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Driver Performance Data Book Update

Older Drivers and IVHS

Transportation Research Board
National Research Council

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DRIVER PERFORMANCE DATA BOOK UPDATE: OLDER DRIVERS AND IVHS

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ACKNOWLEDGEMENTS

Michael Perel of NHTSA brought the idea of updating the 1987 National Highway Traffic Safety Administration's "Driver Performance Databook" before Transportation Research Board Committee A3B02, Vehicle User Characteristics. The Committee agreed it was an excellent idea and Mr. Perel agreed to lead the effort to develop the update materials. In the process Mr. Perel surveyed committee members about research to include in the update, arranged resources for researchers to prepare the literature summaries, developed the document format, reviewed all summaries, and wrote the introduction. A sincere thank you to Mr. Perel from the Vehicle User Characteristics Committee and TRB staff.

The Committee wishes to thank Dr. R. Quinn Brackett, Jr. of Brackett and Associates, College Station Texas, for preparing the summaries of older driver research and Dr. Walter W. Weirwille of Systemetrics, Inc., Blacksburg Virginia, for preparing the summaries of IVHS research.

A special thank you from the Committee and TRB to the National Highway Traffic Safety Administration and the Federal Highway Administration, with the assistance of Ms. Elizabeth Alicandri, for providing the resources necessary to prepare and produce this circular.

To those committee members who sent materials to Mr. Perel and who participated in the review of completed summaries, thank you.

The articles and reports selected for inclusion in this circular came from many sources. Our thanks to the publishers listed below who gave permission to reproduce graphs or tables from their publications.

AAA Foundation for Traffic Safety
American Association for Automotive Medicine
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Society for Information Display
Swedish Road and Traffic Research Institute
The Gerontological Society of America
TNO Institute for Perception

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INTRODUCTION

This Circular is a compilation of summaries of driver performance data from two areas of research: older drivers and intelligent vehicle highway systems (IVHS). The summaries were written in a format similar to the one used in the National Highway Traffic Safety Administration's 1987 Driver Performance Data Book. This circular has the same objective as the Driver Performance Data Book: to provide summaries of research data relevant to understanding driver performance capabilities and limitations that can influence crash prevention. Both documents are intended to provide users with a quick overview of available data on a particular topic and a reference to use for finding more detailed information.

Research was identified for selection based on the following criteria:

1. The research must contain quantitative data on older driver behavior or performance or focus on behavior or performance of drivers of any age when using vehicle or roadway-based advanced technology devices. Theoretical analyses, basic research, or analyses of accident statistics unrelated to driver behavior or performance would not be included.
2. The study should have implications for motor vehicle design or highway/traffic control design.
3. The data should have been collected as part of a pilot test with very few subjects.
4. The data should not have been collected after 1986 or should have been a major effort not included in the 1987 Driver Performance Data Book.
5. The research should have been of high quality, using appropriate experimental design and controls.

There was no attempt to perform a critical review of the literature or integrate the data relative to any particular topic. The objective is simply to present data as they appear in the literature without the imposition of a reviewer's personal bias, which may or may not agree with the reader's particular bias. Users are thus encouraged to review the original source of data whenever possible.

Although a thorough search on available research was attempted, several studies may have been overlooked. In the older driver area, relevant research was difficult to find because many studies did not have older drivers specifically mentioned in the title or abstract. Instead, these studies included older drivers as subjects along with younger subjects in order to obtain data more representative of the driving population. Where possible we tried to identify and summarize the data in these studies.

In the IVHS area, three types of data were sought: 1) basic information on driver performance (e.g. reaction times, decision times) that would be useful in evaluating possible IVHS technologies; 2) measures of driver performance using specific IVHS technologies; and 3) measures of driver performance using IVHS devices. IVHS is a relatively new area and because of the proprietary nature of the technology, the latter type of data may not be available in the public domain.

Readers are encouraged to send copies of relevant research reports or journal articles not found in this circular for inclusion in future updates of this driver performance database. Information should be addressed:

Office of Crash Avoidance Research, NRD-50
National Highway Traffic Safety Administration
Washington, DC 20590

Readers are also encouraged to summarize their own relevant research in the format of this document and forward it to the above address.

OLDER DRIVERS

Driver Characteristics

AGE AND GENDER AS A FACTOR IN SEVERE AND FATAL TRAFFIC CRASHES

THE RATIO OF VARIOUS QUANTITIES AT AGE 65 TO THEIR VALUE AT AGE 40 AND AGE 20				
Variable	MALES		FEMALES	
	65/40	65/20	65/40	65/20
Number of drivers killed	.460	.123	.565	.223
Number of drivers killed per capita	.715	.291	.771	.441
Number of drivers killed per licensed driver	.755	.311	1.052	.951
Number of drivers killed per unit distance traveled	1.332	.275	1.765	.546
Estimated driver involvement in severe crashes per licensed driver	.422	.111	.676	.233
Estimated driver involvement in severe crashes per distance traveled	.734	.097	1.133	.246
Drivers involved in PED*	.328	.118	.283	.096
Drivers per capita involved in PED	.511	.279	.374	.183
Drivers per licensed driver involved in PED	.526	.286	.510	.245
Drivers per unit distance traveled involved in PED	.921	.281	.874	.252
Probability that a given death is a motor vehicle is a fatality	.088	.018	.130	.023
Longevity increase per capita if all motor vehicle fatalities eliminated	.261	.080	.348	.153
Total longevity increase if all motor vehicle fatalities to specified age eliminated	.219	.036	.408	.098

*PED = crashes (involving one vehicle) in which pedestrians were killed
Source: Evans, 1988

RESULTS

A. The severe and fatal crash experience of 20-year-old drivers was greater than that of drivers 65, for both males and females. When making the same comparisons for the 40-year-old population, driver fatalities per unit distance is greater in 65 year old individuals. In addition, 65-year-old female drivers were involved in more severe crashes and experienced more drivers killed per licensed driver than 40-year-old females. The crash experience was greater for males than for females in all age groups with one exception, 65-year-old females had a slightly higher risk of death given involvement in a motor vehicle crash.

B. When examining the data, the most notable trend is the declining distances driven for the older population in comparison to the younger drivers. The problem of the aging driver is more one of reduced mobility of that population rather than their reduced safety.

TEST CONDITIONS/PROCEDURES

Number of Subjects: Not reported
Age distribution of subjects: 20, 40 and 65 years old
Subject characteristics: Those involved in fatal crashes from 1981 to 1985.
Information was collected from several sources for analysis on the risks for older drivers and the risks they impose on others. Fatal Accident Reporting System (FARS) files provided information on traffic fatalities in the U.S. from the years 1981-1985. The U.S Census provided population by age and gender, and the Federal Highway department provided the number of licensed drivers for the year 1983. The Nationwide Personal Transportation Study provided an estimate of the distance of travel per driver for the year 1983 based on a questionnaire study conducted. Probability that a fatality results from an impact came from Evans (1988). Mortality data from the National Center for Health Statistics.
Subject tasks: Not applicable

KEY TERMS Older drivers, vehicle fatalities, gender, age, pedestrians

REFERENCE Evans, L. (1988). Older driver involvement in fatal and severe traffic crashes. Journal of Gerontology: Social Sciences, 43, 6, 186-193.

OLDER DRIVERS

Driver Response Time

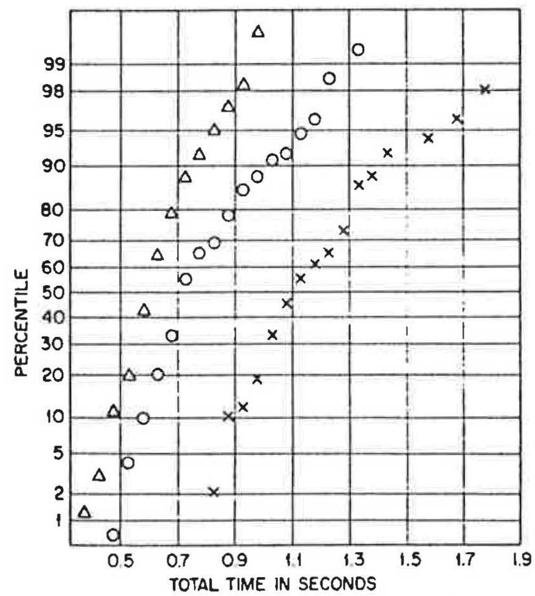


Figure 3. *Normal probability plot of total perception-response times for young subjects (X = surprise, O = alerted, Δ = brake).*

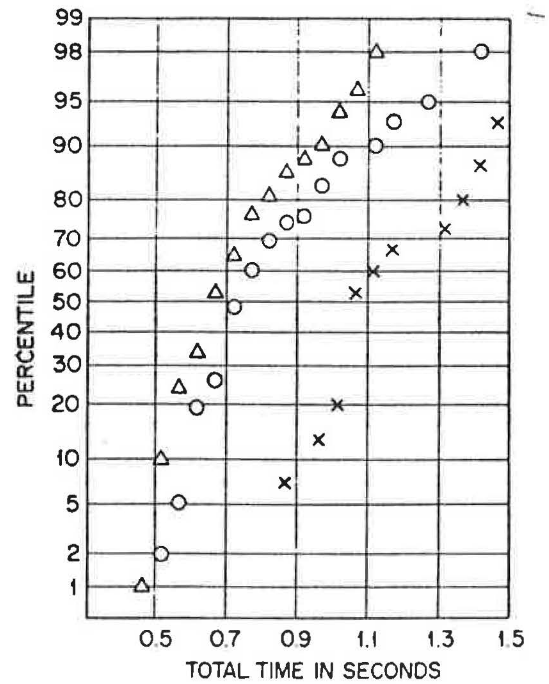


Figure 6. *Normal probability plot of total perception-response times for older subjects (X = surprise, O = alerted, Δ = brake).*

RESULTS

A. The data show found that 95% of drivers in both the young and old age groups produced a perception-response (PR) time of 1.6 seconds. This PR time was generated when drivers were confronted with an unexpected roadway obstacle when subsequently cresting a hill.

B. The results suggest that the current standard of 2.5 seconds for PR time estimate currently used in determining stopping sight distance is sufficient for all age groups. This figure is used when designing roadway geometry, for sign placement and delineation spacing. The current estimate, based on these findings, would be reasonable even with the addition of factors such as fatigue or alcohol.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 64
Age distribution of subjects: 18-84
Subject characteristics: The "young"group ranged in age from 18 to 40 and were composed of 32 males and 17 females. Those classified as "older"

were seven males and eight females ranging in age from 50 to 84.

Subject tasks: The subjects were required to complete a series of twelve trials conducted on a rural two-lane road at a set speed. The subjects were exposed to seven alerted and unaltered conditions of an impending obstacle located after the crest of a hill. Response time was collected on the elapsed time for releasing the accelerator (perception time) as well as acceleration to brake time (response time). Five additional trials were conducted to record the response time to the activation of an installed brake light attached to the hood of the test vehicle.

KEY TERMS driver, age, safety, perception, vision, reaction time, response time, hazard avoidance.

REFERENCE Olson, P.L., Sivak, M. (1986). Perception-response time to unexpected roadway hazards. Human Factors. 28(1), 91-96.

SEQUENTIAL PSYCHOMOTOR RESPONSE TIMES

Cumulative Response Latency (msec)

Control Movement	YMA n=30 Mean	YMA n=30 SD	OSS n=31 Mean	OSS n=31 SD	OCV n=20 Mean	OCV n=20 SD
Single Control	590	166	627	122	624	107
Accel-brake	1160	357	1391	524	1270	428
Accel-steer	1191	397	1359	453	1242	396
Accel-brake-accel	1661	469	1984	615	1861	521
Accel-steer-steer	1664	472	1985	516	1859	501
Accel-brake-steer	1715	424	2135	651	2009	556
Accel-steer-brake	1783	526	1958	447	1974	554

Times given for responses made without error.
YMA=young/middle-age, OSS=older, self-selected, OCV=older, cross-validation

Movement-by-Movement Latencies (msec)

Control Movement	YMA n=30 Mean	YMA n=30 SD	OSS n=31 Mean	OSS n=31 SD	OCV n=20 Mean	OCV n=20 SD
Initial resp						
2-mvmt	569	343	590	343	522	370
3-mvmt	559	369	575	352	532	399
2nd resp						
2-mvmt	775	380	981	507	865	420
3-mvmt	777	414	968	466	869	433
3rd resp						
3-mvmt	916	494	1246	595	1138	551

RESULTS

A. Response latencies for sequential control movements increase as the number of movements increase. Older and younger drivers to be functionally equivalent in the performance of predetermined single control movement responses. Older drivers showed a significant decrement in performance of 2 and 3 movements when compared to the young driver.

B. These results indicatet elderly drivers would be at a disadvantage when emergency avoidance maneuvers are performed immediately following a previous maneuver or when a sequence of control movements are required.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 81
Age distribution of subjects: 19-80
Subject characteristics: Drivers were in three groups: 30 "young/middle aged", 19-49 years of age, 31 "older, self-selected" drivers ages 65-80, and 20 "older, cross-validation" ages 65-77. Gender was approximately evenly distributed throughout. The young/middle age group and the self-selected group responded to newspaper adds, while the cross-validation group was obtained through direct contact at driver license stations. All drivers were free of visual pathology.
Subject tasks: Slides of a red ball, green ball, right blue arrow, and a left blue arrow were used to direct a response to operate the brake, accelerator, steer right, or steer left. Slides were projected on a screen directly along the drivers line of sight at a distance of six feet. Response latencies to the sequence of one, two or three slides were recorded. Slides were presented for 400 milliseconds and the interval between presentations was 50 milliseconds.

KEY TERMS Traffic control, driver, age, safety, capability, performance, display, information, sensory, perceptual, cognitive, psychomotor, vision, reaction.

REFERENCE Staplin, L., Lococo, K., Sim, J. (1990). Volume II: Traffic control design elements for accommodating drivers with diminished capacity. (Final Technical Report) U.S. Department of Transportation, Federal Highway Administration, Ketron, Inc., Malvern, PA.

OLDER DRIVERS

Driver Visual Performance

CONTRAST FOR PAVEMENT STRIPING ON CURVES

TEST GROUP	DISTANCE TO CURVE							
	100 FT				200 FT			
	No Glare		Glare		No Glare		Glare	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
YMA (n=29)	1.20	.36	2.42	1.69	1.23	.29	2.35	1.16
OLD (n=30)	1.27	.54	2.88	2.06	1.32	.51	3.25	3.05

YMA=young/middle-age, OLD=older

RESULTS

A. Contrast requirements for pavement striping used to discern direction of curves increase significantly under disability glare created by simulated on-coming headlamps. These requirements are not affected by distance. The contrast requirements of older drivers were significantly greater than those of younger and middle aged drivers.

B. These results suggest that drivers, especially older drivers, would benefit from increased brightness of pavement striping.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 59
Age distribution of subjects: 19-77
Subject characteristics: Participants were divided into two groups: 29 in the "young/middle aged" group were 19-49 years of age, and 30 were in an "older" group, 65-77 years old. Gender was approximately evenly distributed throughout. All subjects were selected via newspaper adds. No subjects were visually impaired.
Subject tasks: Four roadway scenes, projected in correct perspective, were used as test stimuli. A section of roadway was shown in the scenes foreground with right or left bearing 7^0 horizontal curves at scaled distances of 100 and 200 feet down stream. Additionally, the scene included, sky, roadway surround, pavement surface and pavement markings. Reflective values of each element of the slides were controlled, using a photometer, in order to simulate night-time conditions. Subjects were tested on determination of roadway

headings using only the stimulus scene with 100% confidence. Pavement marker brightness was varied as the experimental treatment.

KEY TERMS Traffic control, driver, age, safety, capability, performance, display, information, sensory, perceptual, cognitive, psychomotor, vision, reaction.

REFERENCE Staplin, L., Lococo, K., Sim, J. (1990). Volume II: Traffic control design elements for accommodating drivers with diminished capacity. (Final Technical Report) U.S. Department of Transportation, Federal Highway Administration, Ketron, Inc., Malvern, PA.

