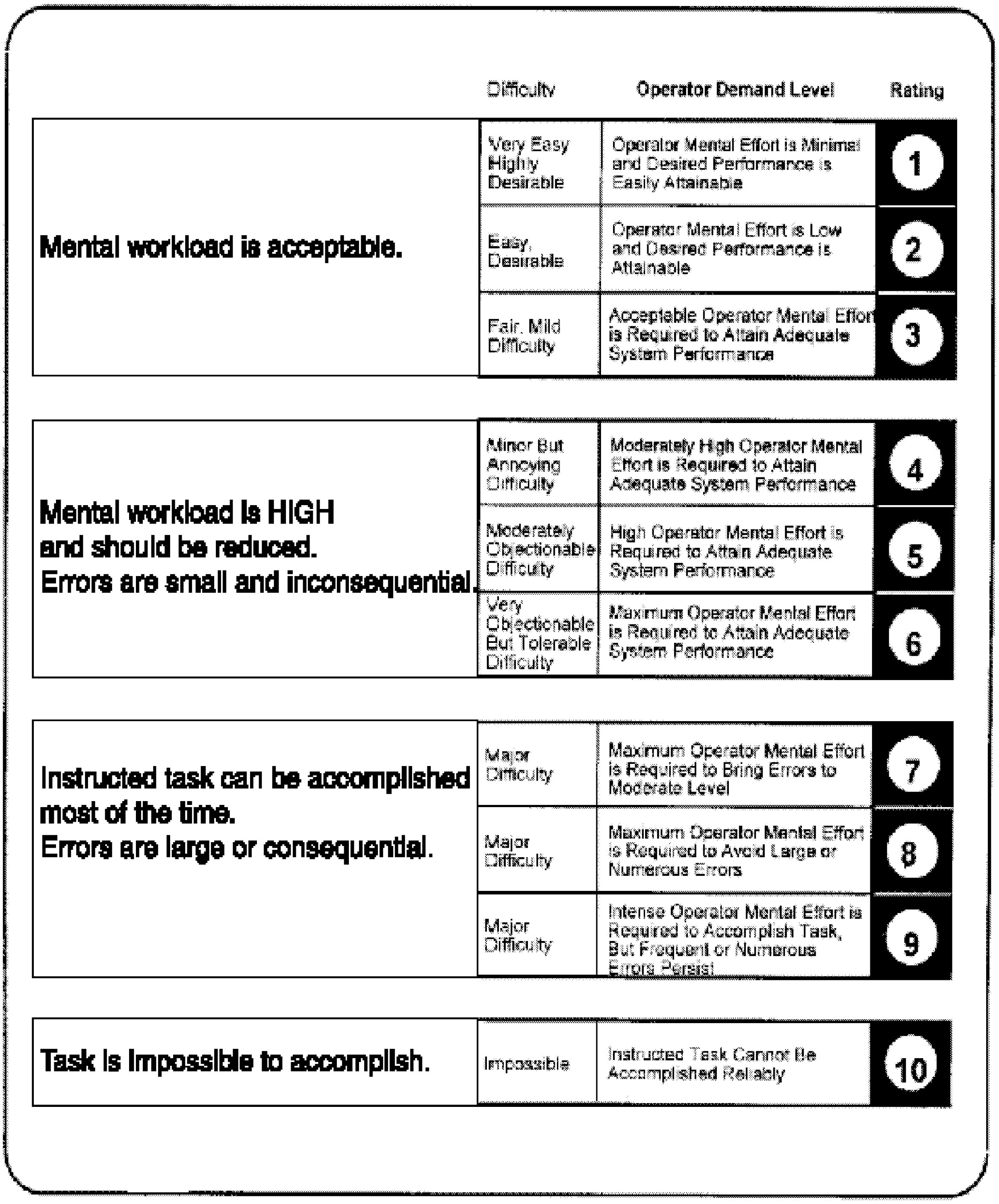
	Map NOT rotating	Map rotating
Parked		
Straight road		
Moderate curve		
Sharp curve		

