Interaction of Non-Driving Tasks with Driving
This report replaces MN/PR-95/20 which was recalled.

Drivers often perform tasks alone or in combination that don't relate to control of their vehicle. This experiment evaluates the impact on simulated driving of performing non-driving tasks. The results showed that some of these tasks significantly degraded driving performance. The task that required drivers to use the map device caused the greatest problem. In addition, older drivers performed less well than younger drivers. The study shows objective reasons for evaluating the trade-offs between maximizing traffic safety and providing drivers with information that requires a high degree of visual attention.

In the experiment, drivers performed the following secondary tasks alone, as pairs, or all three simultaneously: talking on a simulated cellular telephone, finding an object in an enclosed container, and using a special radio with head-up map and text displays. The experiment required drivers to maintain speeds of 25 to 30 miles per hour, keep the car centered in their traffic lane, and respond quickly to the appearance of simulated brake lights. Researchers divided subjects into four groups of 10 members each: young females and males with an average age of 31 and older females and males with an average age of 70.
The Interaction of Non-Driving Tasks with Driving

Final Report

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Table of Contents

Executive Summary ................................................................. 1
Introduction .................................................................................. 3
  Objective ................................................................................. 3
  Scope ...................................................................................... 3
Literature Review And Analysis ................................................... 4
  Divided Attention Issues in Driving ........................................ 4
  Workload And Secondary Tasks .............................................. 5
  Multitasking ........................................................................... 6
  Information Processing Workload ............................................ 8
Methods ...................................................................................... 11
  The Simulation Facility ............................................................ 11
    Simulated Driving Environment ......................................... 13
Independent Variables ............................................................... 14
  Conversation Task ................................................................. 14
  Visual Task ........................................................................... 15
  Tactile Search Task ............................................................... 16
Dependent Variables .................................................................... 17
  Lane Drift .............................................................................. 17
  Speed Regulation ................................................................. 18
  Response Time ....................................................................... 18
Procedure ................................................................................... 19
  Multitasking .......................................................................... 19
  Terminology .......................................................................... 20
Experimental Design ................................................................. 21
  Subjects ............................................................................... 22
Results ....................................................................................... 23
  Statistical Analysis ............................................................... 23
    Selection of a Statistical Tool .............................................. 23
    Speed Deviation Results ................................................... 23
    Steering Deviation Results ................................................ 25
Discussion .................................................................................. 29
  Age Effects .......................................................................... 29
  Task Effects .......................................................................... 29
Conclusions And Recommendations .......................................... 31
References ................................................................................ 33
List of Tables

<table>
<thead>
<tr>
<th>Table Number</th>
<th>Table Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conversation Task Questions</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Multitasking Sets</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>One-Way ANOVA for Speed Maintenance Error</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>One-Way ANOVA for Steering Error</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>One-Way ANOVA for Response Time</td>
<td>28</td>
</tr>
</tbody>
</table>

List of Figures

<table>
<thead>
<tr>
<th>Figure Number</th>
<th>Figure Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Side projection view of the simulation facility illustrating the Honda 1990 fixed-position vehicle, the overhead projection system and the screen orientation and driver visual viewing angle.</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Electrohome ECP-3000 Projection system.</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Object creation procedure in the XTAR graphics simulation system.</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Electronic map display device.</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Histogram for Speed Deviation showing tasks and age effects.</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Histogram for Steering Deviation showing tasks and age effects.</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>Histogram for Response Time showing effects of tasks and age.</td>
<td>27</td>
</tr>
</tbody>
</table>
Interaction of Non-Driving Tasks with Driving

Executive Summary

Congestion on highways and its high cost increasingly concerns transportation agencies. The Intelligent Transportation Systems community is evaluating congestion reduction ideas. One of these ideas is to provide travelers with devices which would give them timely information for route selection and congestion avoidance. The Trilogy and Genesis programs are two examples of such evaluations.

There are human factors considerations related to the use of such devices. This is especially true given the task loadings which motorists impose on themselves. We often see drivers performing tasks alone or in combination which have little to do with the control of their vehicle; grooming, eating and drinking, reading text, talking on cellular telephones and the like are commonplace. The objective of this experiment was to evaluate the impact on driving of performing representative tasks during simulated driving. The experiments were performed in the Human Factors Research Laboratory’s driving simulator.

Three secondary tasks (talking on a simulated cellular telephone, finding an object in an enclosed container, and using a special radio with head-up map and text displays) were performed while driving the simulator. These secondary tasks were performed alone, as pairs or all three simultaneously. Subject drivers were required to maintain speeds of 25 to 30 mph, to keep the car centered in their traffic lane, and to respond quickly to the appearance of simulated brake lights.

The subjects were divided into four groups; young females and males (31 years of age on average) and older females and males (70 years of age on average). The groups had equal numbers of subjects. Each subject performed each of the task loading conditions plus a control task twice.

The results showed that age but not gender was statistically significant and that doing some of the tasks significantly degraded driving performance. The task which caused the greatest problem was the task which required drivers to use the map device.
This study showed that there were objective reasons for considering the evaluation of trade-offs between providing drivers with information requiring a high degree of visual attention and traffic safety.
Introduction

Objective

The objective of this research was to determine the effect on driving performance and on driving safety of doing non-driving tasks while driving a car. At least in its earliest stages, as evident in recent in-vehicle driver aiding systems, some Intelligent Vehicle Highway Systems (IVHS) programs appeared to be adding to the attentional load associated with driving a vehicle (Hancock and Caird, 1992). What we did not know was which combinations of perceptual and motor tasks combined to overload the driver, nor did we know the outcome of either momentary or prolonged driver overload.