SIGN DISCRIMINATION DISTANCE (in meters)	
YOUNG DRIVERS (n=13) Mean SD	OLDER DRIVERS (n=7) Mean SD
53.85 8.09	41.22 5.27

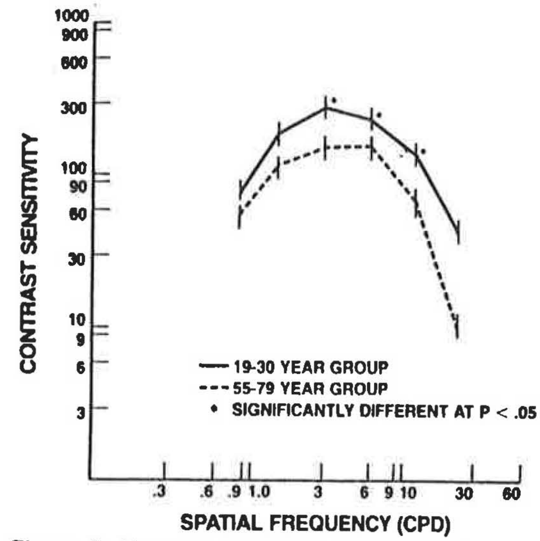


Figure 2. *Contrast sensitivity curves for two age groups. The groups have significantly different contrast sensitivities at 3, 6, and 12 cycles/deg (cpd).*

RESULTS

A. Younger drivers were capable of discriminating signs at greater distances than older drivers despite equivalent visual acuity measured using the Snellen's acuity test. Measured contrast sensitivity indicated the older driver had significantly lower sensitivity for the 3, 6, and 12 cycles per second sine-wave targets. A significant correlation was found between sensitivity to 1.5 and 12 cycles/degree and discrimination distances. This may reflect observers use of different regions of spatial information to perform the road-sign discrimination task.

B. Contrast sensitivity, rather than visual acuity, appears to be related to a driver's capability to discriminate highway signs. It is suggested that the use of contrast sensitivity could assist in the standardization of sign size and placement requirements as well as replacing visual acuity as a test for visual capability for drivers. Increasing sign size would allow the use of larger letters which would increase legibility for older drivers. Alternatively, placing signs further upstream of decision points might compensate for the reduced legibilty distances of older drivers.

TEST CONDITIONS/PROCEDURES

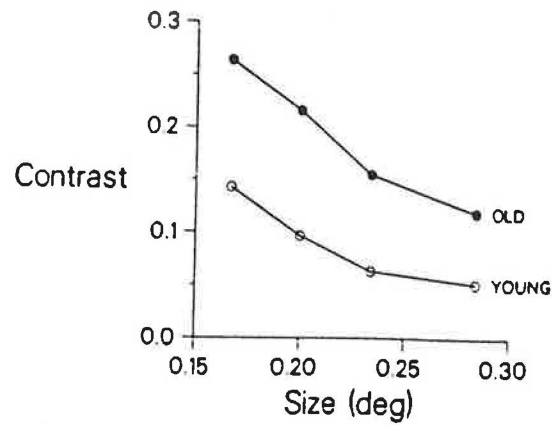
Number of Subjects: 20
Age distribution of subjects: 19-79
Subject characteristics: Volunteers were used for this study, thirteen "young" (ages 19-30), and seven "older" (55-79). Subjects compensated for participation by being given a free visual examination.
Subject tasks: Three tests were given to each participant to test the

ability to discriminate simple road signs: Snellen's visual acuity letter chart, Contrast sensitivity, and discrimination distances. Contrast sensitivity thresholds were measured using three microprocessor-controlled testers in which the observer pressed a button when the stimulus became visible or invisible. Contrast thresholds were measured using six different gratings: 0.75, 1.5, 3.0, 6.0, 12.0, and 24.0 cycles/degree. In the highway-sign discrimination task, a projected movie of an approaching road sign at 30 cd/m^2 luminance was viewed. A response button was pressed by the observer when a specific sign became discriminable, thus stopping a timer.

KEY TERMS Contrast sensitivity, vision, visual acuity, discrimination distances, road signs, age

REFERENCE Evans, D.W., Ginsburg, A.P. (1985). Contrast sensitivity predicts age-related differences in highway-sign discriminability. Human Factors, 27(6), 637-642.

CONTRAST AND COLOR OF VISUAL DISPLAYS



RESULTS

A. The brightness contrast necessary for letter recognition in normal, daytime lighting conditions, is dependant upon the letter size, color contrast with the given background, and age. Older subjects were found to require an average of 2.13 times the contrast which younger subjects needed and were not able to discriminate color differences as well. Of the six colors used, older subjects preferred green and bluegreen and disliked red and blue.

B. The average luminance levels chosen by all subjects was ideal for lettering of instrument panel displays used at night. These absolute luminance levels differed greatly between colors.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 70
Age distribution of subjects: 16-55+
Subject characteristics: Seventy licensed drivers participated in this study. Fifty-four individuals (30 female and 24 male) over the age of 55 years, and 16 under the age of 44 (6 female and 10 male) were tested.
Subject tasks: Subjects viewed three letters for 600 msec on a CRT display and were asked to identify two of the three. These letters were varied in background luminance and letter color and size resulting in 35 different combinations. The first trial was presented such that the letters and background were the same luminance. If the letters were not identifiable on the first presentation, three new letters were randomly selected for the next presentation as well as increasing the contrast by 0.03 [Contrast = (Lmax - Lmin) / (Lmax + Lmin)].

KEY TERMS Brightness, luminance, contrast, color, legibility, lettering

REFERENCE Poynter, D. (1988). The effects of aging on perception of visual displays (SAE Technical Paper Series. Passenger Car Meeting and Exposition. 881754, Oct 31-Nov 3). Dearborn, Michigan.

DISCOMFORT GLARE

Table 2. Mean Discomfort Ratings for all Subjects as a Function of Direction of Gaze

Glare (log lux at 100')	Direction of Gaze		
	Straight Ahead	At Glare Source	Right Edge of Lane
0.79	2.2	2.0	-
0.26	4.2	3.9	4.2
-0.14	6.1	5.6	-
-1.22	7.7	7.5	7.8

Table 3. Percent of trials in which subjects said they would not be willing to look into the glare to see if the turn sign were on

Glare (log lux at 100')	Age Group		Means	
	Young	Older	Percentage	deBoer Rating
0.79	87	73	80	2.0
0.26	47	37	42	3.9
-0.14	13	17	15	5.6

RESULTS

A. Ratings of glare discomfort predicted using the Schmidt-Clausen and Brindles method were lower than those obtained using the deBoer scale. This effect is primarily due to the subjects adaptation to glare, which is not taken into account by the former studies predictive equation. Discomfort ratings using the deboer scale were not significantly different as a function of direction of gaze. Although older drivers tended to rate certain glare levels as more uncomfortable than younger drivers, there were no significant differences in the willingness to look at the source.

B. Glare discomfort has proven difficult to include into models as there is currently insufficient data to be accurately included into a model. Differences between the current predictive model and field study data make it clear, however, that revisions are needed before the model can be considered descriptive of glare discomfort.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 30
Age distribution of subjects: 30-77
Subject characteristics: Two groups of subjects participated, young (30-40 years of age) and old (65-77 years of age).
Subject tasks: Five levels of glare were provided by a pair of non-halogen headlamps and neutral density filters. Separation distances between the test car and glare car were varied to distances out to 1,500 feet of separation. As the glare car was moved closer to the test car, light measurements were taken at the participants eye level. At each measurement point the subject rated the comfort of the glare using the

deBoer comfort scale and the resultant ratings put into a mathematical model of glare discomfort developed by Schmidt-Clausen and Bindels. Each glare situation was replicated three times.

KEY TERMS Headlight, night visibility, target detection, glare, older drivers.

REFERENCE Olson, P.L., Aoki, T., Battle, D., Flannagan, M. (1990). Development of a headlight system performance evaluation tool. (Final Report) National Highway Traffic Safety Administration, U.S. Department of Transportation, University of Michigan, Michigan.

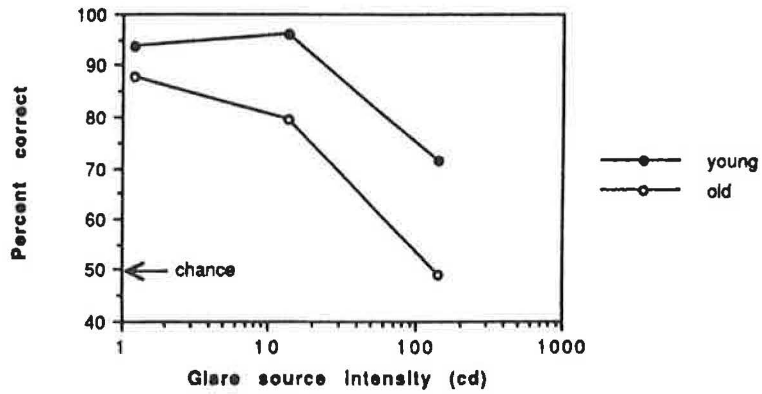


Figure 5. The interaction of age and glare source intensity for percent correct on the gap-location task.

RESULTS

A. Visual performance in target detection decreased as the reflectivity of rearview mirrors decreased. Nearly all gap judgements with high intensity glare were thought to be guesses. Low reflectivity did not decrease gap judgement confidence since they felt were guessing regardless. The effect of reflectivity on discomfort glare and its relationship with illumination at the subjects eye was not found to be predictable. No differences in performance was found for either age group.

B. It was recommended that a continuous reflectivity control be provided for electrochromic mirrors. This would allow users to have the ability to optimize viewing during high glare conditions.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 20
Age distribution of subjects: 20-77
Subject characteristics: Two groups of subjects participated: young (20-27) and old (64-77). Gender was equally divided in both groups and were tested to ensure visual acuity of 20/30 or better. All were financially compensated for their participation.
Subject tasks: Participants were seated within an automotive simulator with a rearview mirror whose reflectivity was adjustable to five settings. The participants task was to view a projection screen through the rearview mirror and identify the location, either top or bottom, of a gap within a

square. After the identification was made, a rating of 50-100 was to be given on their confidence in their decision and a rating between 1-9 on their rating of the discomfort from the glare source. A rating of 50 was the lowest permitted, and was supposed to indicate that the gap judgement was a complete guess. This scenario was repeated for a total of 30 trial consisting of three glare intensities, five mirror reflectivities, and two gap positions.

KEY TERMS Rearview mirrors, acuity, reflectivity, electrochromic, glare, discomfort glare, disability glare.

REFERENCE Flannagan, M.J., Sivak, M., Gellatly, A.W. (1990) Rearward vision, driver confidence, and discomfort glare using an electrochromic rearview mirror. (Final Report) Ichikoh Industries, Ltd., University of Michigan, Transportation Research Institute, Michigan.

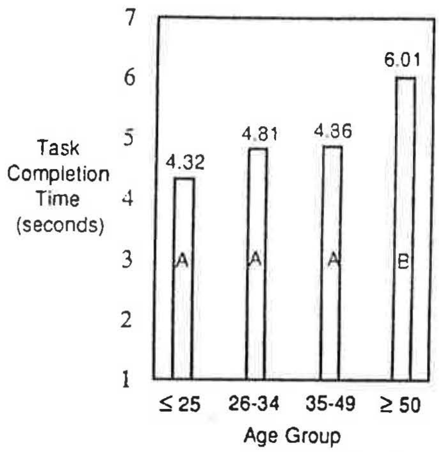


Figure 2. Task Completion Time by Age Group. Different letters indicate significant age group differences.

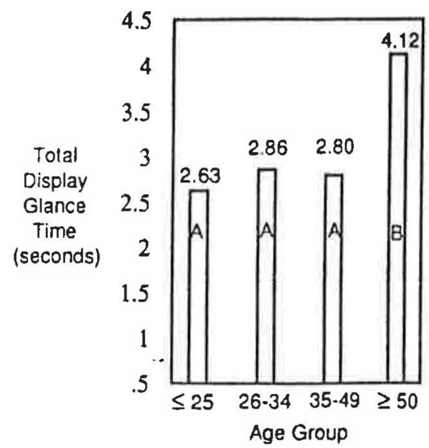


Figure 3. Total Display Glancē Time by Age Group. Different letters indicate significant age group differences.

RESULTS

A. Various measure of driver behavior were obtained while drivers performed conventional and new instrument panel taskS. For these tasks, older drivers took longer, had longer glance times, longer eye transition times, and hands-off-wheel times. Their braking times were also longer than for the younger age groups. When looking at navigational ability using various tools, no difference was found between age groups, however, older drivers required more time to extract the same information. When faced with high demand driving, all age groups of drivers responded appropriately, yet drivers over the age of 30 watched the driving scene longer than younger drivers.

When examining luminance and color, it was found that older drivers require higher luminance levels and performed poorly in reading smaller character sizes. When luminance and size were sufficient for the older drivers, the discrepancies between the age groups was eliminated thus indicating that small, low luminance displays should be avoided. Color, in relation to attractiveness and comfort, was approximately the same for all age groups.

B. Over-all it was found that older drivers are very accepting of new technology.

TEST CONDITIONS/PROCEDURES

Number of Subjects: Varied. A series of experiments were conducted over a four year period.
Age distribution of subjects: 18-73

TEST CONDITIONS/PROCEDURES

Number of Subjects: 24
Age distribution of subjects: 19-80
Subject characteristics: Participants were categorized into three groups: young (19-23 years of age), older (60-80), and European (20-37). There were eight subjects in each group, four males and four females.
Subject tasks: Subjects were asked to observe signal lamp displays and respond, as rapidly as possible after signal onset, whether the display indicated vehicle presence or vehicle braking. The displays were configured with either two separate or two combined lamps representing a single side of a display on the rear of a vehicle. The luminous intensity of the displays were presented in a counterbalance fashion. The ambient illumination was 2.2 lx, both on the lamps and at the driver's eye.

KEY TERMS Brake lamps, signal intensity, reaction time, older drivers, luminance, lighting

REFERENCE Sivak, M., Flannagan, M., and Olson, P.L. (1987). Brake lamp photometrics and automobile rear signaling. Human Factors, 29(5), 533-540.

REFLECTIVE LUMINANCE AND COLOR

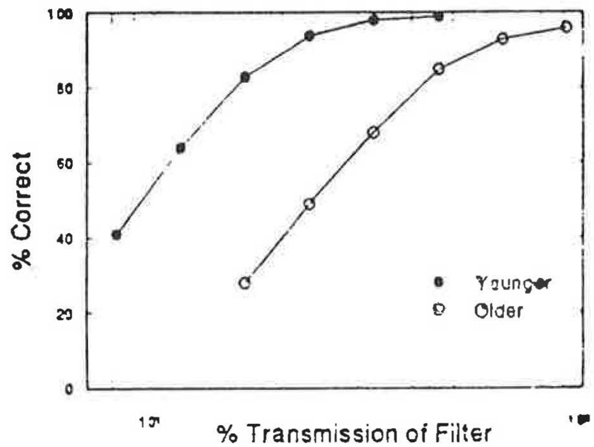


Figure 3. Percent of vehicles correctly identified for younger and older subjects.

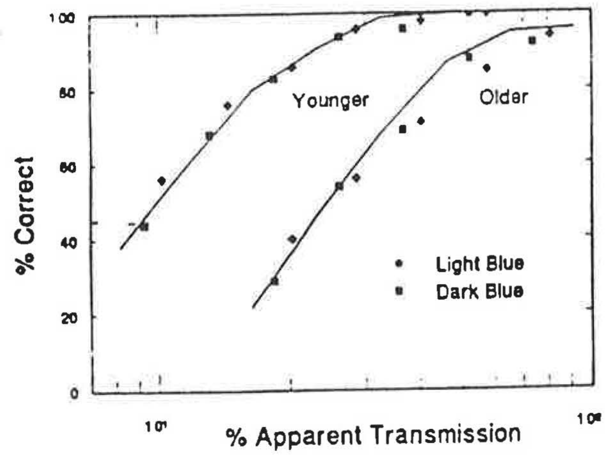


Figure 5. Performance results for blue images as a function of transmission based on the brightness of the image. Solid line is for neutral image.

RESULTS

A. The ability to locate vehicles within a rearview mirror is a function of the dominant wavelength of the mirror or target. As color purity increased, the percent accurately located also increased. Driver performance was more accurately predicted by the brightness of the image presented rather than by its luminance. Colored images which appear brighter than equal luminance neutral images also provided better performance. Images which were blue or amber were easier to locate than the neutral images of equal luminance. Older subjects required 2.5 times more transmission luminance to attain the same level of performance when identifying vehicles within a rearview mirror.

B. Refelectivity measurements using luminance will not accurately predict driver performance for other than neutral mirror for which luminance and brightness are equivalent.