2. Please **rank** order the occlusion conditions by difficulty (1-easiest, 6-most difficult)

Occlusion Difficulty Ranking		Map Views (Display is visible)		
		Short -1 s	11/2 s	Long - 2 s
Time Between Map Views (Display is Dark)	Short - 1 s			
	Long - 3 s			

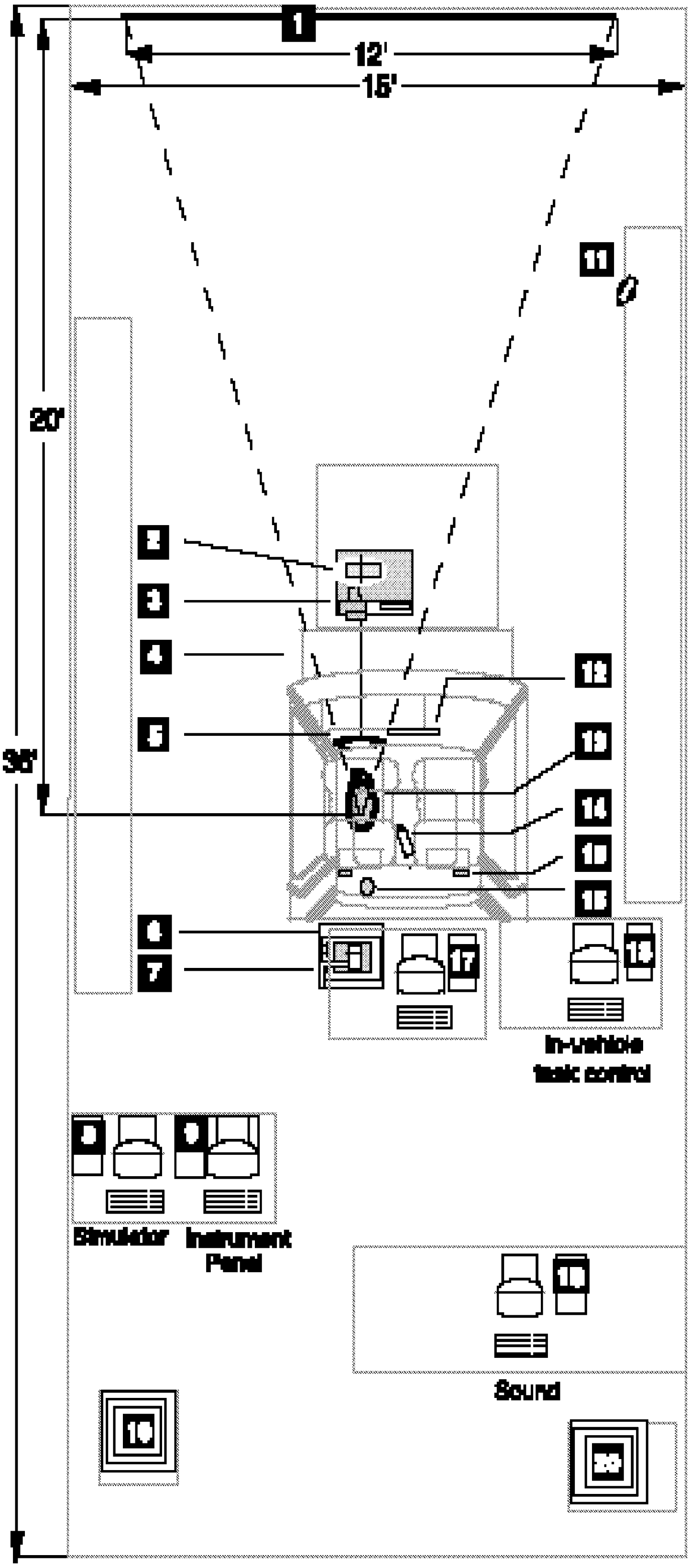
Other comments and feedback about this study? (please think of at least 2 …)