Drivers are often engaged in many activities while driving which seem to have nothing to do with the task of safely driving a car. These extra activities are done even while driving in heavy traffic and at high speed. We see for example drivers eating and drinking, talking on telephones, combing hair and applying makeup using a mirror, perhaps listening to the radio or stereo, and reading a map or newspaper or other printed material, (and even in extreme cases, watching television). How safe is it when these non-driving activities, singly or in various combinations, accompany driving? Given the narrow attentional bandwidth of an average driver, even just driving may on occasion use all of that bandwidth. What happens as we overload it? Providing an answer to this question was the objective of this research.

Scope

In the simulation experiment described here we used a relatively simple driving maneuver; simulated driving down a straight road at a constant speed. There were no distractions such as other traffic, signs or intersections. We did not use glare sources and illuminances were typical of ordinary daytime driving. There were no weather conditions which might cause difficult driving. We wanted the added difficulty in these experiments to come from the secondary tasks rather than the driving task per se.

We used three loading tasks requiring three sensory modes: auditory (simulated cellular phone conversation), visual (finding a symbol on an electronic map display and reading a textual traffic message on the map display), and searching by feel for familiar objects in an enclosed container. In a previous study we evaluated a Radio Broadcast Data System (RBDS) which presented traffic messages by digitally
synthesized speech. The idea was that drivers would be less distracted if they did not need to read the display thus taking their eyes from the road. We found that it is the driver’s attention that is most important and not the direction of their gaze. That is, when their minds were occupied with understanding the message and perhaps deciding how, if at all, to act on the message they were not attending to their driving. This effect is stronger than effects due to the mode of transmission, visual or auditory.

In this experiment we used two groups of subjects; younger drivers and older drivers with equal gender representation in each group.

Literature Review And Analysis

Divided Attention Issues in Driving

One of the critical problems of driving in an IVHS environment is the question of distributed attention. It is clear that the present trend for increased information in the driving environment (both inside with map navigation and personal informational devices) and outside (via variable message signs) places greater attentional demands on the driver. Also, we are aware that division of attention among multiple tasks leads to degradation of primary (steering, speed maintenance and braking) performance, especially in high demand (i.e., congested traffic) conditions. The seminal work of Brown and Poulton (1961) at the Applied Psychology Unit in Cambridge, England attests to these performance changes. What is as yet unknown is the relationship between the division of attention and safety in terms of collision avoidance. We do know that attention is implicated far more in driving safety than simple visual function. This accounts for the poor relationship between visual function, as measured in driver screening and licensure tests, and subsequent driving accident records. As divided attention is clearly a critical factor in safety, it is central to an understanding of how in-vehicle intelligent-traveler communication devices can be used.

Current demonstration projects (such as Travtek, Trilogy and Genesis) provide displays within the vehicle, but require the driver to redirect vision away from the path of progress to assimilate information. Safety is the putative reason why the driver cannot reprogram the route of the vehicle from the screen while the car is in motion. However, if drivers are able to change displays (e.g., for time and date), and if drivers are able to reprogram routes if they have deviated from their preset route, then distraction becomes a problem. In fact, during driving it is frequently the case
that the display becomes the center of attention and primary demands such as
headway and velocity control are neglected with problematic results.

Attention takes a finite time to switch and although models of driver capability
show that intermittent sampling of the forward view does provide the capability for
vehicle control, the problems arise in unusual or emergency conditions. Quite
simply, this is why we can tune present head-down radios without a collision each
time. However, increasing the time attention is spent looking inside the vehicle
increases proportionately the opportunity of collision.

One potential solution, offered to this switching dilemma, is the use of head-up
displays in which information is presented on the windscreen. Such vehicles are
already in operation, although the information they display is non-vital and
therefore represents a technical rather than human factors approach. There are,
however, problems with head-up displays namely "where" to present the
information in terms of focus of the driver. If the displays are focused on the
windscreen, then attentional capture could leave drivers as blind as if they were
looking in a different direction. This capturing effect is especially true if drivers
are fatigued. In this case, time is required to switch attention via switching of focus
from the forward driving scene to the head-up display. If displays are focused at
infinity then drivers must distinguish information from a constantly changing
background and this can become as demanding an attentional task as the inside-
outside switching it was intended to alleviate. In short, information presentation
within the vehicle is a trade-off with attention directed toward vehicle control.

Workload And Secondary Tasks

Ivan Brown and his colleagues at Cambridge University (1961), have shown that
doing two things at once degrades driving performance as a function of traffic
density. There are also published studies using the subsidiary tasks mentioned above
in realistic driving situations (such as those at the Traffic Research Center,
University of Groningen). There are also experiments which use a secondary task
paradigm to estimate the mental workload (as contrasted to physical workload) caused
by a primary task (Hancock, Wulf, Thom, and Fassnacht, 1990). The primary task in
the present context is driving a car. The general finding is that as the driver devotes
more and more attention to an increasingly difficult driving task, performance on
the primary task (driving the car), up to some difficulty level, does not change but
performance on the secondary task deteriorates. However, eventually the increasing
difficulty of the secondary tasks will degrade primary task performance. This is the
basis for the hypothesis that secondary tasks will increase the mental workload of the driver until the driver becomes overloaded and driving performance fails. If traffic is heavy or the weather is bad, overload may happen with very little secondary task loading.