TEST CONDITIONS/PROCEDURES

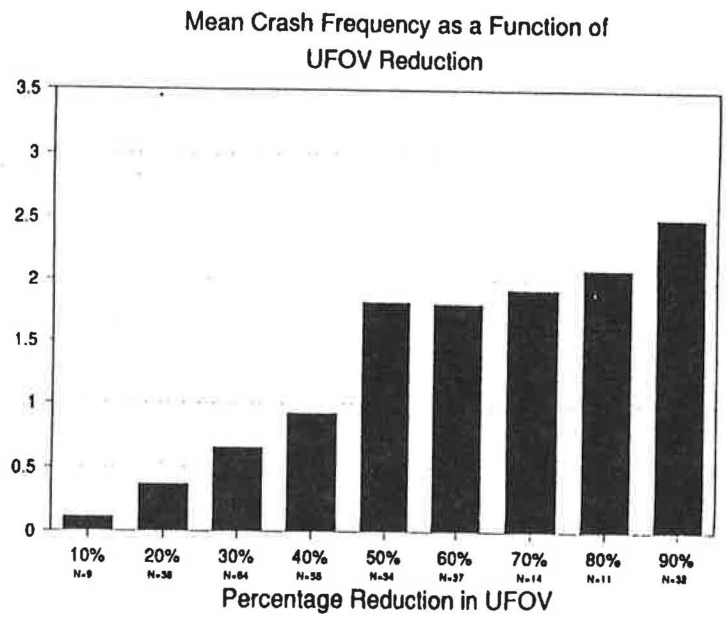
Number of Subjects: 14
Age distribution of subjects: 21-62
Subject characteristics: Licensed drivers were divided into two groups of young and old. The age in the young group ranged from 21-26 and the older group from 50-62.
Subject tasks: This study was concerned with how performance varies with the luminance and purity of two levels of three colors as well as a neutral

color within a laboratory setting. The experiments were conducted using a series of filters and mirrors to project the images onto a screen for viewing. The study was divided into two parts: the first looking at brightness, and the second at performance. Part I, brightness, required the subjects to adjust the luminance of a colored rectangle until it matched the luminance of a given neutral rectangle. Part II, performance, was designed to test the subjects ability to locate a vehicle as a function of the luminance of the vehicle. Subjects were shown a series of slides of a three lane highway which had the color and luminance varied. The task of the subject was to indicate which lane the target vehicle was located in.

KEY TERMS Luminance, brightness, reflectivity, light, color, drivers, elderly.

REFERENCE Helder, D.J. (1992). The effect of mirror color on driver performance. (SAE Technical Paper Series. International Congress & exposition). Detroit, Michigan.

USEFUL FIELD OF VIEW AND CRASH EXPERIENCE



RESULTS

A. Performance on various measures of visual and mental functioning was used to predict at-fault crash experience of older drivers. Useful field of view (UFOV) was found to contribute significantly to predictive models developed. Reductions in UFOV corresponded to increases in at-fault crashes. Subjects with great reductions (>40%) in UFOV experienced significantly more at-fault crashes than those with smaller reductions. The UFOV measure also was sensitive enough to detect 89% of those involved in at-fault crashes.

B. These results indicate that any policy to restrict driving privileges solely on age would not be well founded. Decisions on the suitability of licensure in the older population should be based on more objective performance measures. Measures of UFOV might serve as such a measure. It is also possible to improve UFOV through training. It is unknown if increases in UFOV as a consequence of training would result in reduced crash experience.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 294
Age distribution of subjects: 55-90
Subject characteristics: Participants were categorized into three crash experience and seven age groups: no crashes, 1-3 crashes, and 4+ crashes in the previous five years, and five year age groups beginning with age 55. Subjects were 136 male and 158 female licensed drivers from Jefferson

County, Alabama.

Subject tasks: Subjects were assessed for visual sensory function, mental status, UFOV, driving habits, and eye health. Visual sensory function tests measured acuity, contrast sensitivity, disability glare, stereopsis, color discrimination, and visual field sensitivity. Mental status was assessed using the Mattis Organic Mental Status Syndrome Examination (MOMSSE). UFOV was measured as a combined score of three subtasks. The first subtask (speed of processing) required the identification of a target of limited duration in the central viewing area. The second subtask (divided attention) required the identification of a target in the central area and the localization of a simultaneously presented peripheral target. The last subtask (selective attention) was similar to the second with the addition of peripheral target distractors. Peripheral targets were high contrast shapes presented at 10 to 30 degrees eccentric to the central target. UFOV was defined as the eccentricity at which a subject could localize the peripheral target correctly 50% of the time. Performance on the subtests was score from 0 (no problem) to 30 (great difficulty). These scores were combined to yield a score between 0 and 90, which represented the percentage reduction of the maximum 35 degree radius field.

KEY TERMS Older drivers, selective attention, divided attention, useful field of view, crashes, accidents

REFERENCE Ball K., Owsley, C., Sloane, M.E., Roenker, D.L., and Bruni, J.R. Visual attention problems as a predictor of vehicle crashes in older drivers. Investigative Ophthalmology & Visual Science, in press.

OLDER DRIVERS

Driver Information Processing

ACCURACY OF SPEED AND DISTANCE JUDGEMENTS

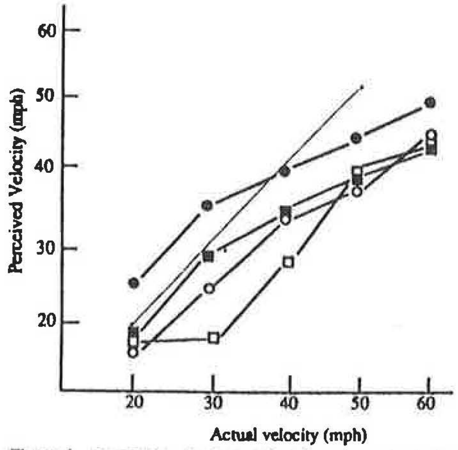


Figure 1. Perceived velocity as a function of actual velocity, age, and gender. □—□, young males; ■—■, older males; o—o, young females; ●—●, older females.

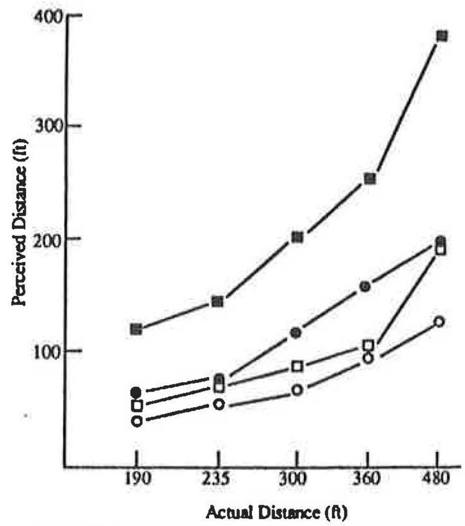


Figure 2. Perceived distance as a function of actual distance, age, and gender. □—□, young males; ■—■, older males; o—o, young females; ●—●, older females.

RESULTS

A. As the speed of approaching vehicles, simulated on videotape, increased, all observers tended underestimate speed. Older females provided better estimates than their younger counterparts. Older males tended to provide better estimates of vehicle distances than those of other subjects. However, all distance judgements were inaccurate.

B. These results suggest that inaccurate judgements of the distance and speed of an approaching vehicle might put some drivers at greater risk than others.

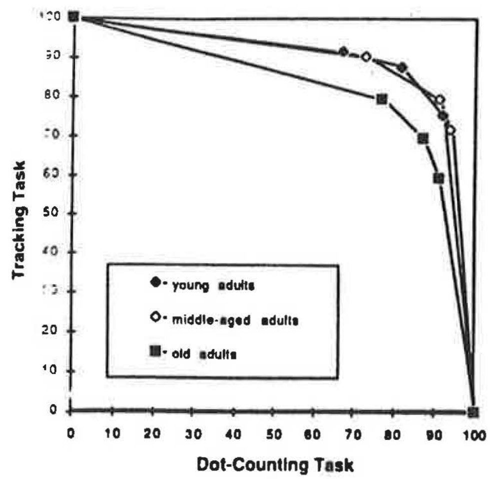
TEST CONDITIONS/PROCEDURES

Number of Subjects: 45
Age distribution of subjects: 16-79
Subject characteristics: Participants were categorized into two groups: young (16-45 years of age) and older (54-79). There were 13 males and 14 females in the young group and 9 males and 9 females in the older group. All but one of the young group were licensed drivers, and reported that they currently drove. All drivers had at least 20/40 visual acuity.
Subject tasks: Subjects were asked to watch videotaped segments of a vehicle approaching an intersection. The segments depicted the vehicle at various speeds and distances. The tapes were taken from the vantage point of a

driver waiting to cross the intersection. Each segment was 5 s in length. Subjects were asked to give verbal estimates of speed (in mph) and distance (in ft). The order of stimulus presentation was random.

KEY TERMS Speed, distance, judgements, age, older pedestrians, older drivers

REFERENCE Scialfa, C.T., Kline, D.W., Lyman, B.J., Kosnik, W. (1987) Age differences in judgements of vehicle velocity and distance. Proceedings of the Human Factors Society - 31st Annual Meeting, 558-561.



PERFORMANCE OPERATING CHARACTERISTICS: Percentage of Single Task Performance with Emphasis Changing from Left to Right -- Dual tasks emphasizing dot counting, both tasks, tracking.

RESULTS

A. Young and middle-aged drivers performed better than older drivers in a simple tracking task, while the older group proved to be more accurate with the dot-counting task. When examining dual tasks however, the older drivers exhibited a significant decline in their ability to perform dual tasks when compared to the two younger groups [$t(56) = 2.80$ & 3.11, $p<.01$].

B. These results that the ability to divide attention is reduced for the older driver. This effect is apparent when comparing the paced to self-paced results of this and previous studies. The increased anxiety in older persons when faced with a timed-task results in greater performance decrement than does self-paced tasks. This performance decrement, as previous research suggests, could effect the ability of older drivers to deal with complex, dynamic driving conditions.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 75
Age distribution of subjects: 21-80
Subject characteristics: Participants were categorized into three groups: seventeen "young" (12 male, 5 female), seventeen "middle-aged" (11 male, 6 female), and 41 "old" (38 male, 3 female). All participants were paid for their participation and were tested regarding intelligence and performance as well as visual conceptual and visuomotor tracking.
Subject tasks: Two performance tasks were administered. The first task, compensatory tracking, required the participant to "steer" a simulator in

order to keep it on a straight road as sidewinds continually pushed the them to the left or right of the road. Stable time-on-target (TOT) was recorded. The second, self-paced visual choice-reaction time, consisted of ten consecutive trials of complex dot-counting. The participants were to count the number of dots within a defined rectangular area within the video screen. This task was combined with the previous tracking task while instructions either alternated the emphasis for attention between the two (single task), or stressed accuracy while doing both (dual task).

KEY TERMS Older drivers, attention, simulation, task performance

REFERENCE Ponds, R.W., Brouwer, W.H., Wolffelarr, P.C. (1988). Age differences in divided attention in a simulated driving task. Journal of Gerontology: Psychological Sciences, 43, 6, 151-156.

DRIVER PERCEPTION OF TRAFFIC RISKS

VARIABLE	LEVEL	MEAN RISK RATING*
Country	USA	4.1
	Spain	4.8
	W.Germany	4.4
	Brazil	4.4
Age	Younger	4.1
	Middle	4.5
	Professional	4.6
	Older	4.7
Gender	Male	4.5
	Female	4.4

* 1 = Minimum Risk, 7 = High Likelihood of an Accident

RESULTS

A. Significant cultural differences were found in the risk ratings of photographic depictions of traffic scenes. U.S. subjects tended to give lowest risk ratings, while Spanish subjects gave the highest. Younger drivers in all countries reported lower risks than middle-aged or older drivers. There were no differences in the ratings of middle-aged, professional drivers and other middle-age drivers, suggesting for this age group, experience does not influence perceived risk. There were no gender differences in risk ratings.

B. Analyses indicated that certain characteristics of the traffic scenes viewed influenced cultural differences in risk ratings. Two traffic scene characteristics that differentially influenced the ratings of the age groups were road surface friction and speed. Risk ratings of older drivers were influenced more by traffic speeds than road friction, while the reverse was true of younger drivers. These findings suggest that age-related driver education or public information campaigns might be desirable.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 320
Age distribution of subjects: 19-75
Subject Characteristics: Four groups of 80 each from the U.S., Spain, West Germany, and Brazil. In each group of 80, there were 20 subjects

(10 male and 10 female) in each of four age groups: 19-21, 35-45, 35-45 (professional), and 65-75 years old. Most subjects came from urban areas and some were paid for their participation.

Subject tasks: Subjects were asked to view 100 slides of traffic scenes, half of which were taken in the U.S. from the driver's perspective, and half taken in Spain from an elevated vantage point. Subjects were asked to rate the risk associated with each slide on a seven point scale (1 = minimum risk, 7 = high accident likelihood).

KEY TERMS Risk-perception, cultural differences, age differences, simulation.

REFERENCE Sivak, M., Soler, J., Trankle, U., Spanghol, J. M. (1989). Cross-cultural differences in driver risk-perception. Accident Analysis & Prevention, Vol. 21, No. 4, 355-362.

DRIVER RISK-TAKING AT INTERSECTION CROSSINGS

INDEPENDENT VARIABLE	LEVEL	MEAN PROBABILITY OF ATTEMPT	MEAN PROBABILITY OF SUCCESS	MEAN MINIMUM CLEARANCE*
Country	USA	.64	.83	9.9
	Spain	.58	.81	10.0
	W.Germany	.50	.87	12.9
Age	Younger	.66	.82	10.0
	Middle	.55	.86	11.3
	Older	.51	.84	11.5
Gender	Male	.62	.85	9.9
	Female	.53	.83	11.9

* - given in pixels

RESULTS

A. Significant cultural differences were found in the mean probability of crossing attempts, successful crossings, and in mean crossing clearances in an intersection crossing task simulated on a VDT. U.S. subjects attempted to cross more often and had the smallest clearances. West Germans had significantly more successful crossings. Male subjects attempted to cross more often and had smaller clearances. Younger subjects attempted more crossings. There were no age or gender differences in successful crossings.

B. The results of the simulation suggest that higher target risk-levels of younger males need to be considered in intersection operations. The results also suggest that female and older subjects may need larger crossing gaps, thus increasing delay at uncontrolled intersections.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 180

Age distribution of subjects: 19-75

Subject characteristics: There were 60 subjects each from the US, Spain, and West Germany.In each group of 60, there were 20 subjects (10 male and 10 female) in each of three age groups: 19-21, 35-45, and 65-75 years old. Most subjects came from urban areas and were paid for their participation.

Subject tasks: Subjects were asked to perform simulated intersection crossings on a video display. This task involved moving a vehicle across a roadway with gaps in traffic of various sizes without crashing. The speed of movement of the cross traffic was constant at 24 mm/sec. Measures taken included probability of a crossing attempt, probability of a successful crossing, and minimum crossing clearance.

KEY TERMS Risk-taking, intersection, gap acceptance, cultural differences, simulation.

REFERENCE Sivak, M., Soler, J., and Trankle, U. (1989). Cross-cultural differences in driver risk-taking. Accident Analysis & Prevention, Vol. 21, No. 4, 363-369.

GAP ACCEPTANCE FOR MERGES

Decision Time and Accuracy for Merge Gaps

AGE GROUP	27-41 YRS	60-80 YRS	
MERGING TASK	Mean (SD)	Mean (SD)	Sign. Level
Response time in seconds	1.59 (.24)	2.42 (.59)	**
Accuracy in percent	89 (.05)	89 (.04)	n.s.

Two-tailed sign: * $p<0.05$ ** $p<0.001$

RESULTS

A. No differences were found between older and younger groups of drivers in the accuracy of estimating appropriate gaps for simulated merges into traffic. An age difference was found, however, in the time required to make these decisions. It was found that the older group needed approximately 50% more time in order to make their decisions about traffic conditions.

B. Despite the latency of response by the older drivers, if given sufficient time, they are equal in performance to other age groups. This finding indicates that the decrease in speed in mental operations is directly correlated with the level of complexity of the given task.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 56
Age distribution of subjects: 27-80
Subject characteristics: 41 older driver, 60-80, and 15 young drivers 27-41 volunteered to participate in the study.
Subject tasks: Subjects were seated in a instrumented vehicle which was parked on an exit lane of a moderately busy urban road. In response to a stimulus light on the dash, subjects were instructed to quickly look up and determine when it would be safe to merge into the traffic. This scenario was repeated for 100 trials. Stimulus-response time was collected with an inboard computer in milliseconds. A video recording of the traffic surrounding the experimental vehicle was made to provide information on the passing traffic (vehicle type, direction of movement, and any disturbing

or unforeseen situations).

KEY TERMS Older drivers, gap acceptance, merges, reaction time, judgement, traffic.

REFERENCE Wolffelaar, P.C., Rothengatter, T., Brouwer, W. (1991). Elderly drivers' traffic merging decisions. In Gales, A.G., et.al. (ed) Vision in vehicles (pp. 247-255). North-Holland, Elsevier Science.