APPENDIX D. MODIFIED COOPER-HARPER SCALE



	Difficulty	Operator Demand Level	Rating
Mental workload is acceptable.	Very Easy Highly Desirable	Operator Mental Effort is Minimal and Desired Performance is Easily Attainable	1
	Easy, Desirable	Operator Mental Effort is Low and Desired Performance is Attainable	2
	Fair, Mild Difficulty	Acceptable Operator Mental Effort is Required to Attain Adequate System Performance	3
Mental workload is HIGH and should be reduced. **Errors are small and inconsequential.**	Minor But Annoying Difficulty	Moderately High Operator Mental Effort is Required to Attain Adequate System Performance	4
	Moderately Objectionable Difficulty	High Operator Mental Effort is Required to Attain Adequate System Performance	5
	Very Objectionable But Tolerable Difficulty	Maximum Operator Mental Effort is Required to Attain Adequate System Performance	6
Instructed task can be accomplished most of the time. **Errors are large or consequential.**	Major Difficulty	Maximum Operator Mental Effort is Required to Bring Errors to Moderate Level	7
	Major Difficulty	Maximum Operator Mental Effort is Required to Avoid Large or Numerous Errors	8
	Major Difficulty	Intense Operator Mental Effort is Required to Accomplish Task, But Frequent or Numerous Errors Persist	9
Task is impossible to accomplish.	Impossible	Instructed Task Cannot Be Accomplished Reliably	10

APPENDIX E. PLAN VIEW OF UMTRI'S DRIVER INTERFACE RESEARCH SIMULATOR



1	8'X10' projection screen with 3M hi-white encapsulated reflective sheeting
2	PMI Motion Technologies ServoDisk DC motor (model 00-01802-002 type U16M4) with Copley Controls Corp. controller (model 413) and power supply (model 645)
3	Sharp color LCD projection system (model XG-E850U) for instrument panel
4	1995 Chrysler Laser mockup with simulated hood
5	3-spoke steering wheel
6	3M overhead projector (model 9550)
7	Sharp computer projection panel (model QA-1650)
8	Power Macintosh G3
9	Macintosh 7100/80AV
10	Video rack
11	Panasonic low level light camera (model WV-BP510) with TV zoom lens (WV LZ 81)
12	LCD (Elotouch 1225L)
13	Eye Tracking device (ISCAN)
14	Panasonic low level light camera (model WV-BP550)
15	Sony speaker system (SRS-48)
16	Bass shaker
17	Eye tracking control
18	Power Macintosh 8500/120
19	Macintosh Quadra 840
20	Audio rack

APPENDIX F. INSTRUCTIONS FOR ROUTE PLANNING

"This is an example of a map that will appear on the display while you drive. I would like to point out to you that many of the streets dead-end into other streets and that the T-intersections that are formed are always denoted by an empty circle. Let's look at a few examples. Can you point at the T-intersection where Bernard street dead-ends? (Go over several more streets until the concept is perfectly understood.)

Next, I would like to show you the task that you will have to perform. You will hear a street name spoken to you, for example, Bernard. After you find where it dead-ends into another street (here) you need to plan a route from the car icon (here) to that intersection. While you plan the route, you should count the number of intersections that you encounter including the last one. In this case, there are 5 intersections. Your response will be 5.

Are you ready for another practice? Ronald (2). Sarah (3). Stewart (5). Great. Now, there are several different routes you can choose for each intersection, but I would like you to follow the following set of rules to form your route.

Rule 1: You must always begin by going up to the intersection above the vehicle icon. Your first step cannot be backwards or sideways only forward.

Rule 2: At any given intersection you should keep going straight unless the intersection is behind you or directly sideways from you.

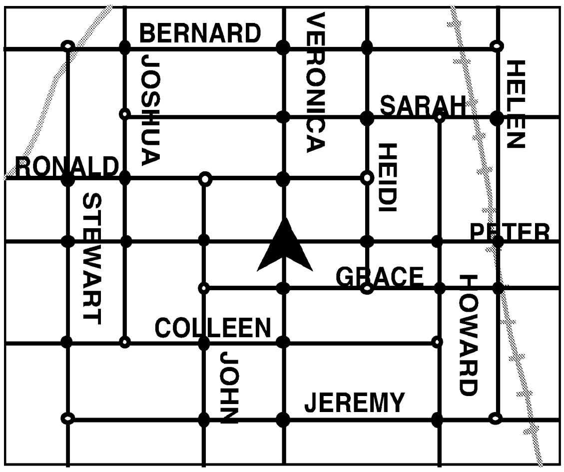
Let me stress here that you should not be concerned about the route being shorter than other routes or any other method of comparison. Your only goal is to decide every intersection whether the intersection is still in front of you or not.