**Multitasking**

The simultaneous performance of multiple tasks is called *multitasking*. In this project we are concerned with the effect of multitasking on driving performance. We performed two experiments to determine the magnitude of changes in driving performance when a motorist was searching for an object, reading a radio's display, or talking on a cellular telephone. (The first experiment was a pilot and its results encouraged us to continue with the project reported here.)

In the case of human performance, each of the individual tasks is called a *loading task* because it imposes a load on attention, cognitive function and/or motor function. Theories of human information processing generally predict that cognitive and motor performance will decrease as a function of the number of tasks being processed concurrently. However, there is disagreement as to the precise nature of this performance decrement. The classic single channel theories of attention (Broadbent, 1958, 1971, 1982; Treisman, 1960, 1969; Treisman & Gelade, 1980; Deutsch & Deutsch, 1963; Moray, 1967, 1969) predict substantial performance decrements in multitasking situations, arguing that human attention can concentrate on only a single task at any given time. The multiple resource theories (Allport, Antonis & Reynolds, 1972; Gopher, Brickner & Navon, 1982) often predict much more modest decrements, since they endow humans with the capacity for parallel processing of multiple tasks, provided that the tasks are not competing for similar cognitive resources.

Cognitive science borrows from computer science in speaking of serial and parallel cognitive processes. Serial processes are those which must be performed in series, one after the other. Parallel processes are those which can be performed at the same time. Generally parallel processing is thought to be the more rapid mode because the human nervous system is thought of as having "more than one mental computer" which can be brought to bear on a task at any given time.

Theoretically it is quite possible that human attention relies both on slower serial as well as more rapid parallel processing. In that case there may be certain combinations of behaviors in which drivers can engage relatively safely, while other combinations might constitute grave dangers. In other words, the effect of
doing more than one thing while driving may depend both on what exactly is being
done while driving and what specific driving behaviors are examined. That is,
certain combinations of mental and physical behaviors may affect certain aspects of
driving while having little or no effect on other aspects of driving.

The most conservative position to take in the midst of this theoretical debate is to
assume a default viewpoint that drivers cannot engage in multitasking unless
empirical research demonstrates otherwise. Furthermore, an empirical
demonstration of the relative safety of one particular combination of loading tasks
should not be taken to generalize to any other combination which has not yet been
tested.

With this in mind, we examined the literature to determine what kinds of
multitasking driving situations had already been studied. Special attention was given
to the concept of representativeness or ecological validity as discussed above. In
practice this means that if we conducted the experiment in both the real world as
well as in our simulation of the real world, we would get nearly identical sets of
results.

Prior research on multitasking-while-driving has often centered around the use
of loading tasks chosen more for their experimental and theoretical convenience
than for ecological validity. For example, Brower, et al. (1991) had subjects count the
number of dots displayed in an on-screen rectangle while driving. Liao (1990) had
subjects respond to colored squares, do mental arithmetic, and track cosine waves
with a joystick while driving. Dewar, Ellis, & Mundy (1976) had subjects respond to
integers between 1 and 99 flashed on-screen. Stephens & Michaels (1964) had
subjects keep a point of light centered on a CRT display.

While such tasks may serve a theoretical purpose of loading the perceptual,
cognitive, and motor systems, they are not the kinds of multiple tasks in which
motorists routinely engage. Assuming that one wants to study multitasking during
driving, it makes sense to use independent variables (loading tasks) and dependent
variable performance measures (driving behaviors) with ecological validity in a
plausible driving situation.

Therefore, the attempt here was to employ the kinds of simple behaviors in which
motorists routinely engage while driving, in order to assess the effects of these
behaviors on various critical aspects of actual driving behavior.

Both McKnight & McKnight (1993) and Brookhuis, De Vries and De Waard (1991)
examined the effects of using hand-held and hands-free cellular telephones. The
former used a form of driving simulation while the latter group collected data during

7
actual driving. McKnight and McKnight (1993) found that driving performance was affected slightly but significantly in subjects over 50 years of age by both casual and intense (mental math computations) phone conversations but performance was only decreased in younger subjects by intense conversations. Placing the call (dialing) required the subject to remove one hand from the steering wheel, but this decreased performance less than intense conversation on the phone or tuning the radio. Tuning the car radio resulted in about the same performance decrement as intense conversation but for this task younger drivers showed a greater decrement than older drivers.

Brookhuis, De Vries and De Waard (1991) had subjects drive in both heavy and light traffic while placing phone calls and talking on the phone. Lateral position control (swerving and steering movements) decreased when subjects were talking on the phone but car following (maintaining spacing and sudden stopping) was not changed due to talking on the phone. There was no change in frequency of checking the rearview mirror when talking on the phone. There was no difference attributable to hand-held versus hands-free phone types. There were no age-related effects in these experiments. In summary this work showed that use of a cellular phone resulted in only slight changes in driving performance.