ICON VS TEXTUAL SIGNS

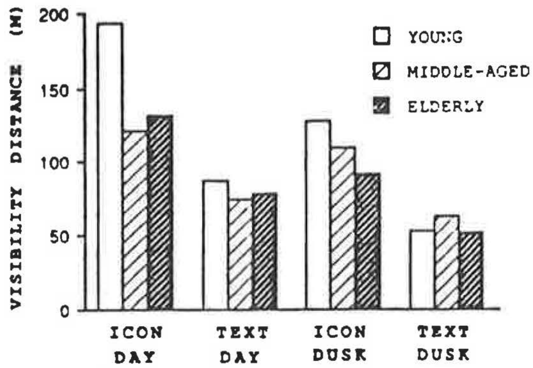


Figure 2. *Visibility distance of icon and text signs for young, middle-aged, and elderly observers under day and dusk lighting conditions.*

RESULTS

A. The visibility distance of icons were found to be much greater than those for text signs across all age groups. This distinction was even more pronounced in simulated dusk lighting conditions. Icon signs proved to be visible at half the size of their textual counterparts in virtually all signs presented. The exception to this finding was a hill sign whose values were comparable due to the large letters used in the text version.

B. A distinct advantage of icon signs would particularly benefit older persons during dusk and night time driving conditions as their vision is impaired in dim illumination. Text signs could be made comparable to icons in visibility distance by enlarging the lettering and limiting the number of words.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 16
Age distribution of subjects: 18-72
Subject characteristics: Eight male and eight females volunteered for participation. These individuals were divided into groupings of young (18-34), middle aged (45-60) and elderly (61-72 years). All had a minimum of a high school education, and were optically corrected. Driving experience ranged from 7.9 to 46.1 years for this population.
Subject tasks: Subjects were asked to view icon and text versions of four different signs provided by the U.S. Dept. of Transportation. The signs were presented at high contrast and were presented in two lighting conditions: "dusk" and "daylight". Both icon and text signs were randomly presented on a computer monitor at a size initially too small to be recognized. The size was gradually increased until the sign could be accurately described. This size was then recorded as the threshold for that sign in that given lighting condition.

KEY TERMS Drivers, older drivers, highway signs, icons, perception, illumination.

REFERENCE Kline, T.J.B., Ghali, L.M., Kline, D.W. (1990). Visibility distance of highway signs among young, middle-aged, and older observers: icons are better than text. Human Factors, 32(5), 609-619.

INFORMATION PROCESSING FOR LEFT TURN SIGNALS

TEST GROUP	CONDITION			
	PROTECTED		UNPROTECTED	
	REDUNDANT SIGN	NON-REDUNDANT	REDUNDANT SIGN	NON-REDUNDANT
	MEAN CORRECT RESPONSE PERCENTAGE			
Younger	88	78	81	76
Older	80	77	58	54
	MEAN LATENCIES FOR CORRECT RESPONSES [1,2]			
Younger	0.72 (0.62)	0.95 (0.77)	0.75 (0.53)	0.92 (0.61)
Older	0.74 (0.48)	1.11 (1.01)	1.03 (0.69)	1.33 (0.68)

1 - Time In seconds, 2 - Standard Deviation in Parentheses

RESULTS

A. Significant differences were found in the mean correct response percentages and response latencies for age, right-of-way status, and sign redundancy for slide presentations of various left turn signal and sign configurations. Young drivers were more accurate and faster to respond than older drivers. In addition, older drivers made more errors on a simultaneous tracking task while attempting to interpret the left turn signal. Signal and sign configurations preceded by a redundant supplemental sign were responded to more accurately and rapidly than signals and signs alone. Signal configurations depicting protected turns were responded to more accurately and more rapidly than those depicted in the unprotected condition.

B. The results of the simulation suggest that older drivers may benefit from the use of upstream supplemental signing of the conditions left turn signals. However, redundant signing may not be sufficient to overcome errors in interpreting signals that convey a meaning inconsistent with previous learning, such as, the green ball.

TEST CONDITIONS/PROCEDURES

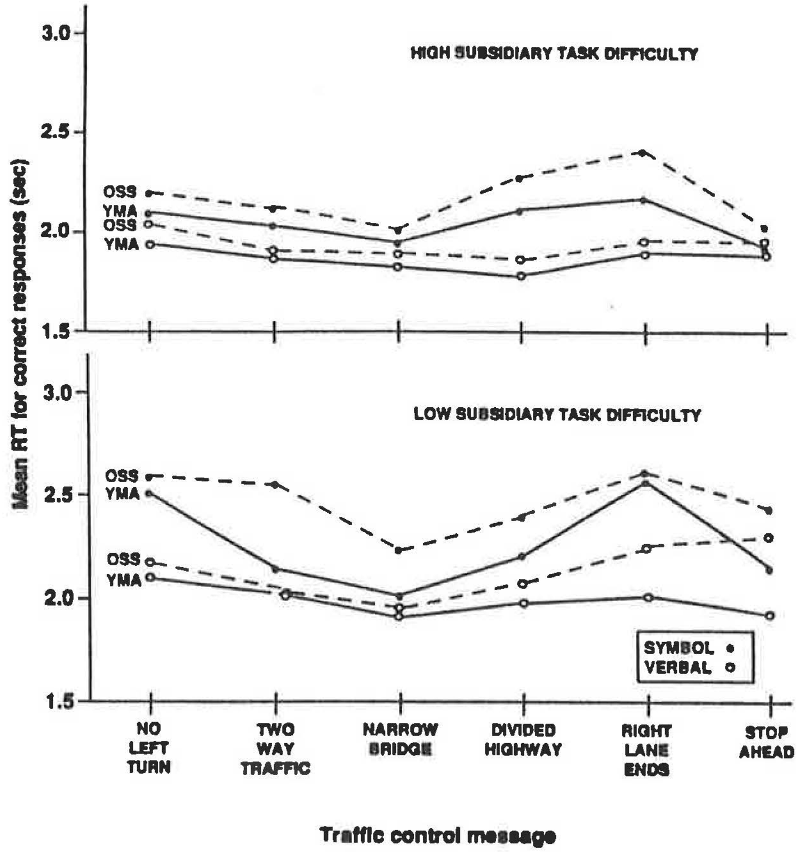
Number of Subjects: 48
Age distribution of subjects: 18-80
Subject characteristics: Licensed drivers, with no visual pathology. 24 in each of two age groups, a younger group, 18-49 years old and an older group, 68-80 years old.

Subject tasks: Subjects were asked to perform a tracking task while viewing slide displays of the approach to 24 signalized intersections. In response to a tone, subjects were asked to decide if a left turn at the intersection was protected or unprotected. This decision was indicated by foot movements from the floor to either an accelerator or brake pedal. Half of the presentations were preceded by a redundant presentation of the supplemental sign that accompanied the signal at the intersection. Also, half the signal presentations indicated a protected condition, the other half an unprotected condition.

KEY TERMS Left turn signals, older drivers, driver information processing, simulation.

REFERENCE Staplin, L., and Fisk, A. D., (1991). A cognitive engineering approach to improving signalized left turn intersections. Human Factors, 33(5), 559-579.

RECOGNITION OF VERBAL AND SYMBOL SIGNS



RESULTS

A. Drivers had significantly faster recognition times and fewer recognition errors for signs with verbal messages than symbol signs. Recognition was significantly slower for older (OSS) relative to young/middle aged (YMA) drivers for five out of six traffic control messages tested.

B. The apparent superiority of the verbal signs might be attributable to the specific task performed. Differences in recognition times between older and young drivers were measured in tenths of seconds which may be of limited practical significance. Further, it is possible that any given sign message and/or message format can be utilized as effectively by older as by young drivers, provided prior experience or training is adequate.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 58
Age distribution of subjects: 19-77
Subject characteristics: Participants were divided into two groups: 27 in the "young/middle aged" group were 19-49 years of age, and 31 were in an "older, self-selection" group, 65-77 years old. Gender was approximately evenly distributed throughout. All subjects were selected via newspaper

adds, hense the term self-selection applies to both groups. No subjects were visually impaired.

Subject tasks: Six symbol sign messages were extracted from the Manual on Uniform Traffic Control Devices: no left turn, two way traffic, narrow bridge, divided highway, right lane ends, and stop ahead. The equivalent verbal messages signs were used for comparison. Three sign slides were projected in sequence onto a simulator screen under mesopic illumination conditions. A test sign slide then followed. Subjects were asked to determine if the test sign was present in the previous sequence of three signs. Choice were made while subjects performed a tracking task with two levels of difficulty.

KEY TERMS Traffic control, driver, age, safety, capability, performance, display, information, sensory, perceptual, cognitive, psychomotor, vision, reaction.

REFERENCE Staplin, L. (1990). Volume I: Diminished driver capability and the use of traffic control devices. (Executive Summary) U.S. Department of Transportation, Federal Highway Administration, Ketron, Inc., Malvern, PA.

Staplin, L., Lococo, K., Sim, J. (1990). Volume II: Traffic control design elements for accommodating drivers with diminished capacity. (Final Technical Report) U.S. Dep artment of Transportation, Federal Highway Administration, Ketron, Inc., Malvern, PA.

SYMBOL SIGN RECOGNITION

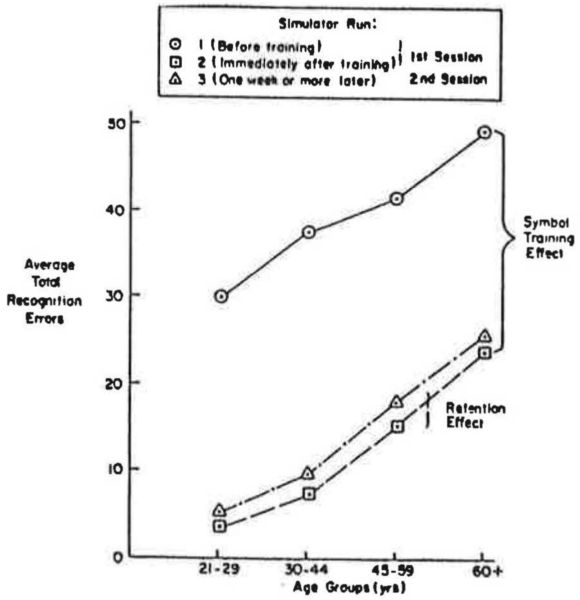


Figure 10. Total Recognition Errors Over 72 Sign Presentations; Averaged Across Each Age Group for Each Simulator Run

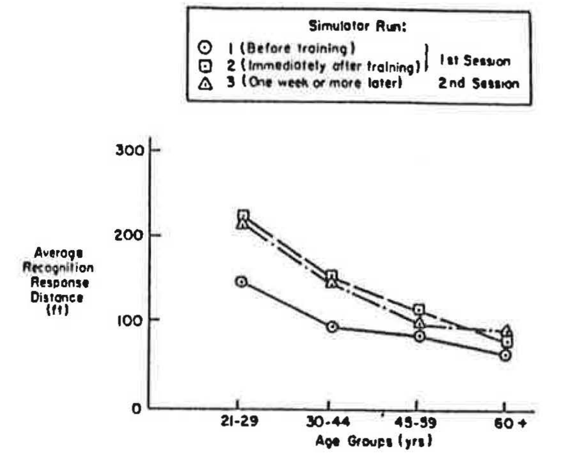


Figure 12. Recognition Response Distance Averaged Over 72 Sign Presentations; Averaged Across Each Age Group for Each Simulation Run

RESULTS

A. Recognition errors decreased for symbol signs after training. However, these errors still increased as a function of age. Symbol sign recognition distance decreased with age and significantly improved with training. Older subjects started with less knowledge of symbol signs but did not have special problems learning their meaning. Training method (education plaque, instructional pamphlet, or both) did not produce significant differences. Symbol signs recognized at greater distances tended to have simple, bold, unique graphics and have the white on blue color code.

B. It is recommended that symbol sign training be given when relicensing drivers and that sign placement account for the longer processing time required by older drivers. In addition, it is recommended that new symbol signs employ bold, simple and unique graphics.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 60
Age distribution of subjects: 21-79
Subject characteristics: Participants were categorized into three groups

corresponding to the type of training they would receive on symbol sign meaning between simulator trials one and two.

Subject tasks: Subjects were asked to drive an interactive simulator and observe and respond to symbol signs presented along a route. Signs remained visible until the driver depressed a foot switch indicating recognition. The recognition distance, the correctness of the identification, and driver's confidence in the response were recorded. In all, 72 different symbol signs were presented in a random order. There were 12 signs from each of the following categories: regulatory, warning-permanent, construction and information (informational, service, recreation). The entire task was repeated three time with training being given between trials one and two. One group was presented the symbol signs with an educational plaque on trial two, another group was given a briefing pamphlet which explained the meaning of the signs, and the third group was given the pamphlet and the supplemental plaques.

KEY TERMS Signs, symbols, sign recognition, symbol recognition, age, older drivers

REFERENCE Allen, R.W., Parseghian, Z., and Van Valkenburgh, P.G. (1980). Age effects on symbol sigh recognition. Federal Highway Administration, Washington, D.C., Report No. FHWA/RD-80/126.

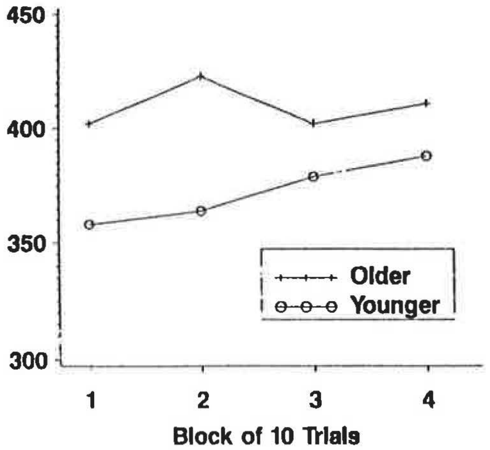


Figure 1. Mean laboratory reation times (ms) by age group and blocks of learning trials.

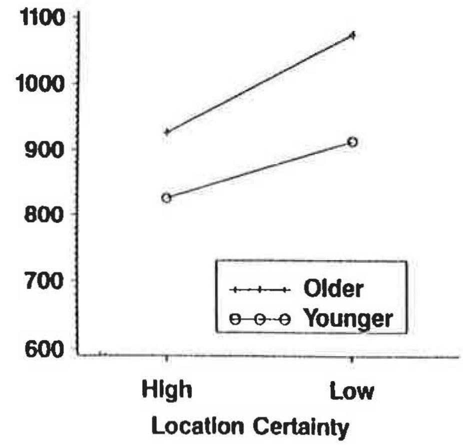


Figure 2. Mean choice reaction times by age' group and location certainty from stationary vehicle.

RESULTS

A. Reaction times of drivers to simulated lane choice decisions varied significantly with the certainty of the location of salient target information. Reaction times increased as certainty about information location decreased. Although the only significant age differences in simple and choice reaction time tasks appeared to be due to task learning, older drivers performed significantly slower on the lane selection tasks for both conditions of certainty.

B. These results indicate that the placement of traffic control devices should be predictable to all drivers. This may be especially true for changeable message signs. Scrolling messages on such signs may require additional processing time. Older drivers need more processing time than younger drivers.

TEST CONDITIONS/PROCEDURES

Number of Subjects: .30
Age distribution of subjects: 30-75
Subject characteristics: Participants with at least 10 years of driving experience and at least 20/80 visual acuity were grouped into a "low accident risk" group (ages 30 to 60) and a "increased accident risk" (ages 65 to 75). Subjects were paid for their participation. (Note: Visual acuity was uncorrected, but was considered acceptable for the task.
Subject tasks: All subjects completed three tasks: a laboratory reaction time task, a reaction time task in a stationary vehicle, and a two choice lane selection task, also in a stationary vehicle. In the lane selection task, subjects were asked to select an appropriate lane based on information

presented by either a traffic signal or a changeable message sign. In an uncertainty condition, the lane choice information could appear in either the signal or the sign.

KEY TERMS Older drivers, attention, reaction time, simulation, uncertainty, target location

REFERENCE Ranney, T.A., Simmons, L.A. (1992). The effects of age and target location uncertainty on decision making in a simulated driving task. Proceedings of the 36th Annual Meeting of the Human Factors Society, Atlanta, Ga.

OLDER DRIVERS

Pre-Crash Behavior

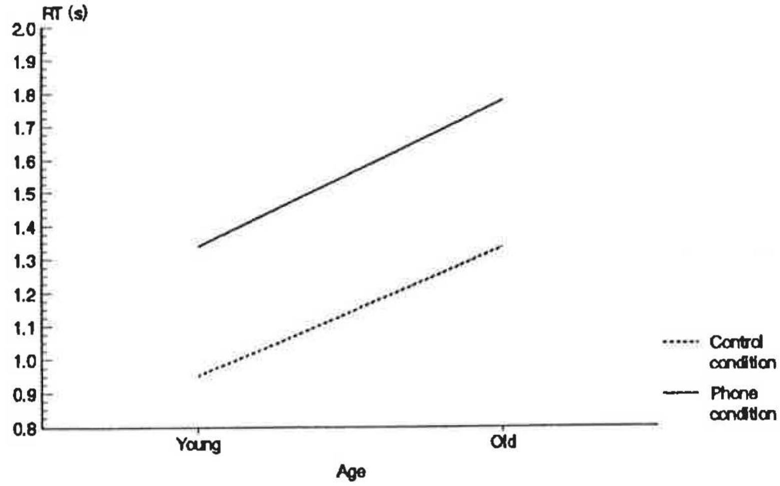


Figure 1. Simple reaction time (mean for 4 visual stimuli) as a function of experimental condition and age.