Rule 3: If the intersection is on your right or left you should turn to that direction. If such a turn does not exist, you should keep going straight.

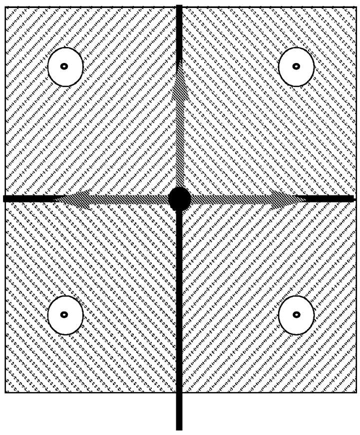
Let's do some examples. Let me show you how I do Helen. OK, here is where we are going. The first step has to take us up here. Now, the target is behind us and to our right so we have to turn right at this first intersection. … (Explanations of the steps taken for each intersection are made.

Now you try a few intersections. Please point at the route while you choose it so I can follow your line of thought.

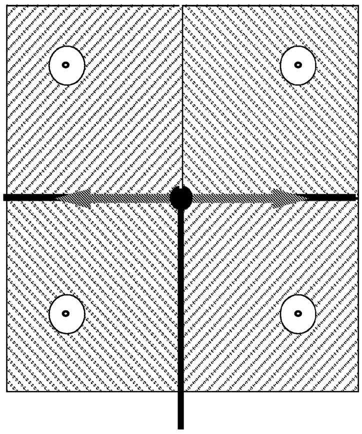
Any questions? I will repeat some of these instructions when you are in the car and you will have some practice."