**Information Processing Workload**

While ecological validity, as used here, refers to the correspondence between the real and simulated driving worlds, there is a related and adjunct way of interpreting our experimental framework. This second way involves the concept of information processing workload. Just as the prolonged performance of a physically demanding task results in an increasing number of errors, information processing can load an operator resulting in errors. Ivan Brown and E.C. Poulton (1961) contributed the idea of secondary task performance as a method for measuring information processing workload. For a physically demanding task we can measure oxygen consumption or carbon dioxide production and use this measure to quantify the difficulty of the task. For information processing workload there are no such directly available and measurable variables. However, Brown and Poulton found that if a subject was asked to perform as well as possible on a task of primary importance (simulated car driving in our experiment) then when the subject was asked to perform a task of secondary importance, the number of errors on the secondary task served as a reliable measure of the information processing workload imposed by the primary task. A recent application of this idea to simulated car driving is discussed in Hancock et al (1990).
The idea underlying this observation is that we can process information up to some maximum rate. Increasing the processing demand beyond that rate results in an increasing number of performance errors. Said differently, as task demand increases, thus imposing an increasing information processing workload, performance deteriorates. There is a confusion here that we strive to avoid and that is the potential confusion between performance and workload, (Hancock & Caird 1993). If we measure a subject's ability to keep the car between the lane stripes, we might find that we can make this task increasingly harder to do but that up to some difficulty level there is no increase in performance errors but only an increase in workload. At some level both performance error and workload will increase. At the lower levels of task demand, performance errors do not measure demand or task difficulty. At these levels we can use secondary task errors to measure information processing workload (task difficulty).

In this project differences in relative importance between primary and secondary tasks were blurred. This was ecologically valid since drivers in the real world performed secondary tasks which clearly interfered with the primary task of driving to the extent that these subsidiary tasks momentarily became primary, thus jeopardizing safety. In our experimental protocols for simulation, drivers were required to control the car and perform certain secondary tasks. In this protocol secondary tasks served not as measures of primary task workload but as sources of task demand or task loading.
Methods

In this section we describe the facility in which the research was conducted, the independent and dependent variables, the formal experimental design and the procedure for performing the experiments.

The Simulation Facility

The Human Factors Research Laboratory’s (HFRL) driving simulation facility was based upon a fixed-based 1990 Honda Accord. Inputs from the driver, in terms of accelerator and brake activation and steering were converted from analog to digital outputs which were fed to a computer model which approximated the equations of motion for the actual vehicle. Outputs from this model were then used to adjust the eye point of the driver in the environment in accord with the inputs passed to the equations. These changes were then displayed in real-time on a screen immediately in front of the car (Figure 1) and this constituted the dynamic driving world observed by the driver. For this experiment calculations of such changes proceeded at an average rate of about 27 times per second. At this value or above, the perception of the driver was one of actual driving.

The simulator used three computers besides the 386 PC for graphical processing. An IBM OS2 supported the traffic messaging software. A Compaq 486 performed the calculations related to the vehicle model and handled the data collection chores. An IBM 286 in the trunk of the car handled the torque motor processing for realistic steering as well as the stepper motor program for operating the speedometer.

The car was equipped with a two-way voice communication system between the subject driver and the experimenter. The experimenter was seated behind the car with access to the computers and their monitors. The experimenter viewed all four monitors from a single location.
The XTAR System

The hardware platform for which the software driving world was created was the XTAR system. This was a medium level graphics generation systems based in a 33MHz 386 machine that attached to the Electrohome ECP-3000 color projection system (Figure 2). Also contained in this loop were the actual vehicle itself and the associated A/D and D/A peripherals that allowed interactive driving responses from the experimental subject.
As noted below, the software package used in the present project for the generation of objects for this driving world was the AUTOCAD design aid system. The XTAR system has been used extensively at HFRL for experiments in which look-ahead driving maneuvers predominate. In terms of computational power, the XTAR system was limited to the calculation of 2,000 flat-shaded polygons per second. (Polygons are the currency of simulation fidelity in this kind of non-texturing system).

Object creation in XTAR was performed in a number of steps, as illustrated in Figure 3.

![Diagram](image)

**Figure 3** Object creation procedure in the XTAR graphics simulation system.

All objects seen in the XTAR system were designed using a very restricted subset of AUTOCAD. Although AUTOCAD was capable of creating very complex objects, only the command that draws a "3-D Face", i.e., a concave polygon, was used by the XTAR system. Once the AUTOCAD file for an object was created, the file was saved in the "dxf" file format. XTAR provided a series of translation tools that converted this dxf file into a format that allowed the object to be loaded at runtime.

**Simulated Driving Environment**

The world used for this study was comprised of a straight stretch of two-lane highway (one lane for each direction of travel). The simulated vehicle was the only
vehicle on the road, no oncoming or cross traffic was present. A mountain range was placed in the remote distance as a back-drop. Road dimensions and markings were based on the standards specified in the 1988 Edition of the FHWA *Manual on Uniform Traffic Control Devices* (U.S. Department of Transportation, 1988). In addition mile marker posts were placed along the right side of the road at intervals of 1,000 feet.

**Independent Variables**

Secondary loading tasks were the primary influences of interest in this experiment. Extraneous but frequently performed nondriving tasks (secondary tasks) were introduced alone and in various combinations. Each secondary task represented behavior that was not necessary for the primary driving task (i.e., manual vehicle control) and would typically be observed of drivers on local highways. The tasks were; (a) conversing, (b) reading an electronic map, and (c) conducting a tactile search for an object inside a container.

**Conversation Task**

The conversation task was carried out through an intercom system between the vehicle and the experimenter's station. One microphone was placed in the car and the other was held by the experimenter. A speaker placed on the rear shelf of the vehicle was used to project the experimenter's voice from a microphone to the participant. Similarly, headphones were used to project the participant's voice from a microphone to the experimenter.