RESULTS

A. Driver reaction time to unexpected events increased with the addition of "hands free" mobile telephone operation. This increase was observed for young and older drivers. The reaction time of older drivers in both the telephone operation condition and the control condition was approximately 0.40 seconds longer than the younger driver. Older drivers also varied in their lateral position on the road more than the younger drivers who tended to move more to the right of the road and keep a steady course. Older drivers tended to rate their mental demand higher when using the mobile phone than the young group and compensated for it by lowering their speed.

B. It is recommended that the design of mobile phones be changed to add functions to the phone systems to assist drivers in delaying ringing and answering. Intelligent phones should have knowledge of traffic conditions which may prove to be too risky to introduce an added distraction and would instead, delay a phone call, or prompt the driver to reduce their speed.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 20
Age distribution of subjects: 60-70
Subject characteristics: There were 10 male and 10 female subjects randomly assigned to treatment and control groups. All subjects were licensed drivers who drove at least 10,000 km/yr. All subjects were financially compensated for their participation. Additional data from young subjects was obtained from a previous study.

Subject tasks: A driving simulator was used to produce road conditions that might be experienced when driving a vehicle. Subjects were seated in a Volvo 740 stationed on the simulator and viewed a simulated two-lane road with horizontal and vertical curves. The subjects task was to simulate driving and operate a phone. Once the phone rang, subjects were required to answer and solve the puzzle presented (Working Memory Span Test), and brake as fast as possible when a red square appeared on the simulator screen.

KEY TERMS Older drivers, reaction time, workload, secondary tasks.

REFERENCE Nilsson, L., Hakan, A. (1991). Effects of mobile telephone use on elderly drivers' behaviour-including comparisons to young drivers' behaviour ISSN 0347-6049). Swedish Road and Traffic Research Institute, Linkoping Sweden.

VEHICLE CONTROL LOCATION EXPECTANCY

CONTROL	LOCATION TIME					
	Vehicle A		Vehicle B		Vehicle C	
	Age Group: Y	O	Y	O	Y	O
Air vent	1.4	3.8 (.02)	1.6	4.0	1.7	5.8 (.02)
Ashtray	1.4	2.3 (.02)	2.3	2.5	3.1	3.9
Battery dspl	1.3	3.8 (.001)	1.9	3.0	1.9	1.9
Cigarette litr	3.2	6.4 (.02)	2.7	2.9	5.9	6.1
Climate cntl	1.8	3.9 (.001)	2.0	3.0	2.7	4.3
Door lock	2.5	3.4	2.0	2.1	1.8	2.2
Emergency brk	1.4	2.0 (.03)	2.2	2.2	1.4	1.9
Eng temp	2.8	2.7	4.0	7.1	9.6	7.5
Hazard flash	7.1	5.9	4.0	6.2	+	+
Headligh sw	2.3	4.7 (.03)	4.0	6.5	2.2	7.8 (.001)
Dimmer sw	6.6	7.2	3.3	4.5	11.7	13.0
Hood release	4.2	5.6	4.8	4.4	+	+
Horn	1.4	1.7	2.0	2.5	1.4	1.9
Oil press	1.3	1.8	1.8	1.8	1.6	2.2
Radio	1.2	2.4 (.009)	1.8	2.6	2.2	8.3 (.002)
Speedometer	0.8	1.5 (.01)	0.9	2.4 (.003)	1.5	1.9
Window cntl	1.5	2.6 (.01)	1.9	2.0	2.4	1.9
Wndshld wpr	1.4	3.6	2.3	3.8	4.4	14.0 (.03)

Y=young, O=older
(Value) if p>=.05
+:no subjects found control w/in 60 sec. limit

RESULTS

A. Drivers have strong location expectations for many controls, and that their expectations mirror common locations found in most vehicles. Older drivers had essentially the same location expectancies as the younger participants. Location expectancies did have an effect on location times for people when they are in an unfamiliar vehicle.

B. Although no substantial differences in location expectancies were found between older and younger participants, older drivers were generally slower at locating controls and displays in unfamiliar passenger cars. Analysis of the data showed that older drivers were slower at locating 30% of the controls. Average times to locate controls in three test cars were significantly and substantially different. This indicates that different display and control layouts impose different attention "loads" on drivers as they search for a control or display.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 38
Age distribution of subjects: 19-87
Subject characteristics: Two groups of drivers, 16 young adults (ages 19-27) and 22 older adults (ages 60-87). No physical or visual handicap. All subjects were paid $30 for their participation.

Subject tasks: Subjects were first asked to locate eighteen different displays and controls on various control panel diagrams. Next, after practicing in their own vehicles, subjects were asked to locate the eighteen controls and displays in three different passenger cars. Subjects were given the task of identifying a visual target and timed while locating specific control and displays. Presentation order of the location target was counterbalanced as was the order of vehicles.

KEY TERMS Driver, age, display, controls, information, cognitive, vision, expectation

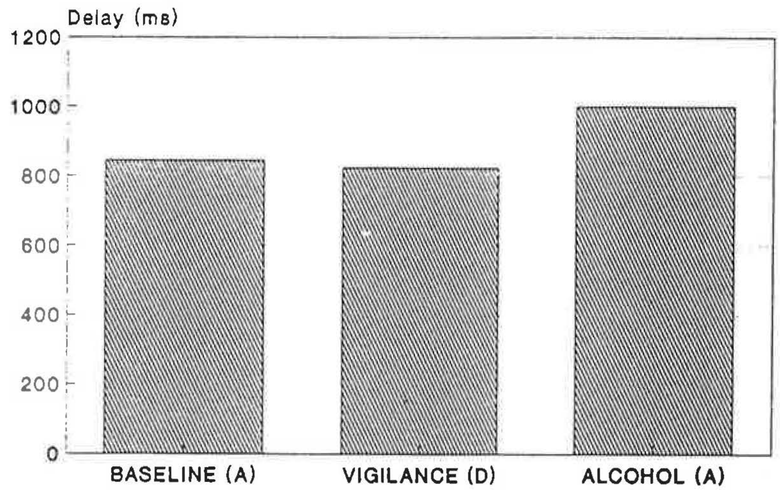
REFERENCE Laux, L.F., Mayer, D. (1991). Locating vehicle controls and displays: effects of expectancy and age. (Final Report). AAA Foundation for Traffic Safety. Rice University, Human Factors Laboratory.

IVHS RELATED

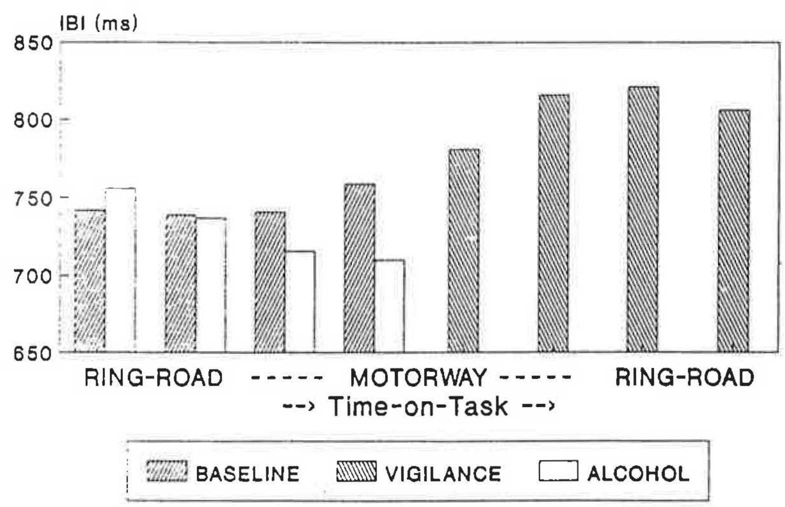
Driver Response Time

CHANGES IN DRIVER PERFORMANCE AND STATUS WITH LOW B.A.C. AND TIME ON TASK

A. CAR-FOLLOWING REACTION DELAY



B. PULSE INTERBEAT INTERVAL



RESULTS

A. The graph shows mean latency in response to speed change of a lead vehicle, for baseline, time-on-task, and alcohol (0.04%) conditions. The increase due to alcohol approaches significance.

These results suggest that a car following task, where subjects are instructed to maintain a constant headway, is sensitive to moderate alcohol dosage, but not sensitive to time on task. Such results could potentially be used in driver performance/status monitoring.

Other findings in the paper show the effects on lane position and steering wheel standard deviation. Lateral deviation-increased with time on task, and it increased with alcohol. Steering wheel standard deviation increased with time on task, but not with alcohol.

B. The graph shows that interbeat interval (which when properly scaled is the inverse of pulse rate) increased with time on task, but decreased somewhat with alcohol. In other words pulse rate gradually decreased with time on task and gradually increased as alcohol level in the blood decreased.

Other findings in the paper show the effects on EEG's (which were not as pronounced) and on lateral deviation (which increased during the time-on-task segment.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 20
Age Distribution of Subjects: 25-40
Subject Characteristics: Dutch males with at least 5 years of driving, and driving at least 5000 km per year.
Healthy and having normal wake/sleep cycles.
Subjects Tasks: Normal driving in sequence:
car following, quiet motorway, moderate motorway, and then car following again.
For alcohol, only the two car-following portions were performed. For time-on-task, all four parts were performed.

KEY TERMS

ALCOHOL, DRIVER PERFORMANCE, DRIVER STATUS, DRIVING TASK, DROWSINESS, FATIGUE, TIME ON TASK

REFERENCE

deWaard, D. and Brookhuis, K. A. (1991) Assessing driver status: a demonstration experiment on the road. *Accident Analysis and Prevention, 23*(4), 297-307.

PERCEPTION-REACTION TIMES IN EMERGENCIES

A. BRAKING TIME COMPONENTS FOR OBSTRUCTION IN ROADWAY (SECONDS)

Driver Perception Time			Driver Reaction Time			Vehicle Braking Resp. Time (wheel lockup)		Total	
Mean	S.D.	99th % tile	Mean	S.D.	99th % tile	Mean	S.D.	Mean	99th % tile
0.56	0.16	0.90	0.28	0.10	0.58	0.12	0.03	0.96	1.60

B. STEERING TIME COMPONENTS FOR OBSTRUCTION IN ROADWAY (SECONDS)

Driver Perception-Reaction Time		Time until Vehicle Abreast of Target
Mean	99th % tile	
1.00	1.80	2.4

RESULTS

A. The results show the components of brake reaction time for a simulated obstruction raised in the roadway when the subject's vehicle is 40 m away. Speed was 60 km/h. Results are for practiced nighttime driving on a two-lane road.

The results suggest that the current design criterion of 2.5 seconds is conservative, since the 99th percentile response (obtained by fitting the normal distribution) was 1.60 seconds, including wheel lockup time. However, results are for alerted drivers who repeated the test several times.

B. The results show the perception-response time for avoidance (steering) maneuvers for the same simulated obstruction and test conditions.

The results again suggest that the design criterion of 2.5 seconds is conservative. However, once again, subjects were alerted and practiced.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 40
Age Distribution of Subjects: Groups of approximately equal size under 35 years and over 35 years.
Subject Characteristics: Licensed Canadian drivers. Roughly equal numbers of males and females in each group.

Subject Tasks: Subjects drove a closed course and were tested a maximum of 5 times in brake reaction tasks. They were instructed to brake for targets in some runs and to steer around them in others. There were four possible "pop-up" target locations, unknown to the subjects.

KEY TERMS

ACCIDENT RECONSTRUCTION, BRAKING TIME, DRIVER PERCEPTION-REACTION TIME, EMERGENCY MANEUVERS, HIGHWAY DESIGN, RESPONSE IN EMERGENCIES, RESPONSE TIME

REFERENCE

Wilson, F. R., Sinclair, J. A., and Bisson, B. G. (1989). Evaluation of driver/vehicle accident reaction times. Fredericton, N.B., Canada: University of New Brunswick, The Transportation Group (January).

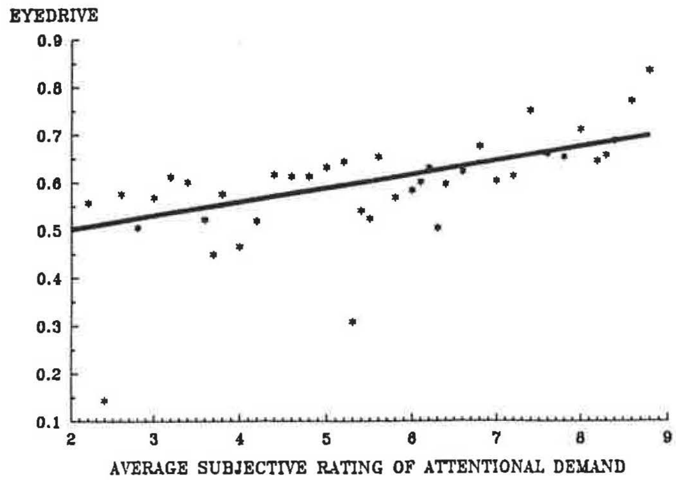
IVHS RELATED

Driver Visual Performance

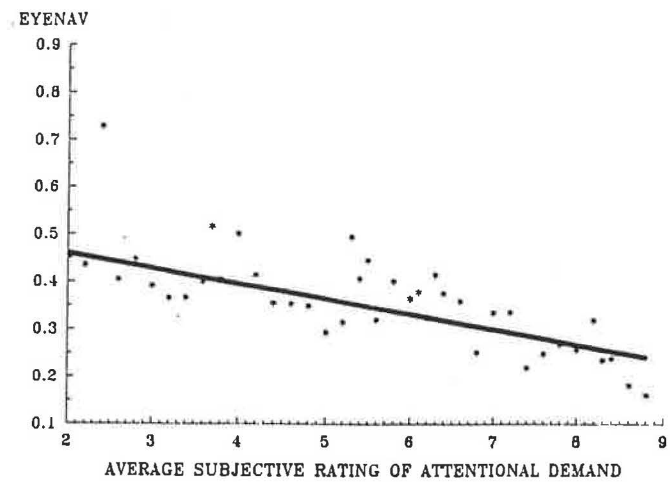
DRIVER ADAPTATION TO HIGH VISUAL-DEMAND DRIVING SITUATIONS

A. ROADWAY DEMAND EFFECTS

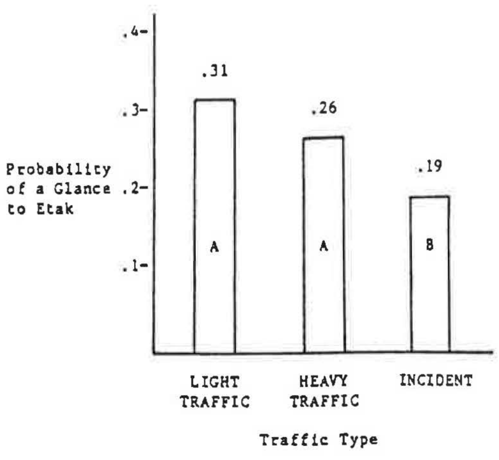
(a)



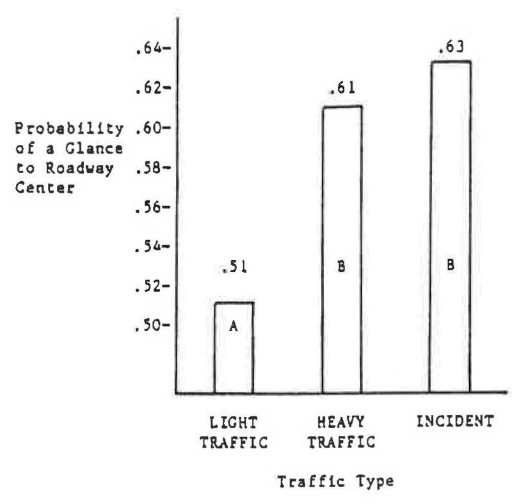
(b)



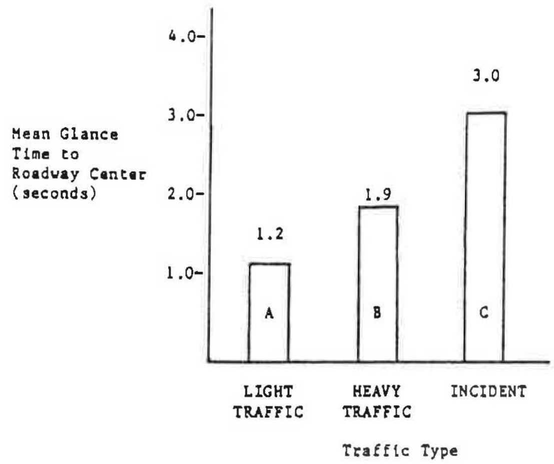
B. TRAFFIC DEMAND EFFECTS



(a)



(b)



(c)

RESULTS

A. The results are for drivers using an in-car computerized moving-map navigation system while driving. The abscissa of both graphs is the average rating of the attentional demand of individual roadway segments by expert raters. (Scale descriptors, numbered 1 through 9, were cast in terms of amount of time the eyes could be off the road. The value 9, for example indicated that eyes could not be taken off the road even for an instant.) The ordinate in (a) is the proportion of total time over each segment that the driver's eyes are on the roadway, mirrors, and speedometer. The ordinate in (b) is the proportion of total time over each segment that the driver's eyes are on the navigation display.