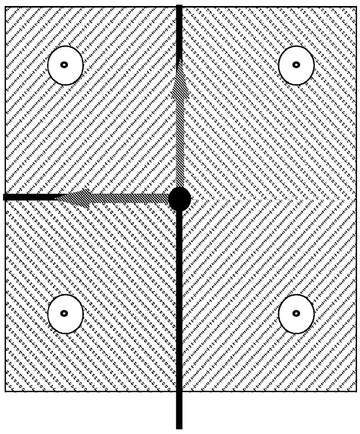
4-way intersection



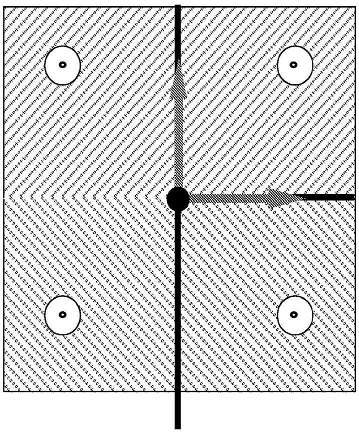
T intersection

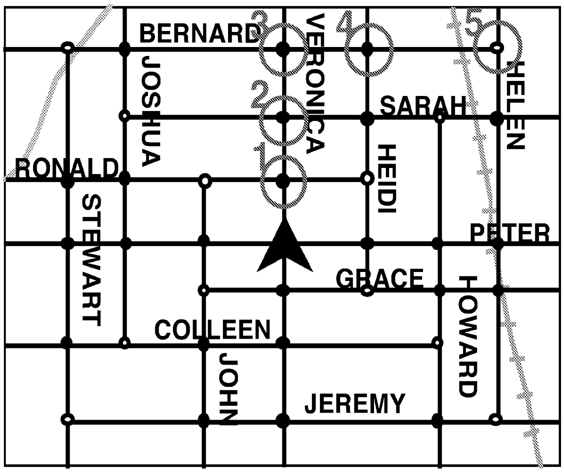


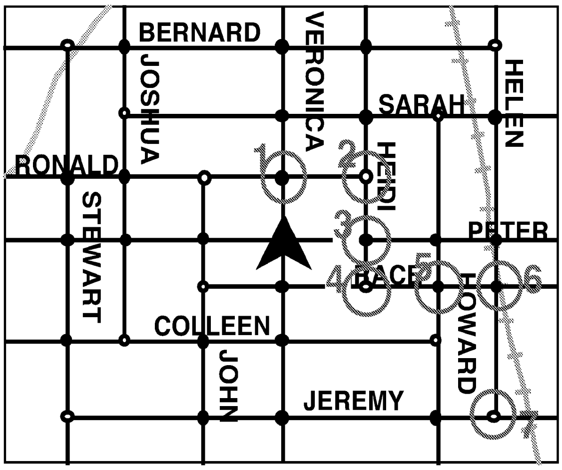
Left branch



Right branch







APPENDIX G. MEASURING THE DEGRADATION OF DIRECTED ATTENTION

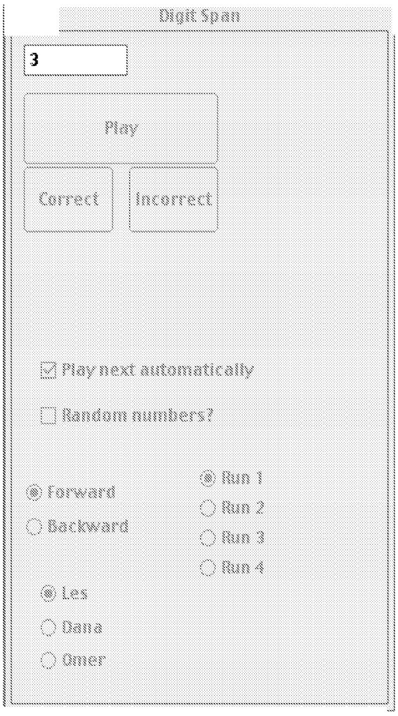
This appendix describes a pilot test to measure the degradation of directed attention during the current experiment using several tests.

Directed Attention (DA) has been defined as the active focusing of attention on relevant material through the inhibition of the irrelevant. In the context of performing a dual task, it is the active focusing on one of tasks while inhibiting the other, and vice versa. It is hypothesized that DA would be impaired after repetitive dual-task performance of a driving task and an in-vehicle map-reading task. This DA impairment, or fatigue, is likely to result in a decline in the ability to direct attention in general, and expected to be measurable by tests of DA. Three such tests are the Necker cube pattern control test, the Digit Span Forward and Backward, and the Trail Making Task. These tests were successfully used by Brewer (1997) on individuals with established Attention Deficit Hyperactivity Disorder (ADHD) and individuals who suffered minor brain injuries. If successful, all or some of these tests can be further used in experimental settings to test the effects of DA on dual task performance in the driving context.

All 24 subjects from the current experiment participated, 12 younger (ages 20 to 28, mean of 23) and 12 older (ages 65 to 71, mean of 68). Eight subjects (2 from each age-gender group) participated in each of three DA tests. The tests were administered on a computer (Macintosh 9500) using assisting software programs to control the test and save data electronically. The data were analyzed for each test separately by running a repeated measures ANOVA with run (before/after the driving session) and two levels of the test as within-subject factors and age as a between-subject factor.

Digit Span Test

In the digit span test, a list of digits is read to the subject at 1s intervals (Lezak, 1995, p. 357). After the last digit is read, the subject repeats all the digits. In a second condition, the subject repeats the digits backwards. The test begins with the easiest level (3 digits) and the number of digits is increased after every successful response until a span of 8 digits is reached or the subject makes a mistake. If a mistake is made, that level is repeated once. When two mistakes are made at the same level of difficulty, that level is recorded as the score.



3

☑ Play next automatically

☐ Random numbers?

● Forward
○ Backward

● Run 1
○ Run 2
○ Run 3
○ Run 4

● Les
○ Dana
○ Omer

Figure 20. Computer screen of digit span DA test

Usually this test is conducted by an experimenter that reads the digits from a piece of paper. In the current experiment, a software program was used. The program was created in REALbasic (REALbasic ver. 3.5.1, REAL Software Inc.)

(Figure 20). It was designed to imitate the paper test with a few changes and improvements: (1) the digit names that the subject heard had been prerecorded by a semi-professional announcer and played through the computer speakers, (2) the interval between digits was exactly 1 s, (3) an option for random numbers was available, but not used, (4) the program automatically advanced the level of difficulty based on the correctness of the response as typed in by the experimenter, and (5) the program saved the response on each level and the final score to a data file.