The conversing task was initiated when the experimenter asked a question of the participant. The experimenter queried the participant on a variety of topics ranging from popular political topics to news items and personal interest (see Table 1). Since the conversation was carried out over an intercom system it did not require manual responses from the participants. Subjects had been instructed that once they received a question they were to continue talking until the experimenter told them to stop talking. In this way the participant was responsible for carrying on the conversation with minimal input from the experimenter. This task could be envisioned as a hands free cellular phone conversation.
Table 1
Conversation Task Questions

Questions used in the practice session
1. How do you feel about the death penalty?
2. What is your position on hand gun control?
3. Do you feel the US health care system needs reform? If so, what changes would you like to see?
4. How do you feel about the performance of your favorite sports team this season?

Questions used in the main experimental session
1. Describe an episode from your favorite television show.
2. Tell me about your family.
3. Do you believe O.J. Simpson is innocent or guilty? What information do you base your decision on?
4. Describe your house or apartment.
5. Tell me about your most recent vacation.
6. Describe what you do in a typical day at work.
7. How productive do you feel the Clinton Administration has been to date? What major accomplishments would you like to see made prior to the end of his term?
8. Describe the last movie you saw.

Visual Task

The visual task was performed using an electronic map device mounted at dashboard level in the forward, center section of the vehicle. The device displayed major Twin Cities metro area interstate highways and state highways on a four square inch screen (see figure 4). The device was also capable of displaying one (or more) of a set of symbols (stars, circles, arrows and double arrows) in two colors (red and yellow) at a specified road junction. Each symbol was associated with a text message regarding some road condition at the associated junction. The device contained four buttons located just below the screen; 'SELECT', 'TEXT', 'FILTER', and 'AREA'. The 'SELECT' button scrolled through the symbols displayed on the screen, highlighting each one as it was encountered. The 'TEXT' button called up a text message associated with the highlighted symbol and displayed it on the screen in place of the previous map display. (The map display was used in this project only to effect loading. This project's purpose was not display device evaluation.) The remaining buttons were not used in this study. The software used to communicate the
traffic information from a 486 CPU computer to the electronic map was Crusader (developed by the Swedish National Road and Transportation Administration).

Figure 4 Electronic map display device.

The mapping task was initiated when the experimenter specified the name and color of a particular symbol displayed on the screen of the map device (e.g., "Select the yellow star."). Subjects had been instructed that upon receipt of such a command they were to; (i) press the SELECT button until the yellow star was highlighted, (ii) press the TEXT button to call up the traffic information associated with the yellow star, (iii) read the text message aloud to the experimenter, and (iv) press the TEXT button again to return to the map display.

Tactile Search Task

A box, 12 inches on each side, was used to hold the various objects for the search task. The box had a black fabric cover sewn over it containing an elasticized hole in the middle. The hole was large enough to allow a hand to enter but small enough to prevent visual inspection of the contents. Objects used in this task included; an eraser, a nine volt battery, a car key, a key ring, a button, a thimble, a small steel
ball, four wooden beads, a binder clip, a spool of thread, a small cube, and a small sponge.

The mapping task was initiated when the experimenter specified the name of a particular object in the box (e.g., "Find the key."). Subjects had been instructed that upon receipt of such a command they were to: (i) reach into the box with their right hand, (ii) search by touch alone for the specified object, (iii) once identified by touch remove the object from the box for visual identification, and (iv) return the object to the box.

Dependent Variables

The magnitude of deterioration in driving performance on the primary driving task was measured to determine the impact of the secondary tasks. The primary driving task required participant control inputs to the steering wheel, accelerator pedal and brake pedal. Performance was based on the ability of the participant to use these three controls to keep the vehicle centered within the lane and to maintain a set velocity. Thus, the measured dependent variables were; (i) lane drift, (ii) speed regulation, and (iii) response time (RT).

Lane Drift

The position of the steering wheel was sensed and recorded. Through the vehicle model, steering inputs were converted into pixels of drift from the center of the lane. These units were saved to an output file which gave a profile of how well the participant kept the vehicle within the lane markers and how well the participant was able to keep the vehicle centered within the lane. Data was not collected continuously, rather it was based on discrete time periods.

For each condition data was recorded over two ten second periods. The first recording period fell during the intercondition interval (i.e., the time between completion of a previous task and initiation of a new task) and was comprised of the ten seconds just prior to the initiation of a new condition. This recording period was considered to be the control or baseline measurement. It provided a measure of participant driving performance while not engaged in any secondary tasks. The second set of measurements were taken during a ten second period when the participant was engaged in a multitasking set (i.e., performing one or more secondary tasks). This recording period was initiated at different times depending on which multitasking set was currently being performed by the participant. It was
comprised of the period when the participant was engaged in the heaviest workload for the multitasking set being performed. For each recording period the data were averaged to form a single value. A difference score was computed as the difference between the control recording period measurement and the performance recording period measurement. This difference score was the base unit used for statistical analysis.

**Speed Regulation**

The position of the accelerator pedal was sensed, quantized, digitized and recorded. This data was used to determine how well the subject was able to keep the vehicle at a speed of between 25 and 30 mph. The same data recording process described for lane drift was used to calculate the difference scores for speed regulation.

**Response Time**

Two red lights, 2 by 3 inches, were mounted on the leading edge of the simulation vehicle's hood. The lights were placed along the hood such that they appeared to be superimposed onto the driving lane when viewed from the driver's seat (i.e., they would be located in the forward view of the participant much the same way a pair of brake lights on a leading car would be seen). These lights were illuminated through a command issued by the experimenter at predetermined times.