   The results show that as the attentional demand of the roadway increases, the driver shifts visual emphasis in a more or less linear fashion toward the driving task and away from the navigation display. The slopes of the regression lines in (a) and (b) are approximately the same in magnitude and opposite in sign.

   The results indicate that drivers do indeed adapt their visual resources to account for increases in roadway demand. The visual resources needed for driving are taken from the navigation task.

B. The results are for drivers using an in-car navigation system in traffic. The independent variable in all three cases is traffic type, that is, low traffic volume, high traffic volume, and incident. An incident was defined as a situation in which a conflict could arise with another vehicle or a pedestrian. Such situations ordinarily demand careful monitoring by the driver.

   The results in (a) show that the probability that the drivers' eyes were on the central forward view was greater when traffic was heavy and when an incident was in progress. These cases produced significantly higher probabilities than the low traffic situation.

   The results in (b) show the opposite effect for the probability that the eyes are on the navigation display. In this case, the light and heavy traffic probabilities differed significantly from the incident probability, with a decreasing trend from light traffic through heavy traffic and then to incident.

   In (c) mean glance length is shown to increase markedly from light traffic to heavy traffic, and then again to incident, indicating that drivers watch carefully in heavy traffic and incident conditions. The glance lengths for the three conditions are significantly different from one another.

These results, taken together, demonstrate adaptation on the part of drivers in which visual resources are apportioned to the forward view as needed to handle observation of heavy traffic and incidents.

In terms of IVHS applications, the results suggest that drivers do rationally adjust their visual resources as needed toward driving demands. However, as the authors point out, there is variability in the data and every effort must be made to minimize in-vehicle visual resource demands.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 24
Age Distribution of Subjects: Three equal size groups: 18 to 31, 31 to 44, and 45 or older.
Subject Characteristics: Licensed American drivers. Equal numbers of males and females in each age group.
Subject Tasks: Subjects were first trained using the in-car navigation system. They then drove to an unknown destination over a road having very low traffic density and having large variations in rated attentional demand. Thereafter they drove to a second unfamiliar destination passing through low traffic and high traffic areas where incidents were likely to occur. In all, 135 incidents occurred, and these were matched with equal numbers of low and high traffic data segments.

KEY TERMS

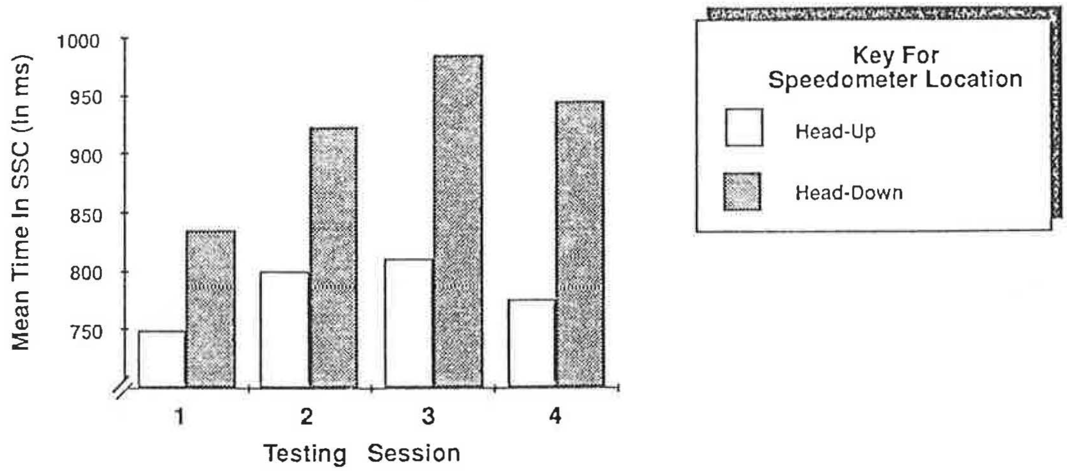
COMPUTERIZED NAVIGATION, DRIVER ADAPTATION, DRIVER ATTENTIONAL DEMAND, DRIVER WORKLOAD, INSTRUMENT PANEL DESIGN, IN-VEHICLE NAVIGATION, IVHS, MOVING MAP DISPLAYS, VISUAL DEMANDS

REFERENCE

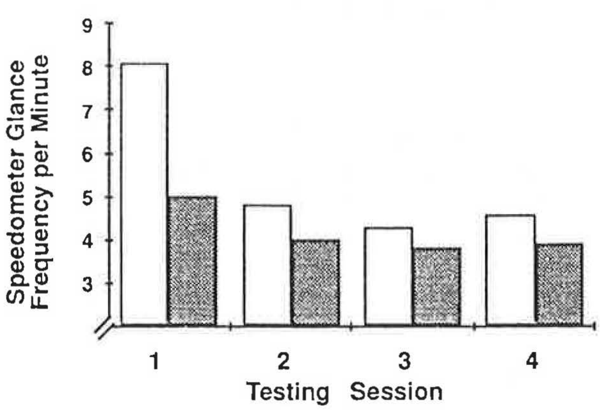
Wierwille, W. W., Hulse, M. C., Fischer, T. J., and Dingus, T. A. (1988). Strategic use of visual resources by the driver while navigating with an in-car navigation display system. Warrendale, PA: Society of Automotive Engineers (SAE). *XXII FISITA Congress Technical Papers, Vol. II*, SAE Publication No. P-211 (October), pp. 2.661 to 2.675. (SAE Paper No. 885180).

COMPARISON OF DRIVER PERFORMANCE WITH HEAD-UP AND HEAD DOWN SPEEDOMETERS

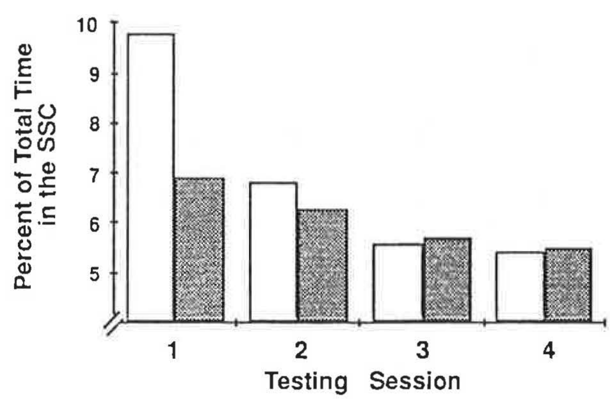
A. MEAN SPEEDOMETER SCANNING CYCLE (SSC) TIME



B. SPEEDOMETER GLANCE FREQUENCY AND TOTAL SAMPLING TIME



(a)



(b)

RESULTS

A. The graph shows how SSC changes with type of speedometer (Head-up/Head-down) and practice. Both the head up and head down speedometers were digital. SSC is the sum of three times: eye transition time from the forward view to the speedometer, speedometer dwell time, and return transition time to the forward view. The graph demonstrates very clearly that the head-up speedometer produces shorter SSC times.

B. The graph in (a) shows that drivers initially sample the head-up speedometer more often than the head-down speedometer. However, with practice the differences are reduced.,

The graph in (b) shows the percent of total time in SSC as a function of speedometer and practice. The trend is similar to that for glance frequency, with longer SSC's initially for the head-up condition. However, with further practice, percent times in SSC's for head-up and head-down speedometers converge.

The results taken together show that the total amount of visual demand (graph in B (a)) is nearly equal for head-up and head-down speedometers. Thus, there is no clear-cut demonstrated safety advantage for either type of speedometer. However, samples are shorter, as shown in A, and the drivers eyes remain closer to the forward view when using the head-up speedometer.

Other results in the paper show that there were no significant differences in speed maintenance, suggesting that performance is about the same for head-up and head-down speedometers.

TEST CONDITIONS/PROCEDURES

Number of subjects: 8
Age Distribution of Subjects: 4 subjects in the younger group (19 to 22 years) and 4 subjects in the older group (64 to 69 years).
Subject Characteristics: Ordinary American drivers without head-up display experience. The number of males and females in each group was equal.
Subject Tasks: Subjects drove an instrumented vehicle in four separate 90-minute sessions. Each session involved driving through a public park with very low traffic levels. The circuit within the park was six miles long and was repeated several times. Head-up and head-down sessions were counterbalanced. (It should be noted that during the head-up sessions, the head-down speedometer remained operative (viewable), but not vice versa. These conditions were used because they mimicked production-vehicle configurations.)

KEY TERMS

DIGITAL SPEEDOMETERS, DRIVER ATTENTIONAL DEMAND, DRIVER PERFORMANCE, HEAD-UP DISPLAYS, IN-VEHICLE DISPLAYS, READING PERFORMANCE, VISUAL DEMANDS, WORKLOAD

REFERENCE

Kiefer, R. J. (1991). Effects of a head-up versus head-down digital speedometer on visual sampling behavior and speed control performance during daytime automobile driving. Warrendale, PA: Society of Automotive Engineers (SAE), Paper No. 910111, presented at the International Congress and Exposition, Detroit, MI (February).

COMPARISON OF PERCEPTUAL TASK PERFORMANCE WITH HEAD-UP AND HEAD-DOWN SPEEDOMETERS

COMPARISONS OF SALIENT CUE DETECTION

RESPONSE TIMES AS A FUNCTION OF SPEEDOMETER LOCATION

(a)

	Speedometer Display Condition	
	Head Down	Head Up
Missed cues omitted		
Means (s)	1.01 (A)	0.57 (B)
SD	0.47	0.16
Missed cues included*		
Means (s)	1.16 (A)	0.65 (B)
SD	0.53	0.30

Means with the same letter are not significantly different ($\alpha = 0.01$).
* These means include missed cue data, which were each conservatively recorded as 3.0 s.

RESPONSE TIMES AS A FUNCTION OF CUE LOCATION

(b)

	Salient Cue Location		
	Left	Center	Right
Missed cues omitted			
Means (s)	0.93 (A)	0.61 (A)	0.83 (A,B)
SD	0.54	0.18	0.38
Missed cues included*			
Means (s)	1.10 (A)	0.61 (B)	1.00 (A)
SD	0.63	0.18	0.45

Means with the same letter are not significantly different ($\alpha = 0.01$).
* These means include missed cue data, which were each conservatively recorded as 3.0 s.

RESULTS

(a) The results show that drivers took only half as long, on the average, to detect and respond to a salient cue in the driving scene when using a head-up digital speedometer (as compared with a head-down digital speedometer).

In the "missed cues omitted" case, data for missed detections have been deleted. In the "missed cues included" case, data for missed detections have been included by conservatively specifying missed response times at 3.0 seconds.

The salient cue used was a ball appearing in the simulated visual scene. Subjects performed three tasks simultaneously. They determined when the simulated vehicle deviated from the correct (previously memorized route); they determined when the displayed speed was more than 5 mph above the posted speed; and, they performed the ball (salient cue) detection task.

(b) The results show the main effect of salient cue location on response time, averaged over head-up and head-down runs. The results demonstrate clearly that cues in the straight ahead location are detected more quickly than those off to the right or left.

Other results in the paper suggest that salient cues are less likely to be missed completely with the head-up speedometer than with head-down speedometer (3 out of a possible 90 vs. 9 out of a possible 90). Also, speed violations are less likely to be missed for the head-up speedometer (zero out of a possible 90 vs. 7 out of a possible 90).

These results taken together suggest that detection of hazardous events is substantially faster when using a head-up speedometer and that missed detections are less frequent.

TEST CONDITIONS/PROCEDURES

Number of subjects: 20
Age Distribution of Subjects: 19 to 51 years; means of 30.
Subject Characteristics: Licensed American drivers with 20/40 or better far visual acuity, corrected when necessary. Subjects were divided into two groups, each group containing five males and five females.
Subject Tasks: Subjects sat in a fixed-base open-loop simulator composed of a video projector displaying a roadway scene with occasional salient cues, and head-up speedometer (for those corresponding runs), and a closer computer display (for the head-down speedometer conditions). Subjects watched the displays as they performed the three tasks described earlier. The first group received the head-up speedometer condition, and the second the head-down condition.

KEY TERMS

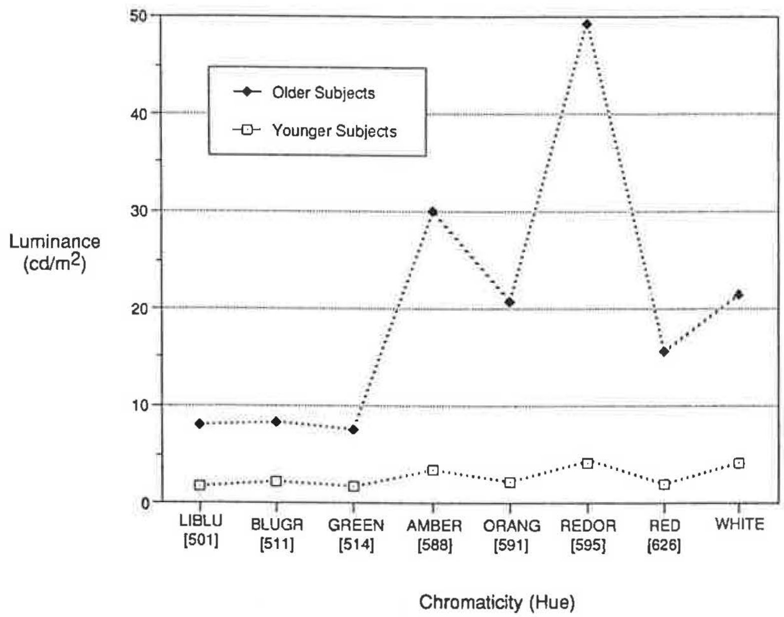
DIGITAL SPEEDOMETERS, DRIVER PERFORMANCE, HAZARD DETECTION, HEAD UP DISPLAYS, IN-VEHICLE DISPLAYS, VISUAL DEMANDS, WORKLOAD

REFERENCE

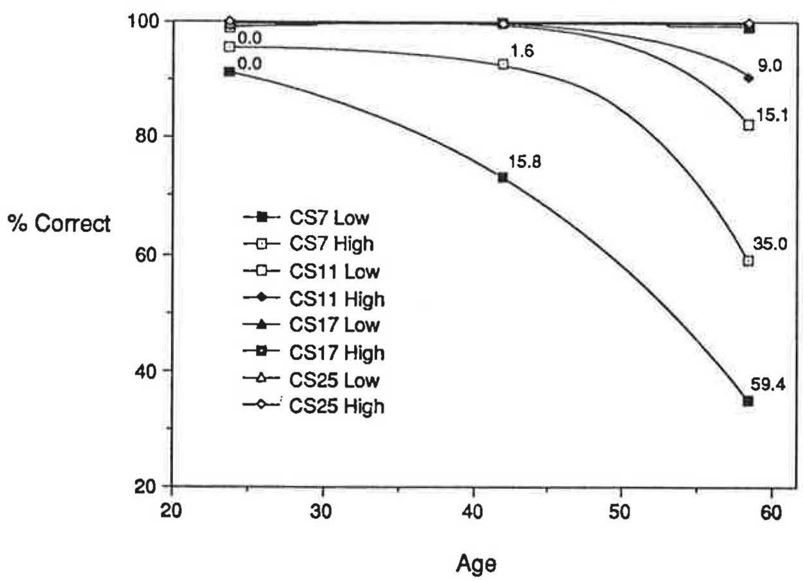
Sojourner, R. J. and Antin, J. F. (1990). The effects of a simulated head-up display speedometer on perceptual task performance. *Human Factors, 32* (3), 329-339.