There was a significant decrease in the number of recalled digits from the forward digit recall to the backward digit recall (F(1,6)=9, P<0.05) (Figure 21). The effect of run (before/after) was not significant. In fact, there was a slight increase in the number of backward digits recalled after the driving study, prior to expectations.

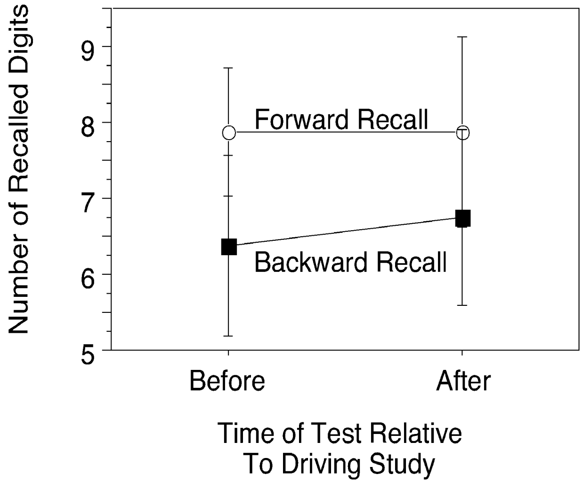


Figure 21. Number of recalled digits before and after the driving study

Trail Making Test

In the trail making test (Lezak, 1995, p. 381), the subject has to connect digits in increasing order from 1 to 25 (TMT-A) or connect digits to characters of two separate lists from 1 to 13 and from A to L (TMT-B). The time to connect all the characters is recorded as the final score. The TMT test is usually administered as a paper and pencil test. In the current experiment, however, a custom software program was used. The program was created in REALbasic (REALbasic ver. 3.5.1, REAL Software Inc.) (Figure 22).