The response time test was initiated when the lights were illuminated. Subjects were instructed to move their right foot from the accelerator pedal to the brake pedal as quickly as possible once the red lights came on. Subjects were told to tap the brake pedal lightly to extinguish the lights. In addition participants were instructed to use only the right foot to brake (i.e., the same foot used to accelerate should be used to brake). Once the lights had gone out, participants were instructed to resume the cruising speed. The lights would not come on unless the subject's foot was on the accelerator pedal.

The illumination of the red lights initiated the recording of elapsed time by the data collection computer. Depression of the brake pedal terminated the running clock. In this way the interval between light illumination and brake pedal depression was recorded. This interval represents the time it took for a participant to perceive the stimulus, process the information and move the right foot from the accelerator to the brake. Thus the response time interval includes both reaction time and movement time.

The data recording process was slightly different for the response time tests. During the control condition the participant received a response time test. One number was generated based on the difference between illumination time and brake...
depression time. The measurement taken under the control condition represented a participants response time when not engaged in any secondary tasks. A second response time measurement was taken when the participant was engaged in a multitasking set. A difference score was computed between these two figures and used as the statistical unit of analysis.

Procedure

Subjects were recruited and scheduled for a particular date and time. On arriving at the laboratory subjects read and signed a Consent Form approved by the University’s Committee on The Use of Human Subjects in Research. The experimenter explained the purpose and potential benefits of the experiment to the subject. Subjects then read a three page document, “Instructions for Subjects.” The subjects were escorted to the simulation room and shown the objects for which they would subsequently search in the enclosed container. The subject was seated in the drivers seat which was adjusted to accommodate the subjects size and preference. The use of the electronic map display, the search task and the response time procedure were explained to the subject. If the subject had no questions, the practice trials were performed until both the experimenter and the subject felt that the subject had learned the procedures and had become accustomed to driving the simulator. This typically took from 15 to 20 minutes. The practice trials were similar to the trials in the main experiment and covered control tasks and presentations of the three types of loading tasks taken individually, paired and all three simultaneously. All of these trials included the response time presentations. Following the practice trials the main experiment began. The experiment lasted about 50 minutes.

Once the simulation data was collected, subjects were asked to complete a standard laboratory form to elicit demographic information. Subjects were then given $10.00 to cover travel and parking costs and thanked for their participation.

Multitasking

It was physically impossible for subjects to perform some combinations of tasks simultaneously. In these cases participants had received instruction on the order in which the tasks were to be performed. In the case of conversing and performing the visual task, participants were instructed to continue conversing until the text display had been selected, at which point they were to read the message on the display, then return to the map display and resume conversing. In the cases of the visual task and searching, participants were instructed to operate the map device until the text message had been called up, at which point they were to begin searching for an
object while they were reading the text message. For the triple set, participants were instructed to perform tasks in the following order: continue conversing until the text message was on the display, begin searching while reading the text, upon completion of reading, resume conversation until the object had been found.

**Terminology**

Subjects were required to perform each of the secondary tasks described above in a variety of combinations. A "null set" condition referred to a task in which the participant's only responsibility was to drive the car. No secondary tasks were performed under this condition. A "single set" condition referred to the performance of only one secondary task while driving. A "dual set" condition referred to the simultaneous performance of two secondary tasks while driving. Finally a "triple set" condition referred to the simultaneous performance of all three secondary tasks while driving. (See Table 2).

**Table 2**

<table>
<thead>
<tr>
<th>Condition Class</th>
<th>Task Set</th>
<th>Condition</th>
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</thead>
<tbody>
<tr>
<td>Loading</td>
<td>Single Set</td>
<td>Driving, Conversing &amp; RT</td>
</tr>
<tr>
<td>Loading</td>
<td>Single Set</td>
<td>Driving, Visual &amp; RT</td>
</tr>
<tr>
<td>Loading</td>
<td>Single Set</td>
<td>Driving, Tactile Searching &amp; RT</td>
</tr>
<tr>
<td>Loading</td>
<td>Dual Set</td>
<td>Driving, Conversing, Visual &amp; RT</td>
</tr>
<tr>
<td>Loading</td>
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</tr>
<tr>
<td>Loading</td>
<td>Dual Set</td>
<td>Driving, Visual, Tactile Searching &amp; RT</td>
</tr>
<tr>
<td>Loading</td>
<td>Triple Set</td>
<td>Driving, Conversing, Visual, Tactile Searching &amp; RT</td>
</tr>
<tr>
<td>Control</td>
<td>Null Set</td>
<td>Driving &amp; RT</td>
</tr>
<tr>
<td>Dummy</td>
<td>Single Set</td>
<td>Driving &amp; Visual</td>
</tr>
</tbody>
</table>

Furthermore, conditions were classed as one of three types. A condition for which the participant's only responsibilities were to maintain primary vehicle control (i.e., drive) and respond to the red lights was categorized as a control condition. A dummy condition was one in which the participant was required to drive and perform a visual task. Under this condition no response time test was given. A loading class condition was one in which the participant was required to perform either a single, a dual, or a triple set of secondary tasks. During each of these conditions a response time test was given.
Experimental Design

The three secondary tasks, taken in all possible combinations, yielded seven experimental conditions (refer to the loading class conditions in Table 2). The addition of the control and dummy conditions created nine experimental conditions. However, each of these latter tasks were presented twice within a set of trials. Thus, there were eleven conditions presented to a participant during one set of trials. Furthermore, these eleven conditions were replicated twice, creating two sets of trials for the main experimental session, as described earlier. All twenty-two conditions were run on a within subjects basis in a repeated measures design (all subjects received all treatments).