CHROMATICITY, AGE, AND CHARACTER SIZE EFFECTS IN AUTOMOTIVE INSTRUMENT PANEL DESIGN

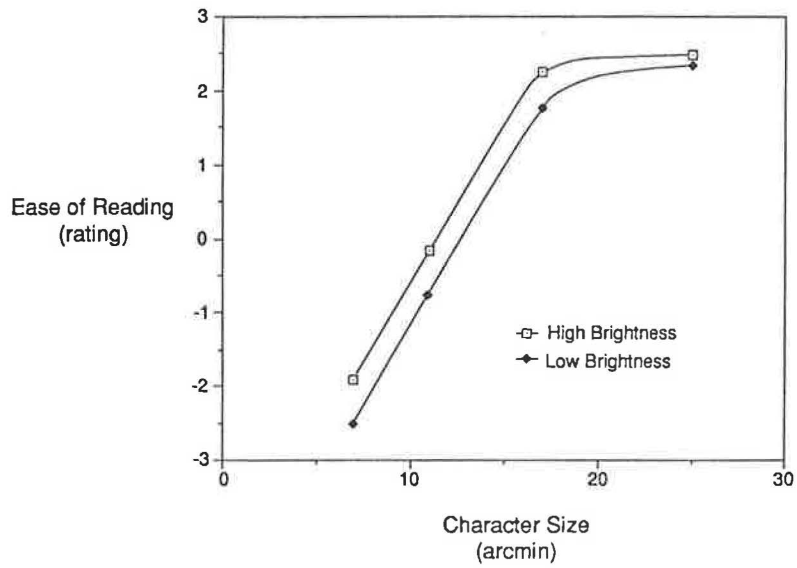
A. LUMINANCE NEEDED AS A FUNCTION OF CHROMATICITY AND AGE



B. EFFECT OF CHARACTER SIZE AND BRIGHTNESS ON PERFORMANCE



C. EFFECT OF CHARACTER SIZE AND BRIGHTNESS ON EASE OF READING



RESULTS

A. The results show that, to achieve desired brightness, luminance level must be changed as a function of the dominant wavelength (shown in brackets) when using legends having character height of 15 min. of arc. The results also show that older drivers require much higher levels of luminance than younger ones, and that this effect is most pronounced for the warmer (reddish) colors.

The results are important for instrument panel design because they indicate the desired range of equivalent legend luminance for nighttime driving as a function of the color of the illumination.

B. The results indicate that character size and age interact in terms of legend reading accuracy. In the graph, CS7 corresponds to 7 min character height, CS11 to 11 min height, etc. "Low" and "high" refer to brightness and correspond to the two luminances at each color in A. (There was little variation in performance as a function of color for the luminance shown in A.) Numbers next to points on the graph correspond to per cent of all presentations in which subjects did not (could not) respond.

C. The results show mean subjective ratings (on a seven point scale centered at zero) for ease of reading. The graph shows that subjects found the 7 and 11 minute legend heights difficult to read and that lower brightness resulted in somewhat lower ratings.

The results shown in B and C suggest that character heights greater than 11 min of arc should be used, preferably 15 min or greater. Using the smaller size degrades the reading performance of older drivers and makes the reading task subjectively more difficult for all drivers.

TEST CONDITIONS/PROCEDURES

Number of subjects: 40 (16 for results in A, 24 for results in B and C)
Age Distribution of Subjects: A: two equal-size groups; 16 to 27 years and 52 to 69. B: three equal-size groups; 19 to 30 years, 31 to 50, and 51 to 73.
Subject Characteristics: American drivers with minimum 20/40 static visual acuity, corrected if necessary, and with normal color vision. The number of males and females in each age group was equal.
Subject Tasks: A: subjects sat in a "parked" simulator under simulated nighttime roadway luminance conditions and adjusted legend brightness (using a psychophysical procedure) to the brightness they preferred. B: Subjects drove a computer-controlled moving-base simulator while they read aloud legends presented on two variable legend displays.

KEY TERMS

DISPLAY DESIGN, DRIVER ATTENTIONAL DEMAND, INSTRUMENT PANEL DESIGN, INSTRUMENT READING PERFORMANCE, IN-VEHICLE DISPLAYS, VISUAL DEMANDS

REFERENCE

Imbeau, D., Wierwille, W. W., Wolf, L. D., and Chun, G. A. (1989). Effects of instrument panel luminance and chromaticity on reading performance and preference in simulated driving. *Human Factors, 31* (2), 147-160.

DISTRIBUTION OF DRIVER GLANCES TO INSTRUMENTS, MIRRORS, AND SIGNS

PERCENTILE VALUES OF GLANCES TO VARIOUS ITEMS

Viewing Task Percentile	Radio	Left-View Mirror	Rear-View Mirror	Speedometer	Temperature Gauge	Defroster	Roadway Name Sign
5th	0.68	0.68	0.32	0.16	0.48	0.44	0.68
10th	0.78	0.75	0.38	0.20	0.56	0.53	0.81
15th	0.86	0.80	0.42	0.24	0.62	0.60	0.90
20th	0.93	0.85	0.46	0.28	0.68	0.66	0.99
30th	1.04	0.92	0.53	0.34	0.79	0.77	1.14
40th	1.16	0.99	0.60	0.41	0.89	0.89	1.30
50th	1.27	1.06	0.68	0.49	0.99	1.01	1.46
60th	1.40	1.13	0.76	0.58	1.11	1.14	1.64
70th	1.55	1.22	0.86	0.70	1.26	1.31	1.87
80th	1.74	1.33	0.99	0.87	1.45	1.53	2.16
85th	1.88	1.40	1.08	1.00	1.58	1.69	2.37
90th	2.06	1.49	1.21	1.18	1.77	1.91	2.66
95th	2.35	1.65	1.43	1.51	2.08	2.30	3.14

RESULTS

The results show the distribution of glance lengths as a function of task and percentile, averaged across drivers. For example, 85 percent of driver glances to the speedometer are 1.00 second or shorter, whereas those to a roadway sign are 2.37 seconds.

The results are based on fitting the *lognormal* distribution to previously published means and standard deviations (or alternatively, means and medians) of glance times.

Additional results show that for radio glance times the actual distribution and the fitted lognormal distribution do not differ significantly, using the Kolmogorov-Smirnoff test.

The results suggest that the lognormal distribution is appropriate, and that for design purposes, percentiles can be easily derived, as shown by the table.

TEST CONDITIONS/PROCEDURES

Number of Subjects: (Analysis relies on published results of two previous studies. In one study 32 subjects were used. In the other 106 were used.)
Age Distribution of Subjects: Distributed across ages from 18 to 73.

Subject Characteristics: Licensed American drivers.
Subject Tasks: Subjects were instructed to carry out specific tasks while eye movements were recorded.

KEY TERMS

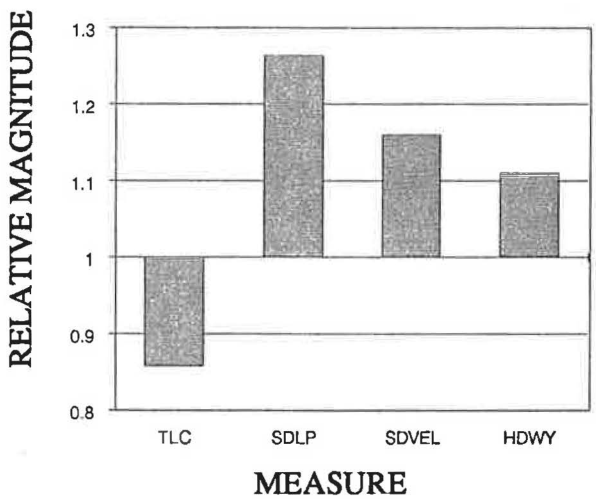
DRIVER DISTRACTION, DRIVER WORKLOAD, INSTRUMENT PANEL DEMAND, TASK COMPLETION TIME, VISUAL GLANCE TIME,

REFERENCE

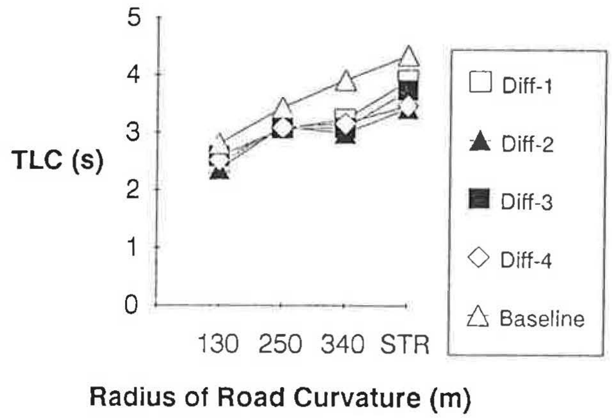
Taoki, G. T. (1990). Duration of drivers' glances at mirrors and displays. *ITE Journal, 60* (10), 35-39.

DRIVING PERFORMANCE WITH AUXILIARY IN-VEHICLE DISPLAYS

A. CHANGES IN DRIVING PERFORMANCE

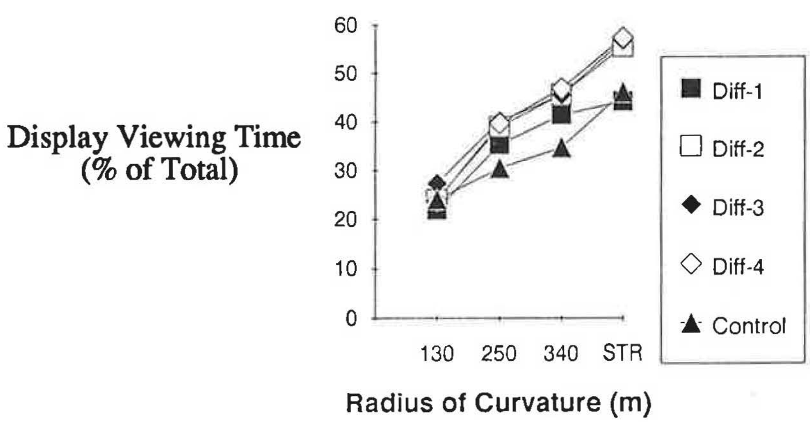


(a)



(b)

B. CHANGES IN DISPLAY VIEWING TIME



RESULTS

A. (a) The results show that when drivers perform self-paced auxiliary tasks using an in-vehicle display, certain driving performance measures are affected. The graph shows that time-to-line crossing (TLC), which is a measure of safety margin in vehicle control, was decreased to about 85% of the value obtained for no auxiliary task. Correspondingly, standard deviation of lane position is increased on the average by 27%. The results were obtained in a vehicle-following situation. The third and fourth measures are longitudinal measures: standard deviation of velocity (SDVEL) and mean headway (HDWY). These measures also increased when performing the auxiliary tasks. The results in the graphs are for a perceptual (visual search) auxiliary task. Results for a memory (Sternberg) auxiliary task were similar.

(b) The graph shows that mean time-to-line crossing (TLC) decreases with increases in road curvature (decreases in radius) as expected. There is a reduction in TLC with introduction of the auxiliary task, but TLC does not change appreciably with auxiliary task difficulty (Diff). The results in the graph are for the perceptual auxiliary task. Results for the memory task were similar.

B. The results show that drivers spent more time viewing the auxiliary display as the amount of roadway curvature decreased (radius of curvature increased.) However, the level of difficulty of the auxiliary task had little effect on viewing time. (In this graph the "control" condition corresponds to looking at the auxiliary display, but not performing a task.)

The results, taken together, suggest that drivers do allow a certain level of intrusion of an auxiliary task into the driving task. However, as the difficulty of the driving task increases, they adapt and direct more resources toward the driving task. Furthermore, as the difficulty of the auxiliary task increases, they do not permit further intrusion into resources needed for driving. Additionally, the results suggest an "undifferentiated" capacity model for auxiliary tasks is appropriate. Drivers exhibited no appreciable differences in performance for a perceptual and a memory auxiliary task.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 30
Age Distribution of Subjects: 19 to 37 years
Subject Characteristics: Canadian student volunteers with a minimum of three years driving experience and owning their own vehicles. Subjects had normal vision and good driving records.
Subjects Tasks: Subjects drove a computer-controlled moving-base driving simulator in a vehicle-following mode while performing self-paced auxiliary tasks. Driving task difficulty was varied by changing the amount of simulated roadway curvature. Auxiliary task difficulty was varied by changing the number of field items in the perceptual task and the memory set sizes in the memory task. Drivers were well practiced on all aspects prior to data gathering.

KEY TERMS

DISPLAY DESIGN, DRIVER ATTENTIONAL DEMAND, DRIVER DISTRACTION, DRIVER WORKLOAD, IN-VEHICLE DISPLAYS, LANE KEEPING, MULTIPLE RESOURCE THEORY, SUBSIDIARY TASKS, TASK DEMANDS, VISUAL DEMANDS

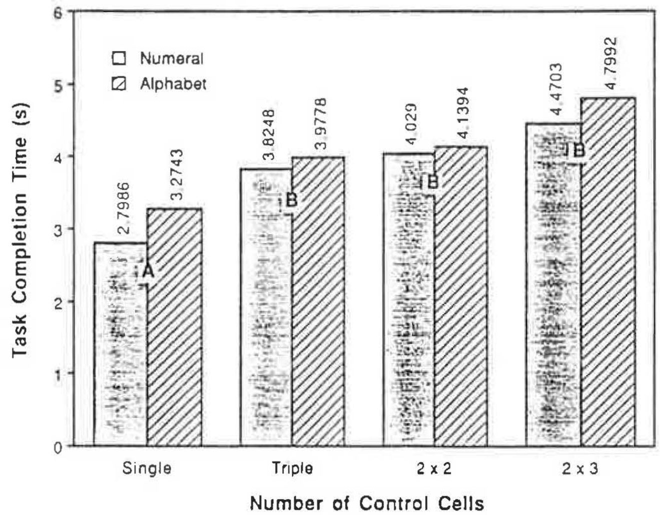
REFERENCE

Noy, Y. I. (1990). Selective attention with auxiliary automobile displays. Santa Monica, CA: Human Factors Society. *Proceedings of the Human Factors Society 34th Annual Meeting, Volume 2*, pp. 1533-1537 (October).

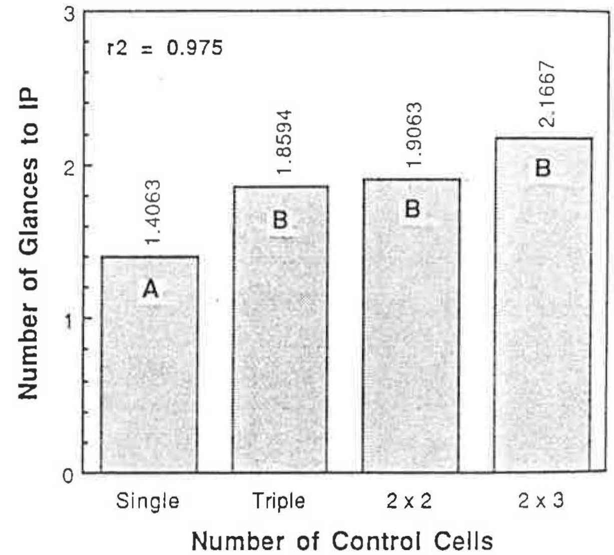
EFFECTS OF CLUTTER AND LABEL DESIGN ON INSTRUMENT PANEL TASK PERFORMANCE

A. MACROCLUTTER EFFECTS

(Effects of number of similar-appearing panels, each containing the same number of buttons.)



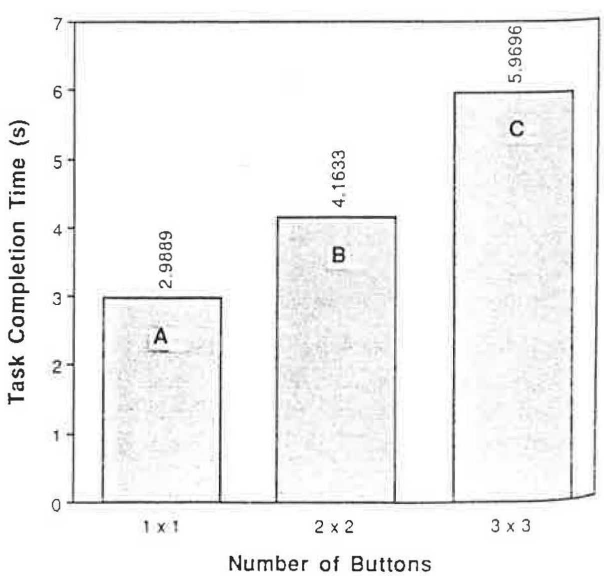
(a)



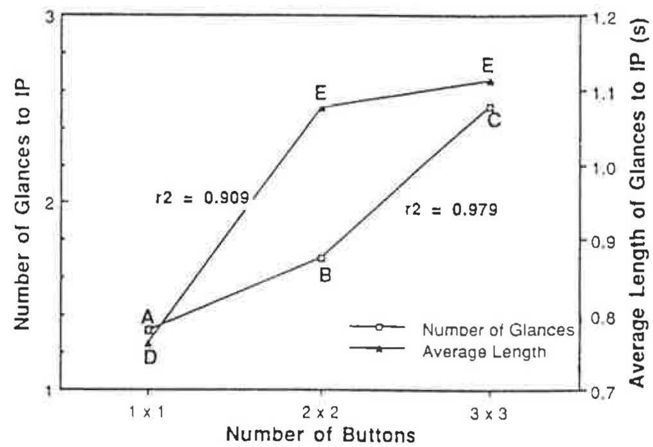
(b)

B. MICROCLUTTER EFFECTS

(Effects of number of similar appearing buttons.)