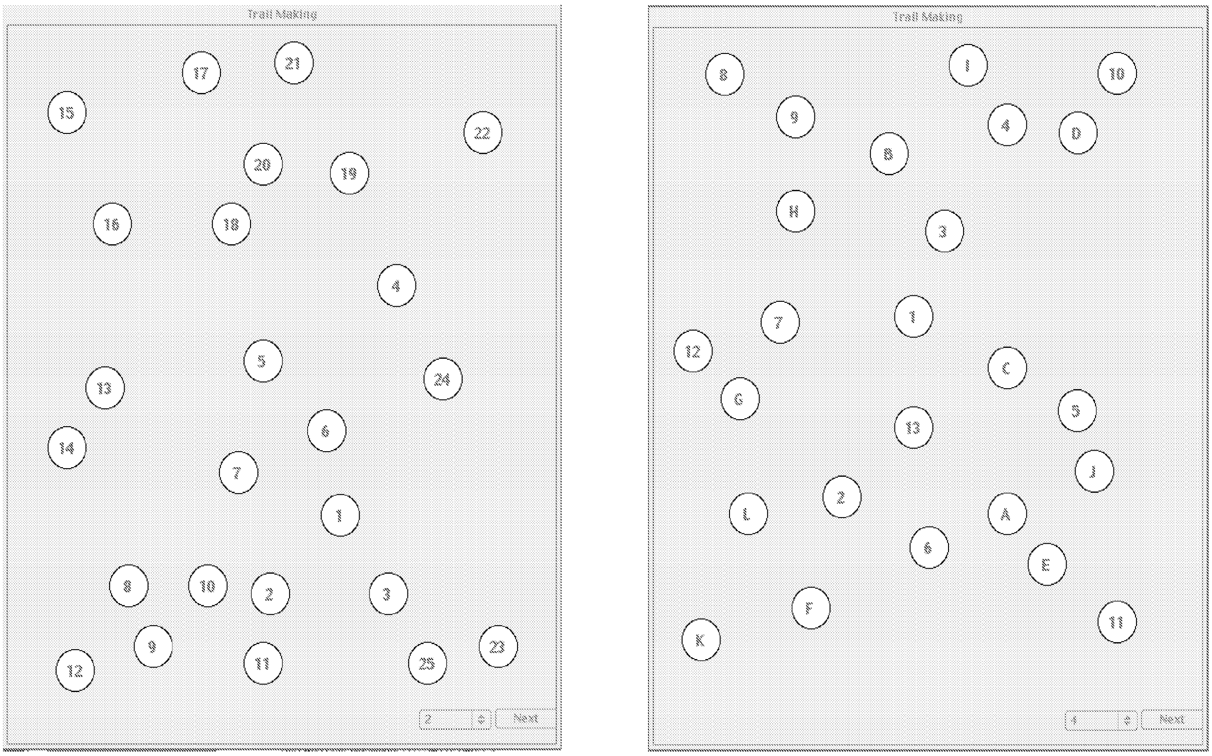


Figure 22. Sample of trail making test on computer screen. Left, TMT-A. Right, TMT-B

The time to complete TMT-B was significantly longer than that for TMT-A (F(1,4)=10.7, p<0.05) (Figure 23). Older subjects took somewhat longer than did younger subjects to complete both tasks (F(1,4)=4.3, p<0.10). The interaction between test (A/B) and run (before/after) was near significant (F(1,4)=6.2, p<0.10). The expected increase in completion time of task B relative to task A after the driving study was not observed, contrary to expectations.

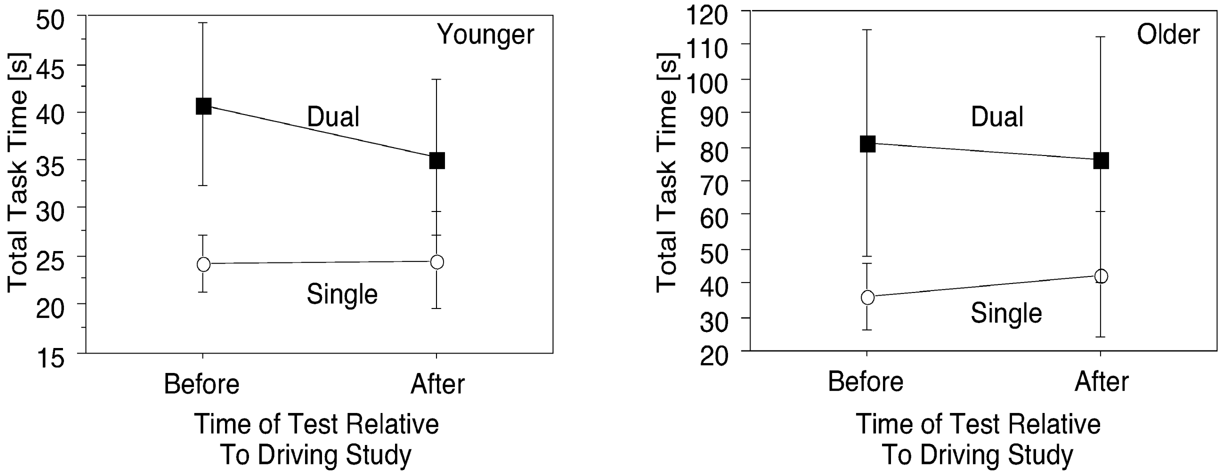
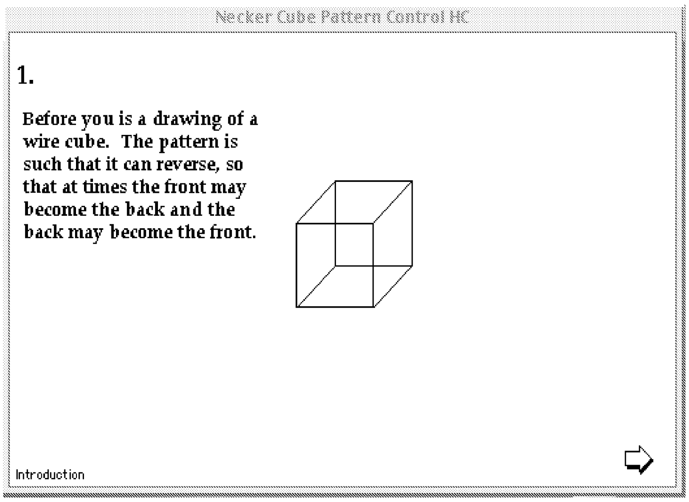


Figure 23. Total time to complete trail making task

Necker Cube

In the Necker cube test, subjects observe a Necker cube and press a button when the image reverses (the front becomes the back or vice versa). In the free condition, the subject observes the cube freely and reports the number of reversals. In the hold condition, the subject tries as hard as possible to prevent reversals from occurring by holding the current pattern for as long as possible and reports when reversals occur. The test was administered using a HyperCard program by Cimprich et al. (1994).