Presentation order for each set of the eleven conditions was randomized. From this initial order a set of five counterbalanced orders were created. Each of these five orders was then reversed to create a total of ten unique presentation orders for the eleven conditions. This process was then repeated for the second set of conditions. Between each condition was an interval ranging from twenty-five to forty-five seconds (the intercondition interval). Eleven unique intervals were created by increasing the interval range from twenty-five to forty-five in two second increments. These intervals were randomized. The same procedure used to determine condition orders was used to determine intercondition interval orders for both sets of trials. The counterbalancing process described above was used to control for practice and boredom effects as well as to prevent participant anticipation for the response time test.

Each of the four participant groups described in the following section contained ten individuals. Each participant within a group was assigned one of the ten unique presentation orders. The same set of ten presentation orders was used for each participant group. Thus, each first person in all groups received the same, unique presentation order, and each second person in all groups received the same, unique presentation order, and so on.
Subjects

There were two groups of 20 subjects. A younger group under 49 years of age and a group older than 52 years. There were equal numbers of males and females in each group. The mean age for the younger group was 31.0 years (31.2 years for the males and 30.8 for the females). The mean age for the older group was 69.7 years (70.5 years for the males and 68.9 for the females). All subjects were required to have a valid Minnesota drivers license, drive at least twice a week and be able to grasp small objects with their right hand while steering with their left hand.
Results

Statistical Analysis

Selection of a Statistical Tool

The three original secondary tasks selected for use in this experiment were not chosen on the basis that each task had an equivalent effect on driving performance. Rather they were chosen based on their ecological validity as discussed previously. As such, each combination of secondary tasks was unique from all other combinations. That is, driving while performing the task for example, was viewed as functionally different from driving while performing any other secondary task or combination of secondary tasks. The differences in performance decrements between the eight unique experimental conditions were not assumed to be additive. Based on the assumption of uniqueness of the multitasking sets, a series of one-way Analyses of Variance (ANOVAs) were conducted, one for each of the three dependent measures.

The histograms for each of the dependent variables give an impression of the relative effects on driving variables and response time and the effect of age of driving performance.

The ANOVAs for the between subjects variables (Age and Gender) showed whether there were significant differences on these bases. The ANOVAs for the within subjects variables indicated the presence (if any) of significant task loading effects on any of the performance variables (Speed, Steering and Response Time (RT)).

When significant differences for Tasks were found, the differences were identified by performing t-tests and assessing their significance by using the table of critical values for Tukey paired comparisons. Use of these Tukey critical values obviated the danger of incorrectly rejecting the null hypothesis. Box plots for representative tasks which had significant effects on driving performance and/or response time are shown.

Speed Deviation Results

The histogram for speed deviation, figure 5, suggests that some tasks as well as age had an effect on subjects' abilities to maintain a speed of 25 to 30 mph. Older subjects never performed as well as younger subject for any of the tasks or task combinations. Certain pairs of tasks as well as the triple combination of tasks seemed to degrade speed maintenance especially for the older subjects.
Figure 5 Histogram for Speed Deviation showing effects of tasks and age.
(The legend for all histograms is that closed bars show results for the young subject group while open bars show older subjects \('\) results. The labels on the abscissa and in the ANOVAs have the following meaning: Sp (Speeding Deviation), St (Steering Deviation), RT (Response Time); R1 and R2 are the two replications; and the tasks are (T for Talking or conversation), M (for manipulating the electronic Map display), F (for Finding the object sin the enclosed container), and the combinations of these three designators showing when these three tasks were performed simultaneously. and C is control task that does not have an associated Response Time.

The ANOVA for Speed Maintenance, Table 4, shows a statistically significant, between-subjects, effect for age but not for gender. Gender was not significant for any of the variables. There was a highly significant effect for tasks but for no
Table 3  ANOVA for Speed Maintenance

### Speed Data

#### Between Subjects

<table>
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<th>MS</th>
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#### Within - Subjects

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</table>

(A probability or p value of 0 implies a probability of less than 0.0001.)

Other within-subject variable or interaction between or among variables.
Replication as a within subjects variable was not significant in the analyses for any of the variables.

The paired comparisons among the tasks revealed that the following tasks were significantly (p < 0.005) different from the control task (no secondary task):
- Replicate 1 Control vs. Map plus Finding;
- Replicate 1 Control vs. Talking plus Map plus Finding;
- Replicate 2 Control vs. Talking plus Finding;
- Replicate 2 Control vs. Map plus Finding

### Steering Deviation Results

The histogram for Steering Deviation, Figure 6, does not show striking differences for either task or age effects. The data suggests that older subjects suffered greater performance degradation than younger subjects, but on
Figure 6 Histogram for Steering Deviation showing the effects of tasks and age.

four of the tasks the reverse was the case. The ANOVA for Steering Deviation,

Table 4 ANOVA for Steering

<table>
<thead>
<tr>
<th>Source</th>
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<tbody>
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<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
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<th>p</th>
</tr>
</thead>
<tbody>
<tr>
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<td>723108.6793</td>
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<td></td>
</tr>
</tbody>
</table>
Table 5, did show a significant effect for age with older subjects having a more difficult time controlling the direction of the car than younger subjects. There were no significant within-subjects effects for tasks or the interactions of tasks with age or gender.