1.

Before you is a drawing of a wire cube. The pattern is such that it can reverse, so that at times the front may become the back and the back may become the front.

Figure 24. Computer screen of Necker cube test

There was a near significant decrease in the number of reversals between the free condition and the hold condition (F(1,6)=5.2, p<0.1) (Figure 25, left panel). The effect of run (before/after) was not significant. Figure 25 (right panel) shows individual scores for this test. Each point in the figure represents the difference between the number of reversals in the free condition to the number of reversals in the hold condition. There was no consistent trend in the direction of responses. (The results of one subject are not shown because he saw no reversals throughout the entire test.)

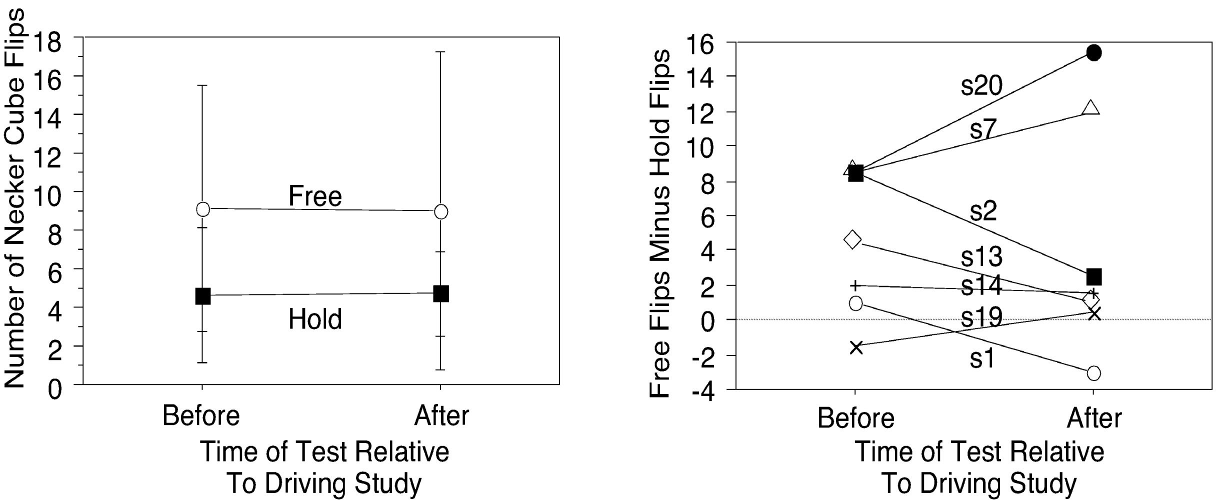


Figure 25. Number of reversals of Necker cube (left) and the difference between free and hold (right)

Conclusions

None of the three tests detected degradation in directed attention or any consistent change across subjects. There are several possible explanations:

1. Degradation in DA occurred but the tests were not sensitive enough to detect it.
2. There was no consistent degradation in DA. The driving task was only one hour; the subjects were all healthy; and their level of alertness was higher after the driving task, thus improving performance.
3. The tests did not detect degradation because performance differences were masked by improvement due to practice.
4. The experimental settings were not optimal for these tests and given the small number of subjects there was noise in the results.

Further experimentation is needed before any of these tests can be used to detect the degradation of DA in similar driving simulator experiments.

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Cimprich, B., Kaplan, S., Beadle, S. & Davis, M. (1994). Necker Cube Pattern Control [Computer software]. Ann Arbor, MI: University of Michigan.

Lezak (1995). Neuropsychological assessment (3rd Edition). New York: Oxford University Press.