The data for response time is displayed as a histogram in Figure 7. There is an obvious age effect with older subjects taking longer to respond to the stimulus lights than younger subjects.

The ANOVA for Response Time, Table 6, showed a significant between-subjects effect for age while tasks, but not interactions of tasks with age or gender, were significant.

Figure 7 Histogram for Response Time showing the effects of tasks and age.
### Table 5 ANOVA for Response Time

#### Response Time Data

<table>
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<tr>
<th>Source</th>
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<th>MS</th>
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<th>p</th>
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</thead>
<tbody>
<tr>
<td>SEX</td>
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<td>ERROR</td>
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#### Within - Subjects

<table>
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<tr>
<th>Source</th>
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<th>p</th>
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</thead>
<tbody>
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<td>Tasks</td>
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<td>1.80894E06</td>
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</tr>
</tbody>
</table>

The t-tests showed that the following comparisons were significantly different at a probability level equal to or less than 0.001:

- Replicate 1 Control vs. Talking plus Map for Replicate 1;
- Replicate 1 Control vs. Talking plus Map plus Finding for Replicate 1;
- Replicate 2 Control vs. Map;
- Replicate 2 Map vs. Talking plus Finding.

The consistent finding in the above comparisons was that the Map task entered into each of the significant findings not only for the Response Time variable but the Speed Maintenance variable as well.
Discussion

The experimental hypothesis was that performing secondary tasks would degrade driving performance. In a limited way this has proven to be the case. We defined driving performance in terms of three dependent variables.

The speed measure showed the changes in the driver's ability to maintain the speed of the car for the 10 seconds just before the introduction of the secondary task as compared to the same ability measured for a 10 second period during the performance of the secondary task or combination of secondary tasks. The control condition for both speed maintenance and steering variables was similarly measured as the difference in performance for two successive 10 second periods without secondary tasks. For the control condition for the response time variable, the stimulus was presented at the end of a control interval during which no secondary tasks had been presented.

Age Effects

Speed maintenance, steering and response time all showed significant age effects. Not surprisingly, the older drivers performed less well than the younger drivers and the older drivers' response times were longer. These findings are in agreement with those of McKnight and McKnight (1993) who found that driving performance was degraded slightly but significantly for older but not younger drivers during cellular phone conversations while driving. These results and the results reported here were not in agreement with Brookhuis, Devries and De Waard (1991) who found that talking on a cellular phone while driving caused either no effects or beneficial effects on driving performance while driving in heavy traffic. There were no age differences in this latter study. We can offer no reasons for these discrepancies in results. In general, increases in reaction time and response time with age is a common finding.

Task Effects

Even by the more stringent critical values for the t-test values, there were four significant differences among four pairs of tasks for both speed maintenance and response time. The interesting feature in this finding is that all eight of these pairs contained, or were restricted to, the Map Task. The Talking and Finding Tasks were
never significant on their own; but only when they were performed in combination with the Map Task.

This finding demonstrates that our initial assumption that different secondary tasks do not have the same impact on driving performance was correct. That is, the effects of performing secondary tasks while driving do not have a simple additive effect on driving performance. Neither the Talking nor the Finding Tasks have significant effects alone or in combination with one exception and that exception is for response time when Talking and Finding are compared to the Map Task. Viewed another way, Talking and Finding activities do not unduly degrade driving performance while the Map Task does cause unwanted degradation in driving.

Within the constraints imposed by this experiment we find support for the idea that attending to a cellular phone conversation or groping about in purses or briefcases are relatively safe activities while using a map display of the kind used here is not.

We can speculate on the source of the problem in using the map display. We do not believe that the problem was caused by the specific implementation of the device; that is, we do not believe that display location or legibility or button type or location or the message format or content were significant factors. Rather, we believe that the amount of attention, particularly visual attention, required while using the device left too little attention to be devoted to controlling the car and responding to outside stimuli.

In the real, as opposed to the simulated world, drivers would be requited to process the information on the display and make up their own minds about which of the icons they might like to select. In our experiment we instructed subjects to select a particular icon. When we asked subjects to read the text display out loud, we could not require them to actually consider the meaning of the message in the context of expeditiously reach their destination. That is, much of the cognitive activity that would occur in the real world did not occur in our simulation. On these grounds, that our simulation did not impose as great a load on the drivers' attention in simulation as it would in the real world, we would predict that driving performance degradation would be even greater in the real world than it was in our simulation.

This speculation has special significance in light of Intelligent Transportation System technologies which seek to provide the driver with in route information as did the map device used in our experiment. We believe we have shown objective reasons for considering the evaluation of trade offs between providing drivers with information and driving safety.
Conclusions And Recommendations

The main conclusions which we can draw from this study are:

- While older subjects were driving, they had more difficulty coping with secondary loading tasks than did younger subjects.
- Older subjects had slower response times than younger subjects under the same task loading conditions.
- There were no gender differences.
- Loading tasks are specific rather than all tasks having the same effect on driving performance and response time.
- The loading task involving the map and text display, which required a high degree of visual attention, caused greater driving performance degradation and slower response times than the tasks not involving the use of the map device.
- When loading tasks are proposed for introduction into vehicles for the general motoring public, trade-offs with driving performance and safety should be considered.

As a final general, and probably anticipated, recommendation we suggest that further research is needed. We believe that both more simulation as well as on-the-road research should be conducted.
References