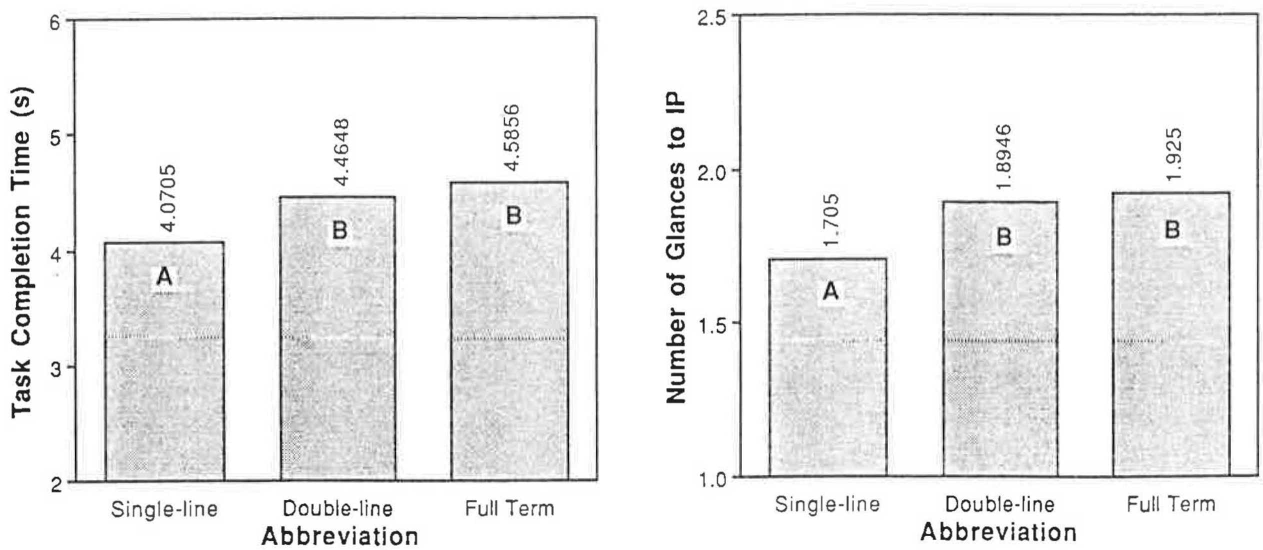


(a)



(b)

C. LABEL ABBREVIATION EFFECTS



(a) (b)

RESULTS

A. The results show that increasing the number of similar-appearing panels (control cells) on an instrument panel (referred to as macroclutter) causes an increase in task completion time (a) and number of glances (b) to the instrument panel. In these results, each control cell contained six sequentially-numbered buttons and six randomly-lettered buttons. Locating and actuating a random lettered button on a specified panel took slightly longer than a numbered button. The arrays of panels were in four different configurations: single, triple (in one horizontal row), 2 x 2 (two rows of two each), and 2 x 3 (one horizontal row of three over another horizontal row of three.)

The results indicate that as additional similar appearing panels of controls are added to the instrument panel of a vehicle, visual demand of the instrument panel and task completion time increase, primarily because of increased search time.

B. The results show that as the number of labeled buttons in single instrument panel array increases (referred to as microclutter), so does task completion time (a), number of glances to the instrument panel (b), and average length of individual glances (b). These increases are again due to increased search time.

The results show that the addition of similar-appearing controls or buttons in an array will cause increased task completion time (a) and increased visual demand of the instrument panel (b).

C. The results show that label abbreviation for controls can produce small but reliable reductions in task completion time (a) and number of glances to the instrument panel (b). In particular, one line abbreviations are better than two-line abbreviations or unabbreviated (full term) labels. These results appear to be due to shorter reading times of the abbreviated labels.

Note: In all of the graphical results, differing letters are used to designate significant differences ($\alpha = 0.05$) from other values in the graph.

TEST CONDITIONS/PROCEDURES

Number of subjects: A:8; B&C:8
Age Distribution of Subjects: 18 to 26 years
Subject Characteristics: Licensed, young American drivers. Half of each group were males, half were females.
Subject Tasks: Drivers drove a computer-controlled, moving base driving simulator (which had been previously validated for instrument panel tasks) while performing a variety of instructed instrument panel tasks.

KEY TERMS

CONTROL DESIGN, DRIVER ATTENTIONAL DEMAND, INSTRUMENT PANEL DESIGN, INSTRUMENT READING PERFORMANCE, IN-VEHICLE DISPLAYS, VISUAL DEMANDS, WORKLOAD

REFERENCE

Kurokawa, K. and Wierwille, W. W. (1991). Effects of instrument panel clutter and control labelling on visual demand and task performance. Plaza del Rey, CA: Society for Information Display. *1991 SID International Symposium, Digest of Technical Papers*, pp. 99-102 (May, ISSN 0097-966X).

EFFECT OF DISPLAY PAGE ACCESS ON IN-CAR VISUAL DEMAND

TOTAL GLANCE TIME (SECONDS) AS A FUNCTION OF INFORMATION AVAILABILITY

Task	Number of observations	Mean	Standard Deviation
Roadway name			
Info. available	26	4.61	2.39
Zoom required	68	12.12	5.36
Roadway distance			
Info. available	46	6.77	4.03
Zoom required	52	10.07	5.64
Cross street			
Info. available	24	4.05	4.16
Zoom required	72	8.91	4.48

RESULTS

The results show, using a computerized in-car moving-map navigation system that mean total glance times to the display increase by an approximate factor of 2 when the driver must first access the correct zoom level (or page in the zoom menu.) The results were obtained for drivers who were commanded to perform various navigation and conventional in-vehicle tasks.

The results are important for IVHS applications because they show (by example) that when the driver must search by means of a menu or other indirect method of access, the visual demands increase markedly.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 32
Age Distribution of Subjects: 18 to 73 years in four equal-size groups: 18 to 25, 26 to 35, 36 to 49, and 50 or older.
Subject Characteristics: Equal numbers of males and females in each age group. Half of all subjects drove between 2000 and 10000 miles per year, and the other half more than 10000. American, licensed drivers were used.
Subject Tasks: Drivers performed static practice on conventional and navigational in-car tasks. They then performed all tasks while driving until proficient. Subsequently, data were gathered along three routes providing three replications. All runs were performed in a computerized navigator-equipped research vehicle on public roads.

KEY TERMS

COMPUTERIZED NAVIGATION, DRIVER WORKLOAD, IN-VEHICLE ELECTRONIC DISPLAYS, IN-VEHICLE MENU DISPLAYS, IN-VEHICLE NAVIGATION, IVHS, VISUAL DEMANDS

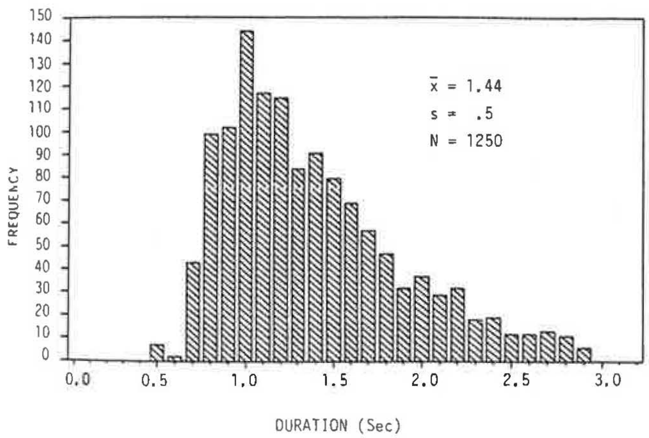
REFERENCE

Dingus, T. A., Antin, J. F., Hulse, M. C., and Wierwille, W. W. (1989). Attentional demand requirements of an automobile moving-map navigation system. *Transportation Research, 23A* (4), pp. 301-315.

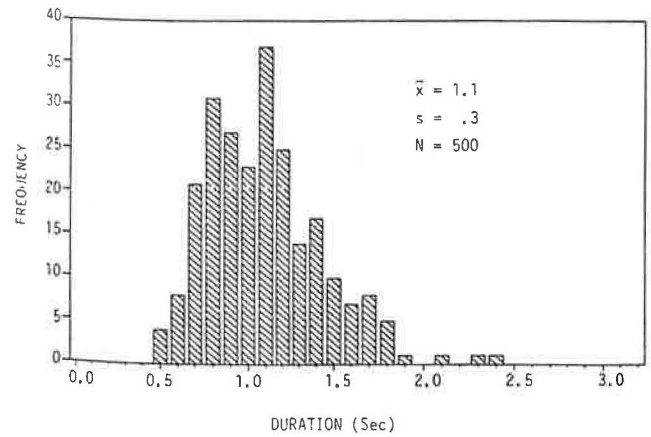
GLANCE DISTRIBUTIONS TO RADIOS AND MIRRORS

A. DISTRIBUTION OF GLANCE LENGTHS

RADIO



LEFT MIRROR



B. COMPARISON ACROSS STUDIES

	Study	# Runs	$\bar{x}$	Median	s	5%	95%
RADIO	A	35	1.27	1.20	.48	.82	2.16
	B	100	1.28	1.29	.50	.89	1.83
	C	72	1.42	1.30	.42	.80	2.50
LEFT MIRROR	A	35	1.06	.96	.40	.80	.20
	*B	100	1.22	1.15	.28	.94	1.80
	C	72	1.10	1.10	.33	.70	1.70

* Commanded mirror looks of discrimination

RESULTS

A. The results show the distribution of glance lengths for a large sample. For radio glances there is a greater spread, which is a result of complex information gathering in many cases. For the left mirror glances, on the other hand, the distribution is more compact because mirror checks are usually simple (presence-absence) detection tasks.

B. This table shows that there is remarkable consistency in the means and standard deviations of glance lengths across experiments. In one study (left-mirror, B) subjects were asked to identify any adjacent car's color. As a result, mean glance time increased slightly. Otherwise, glance lengths are highly stable across experiments.

The results indicate that the distribution of glance times tends to spread as the variety and complexity of tasks increases. Also, simple check readings result in shorter glance times and more compact distributions. For design of IVHS related systems, mean glance time and distribution represent important evaluation parameters.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 106 apportioned to three different experiments.
Age Distribution of Subjects: Half were age 35 or younger, half were age 45 or older.
Subject Characteristics: Each age group had approximately the same number of males and females. Subjects were licensed American drivers.
Subject Tasks: Drivers drove at speeds of 45 to 55 mph in light to moderate traffic for runs of 45 min to 1 hour. Subjects executed verbal commands while driving.

KEY TERMS

DRIVER DISTRACTION, DRIVER WORKLOAD, INSTRUMENT PANEL DEMAND, TASK DEMANDS, VISUAL GLANCE TIME

REFERENCE

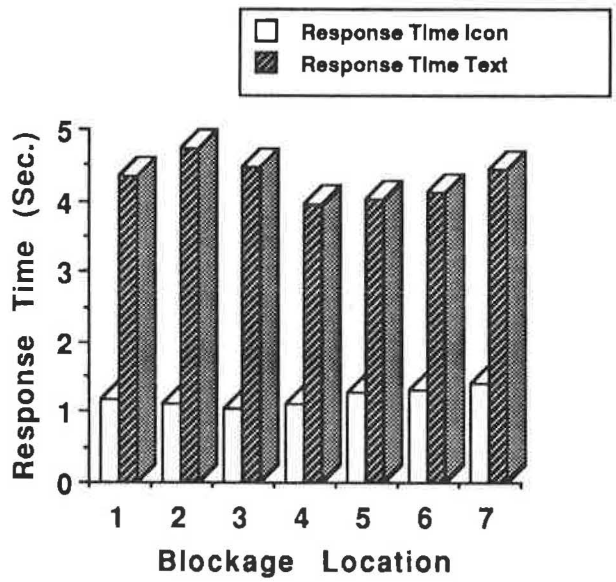
Rockwell, T. H. (1988). Spare visual capacity in driving-revisited: new empirical results for an old idea. In A. G. Gale et al. (Eds.), *Vision in Vehicles II*. Amsterdam, Netherlands: Elsevier Science Publishers, North Holland Press, pp. 317-324.

IVHS RELATED

Driver Information Processing

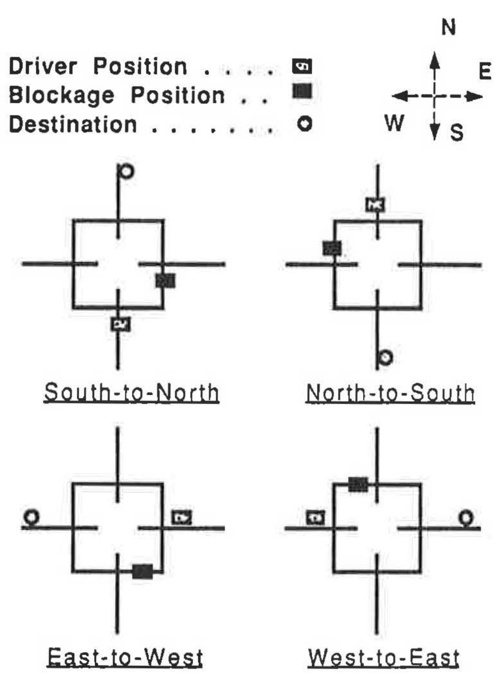
DISPLAY DESIGN APPROACH COMPARISONS FOR NAVIGATION

A. ALPHANUMERIC vs. ICON DISPLAY COMPARISON



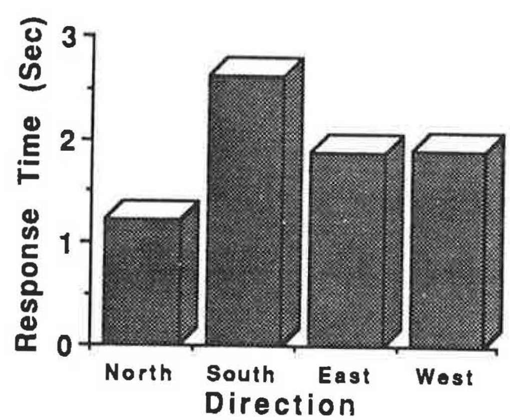
B. EFFECT OF TRAVEL DIRECTION WHEN USING A NORTH-UP DISPLAY

ICON DESIGN USED



(a)

RESULTS



(b)

RESULTS

A. The results demonstrate that drivers' responses to blockages at intersections (requiring diversion) were significantly faster for icon-presented information than for alphanumeric-presented information. (Response time was defined as the time required to make a decision to turn right or left to avoid a blockage.) In both cases, information was presented head up, and drivers had a paper map as backup. (The ICON information was presented in a format similar to the upper-left icon in B (a) shown below the graph in A. The icon presentation was "north-up" and drivers drove from South to North.) The differences in the graph are so striking that if the icon-response times are increased by a factor of 3, they are still significantly shorter than the response times for alphanumeric presentations.

B. The results show the effect of driver direction on a north-up display. The icons used in the study as a function of direction of travel are shown in (a) and the corresponding response times are shown in (b). The results demonstrate that an "ego-centered" presentation (north-up while heading from south to north) produces shorter response times to blockage. The other three presentations require cognitive remapping of the information.

Further results under B show that, while drivers made errors on all three non ego-centered presentations (north-to-south, east-to-west, and west-to-east), they made no errors on the ego-centered (south-to-north) presentations.

The results are important for navigation system design because they suggest that pictorial or iconic presentation can produce results that are superior to alphanumeric presentation. Furthermore, iconic information that maps consistently with the driver's orientation and left/right turning information can similarly produce results that are superior.

TEST CONDITIONS/PROCEDURES

Number of Subjects: A: 10; B: 10
Age Distribution of Subjects: A: 21 to 38 years; mean: 29.5; standard deviation: 6. B: 21 to 39 years; mean: 28.8; standard deviation: 5.
Subject Characteristics: Students, faculty, and staff at University of Minnesota.
Subject Tasks: A: subjects memorized a paper map for five minutes. Then they drove a fixed base simulator in which successive schematic intersections were presented, some of which required route diversion due to blockage. Iconic or alphanumeric route guidance information was presented head up (that is using the same projector as the schematic route.) B: procedures were similar to A, except that driver direction of travel was varied.

KEY TERMS

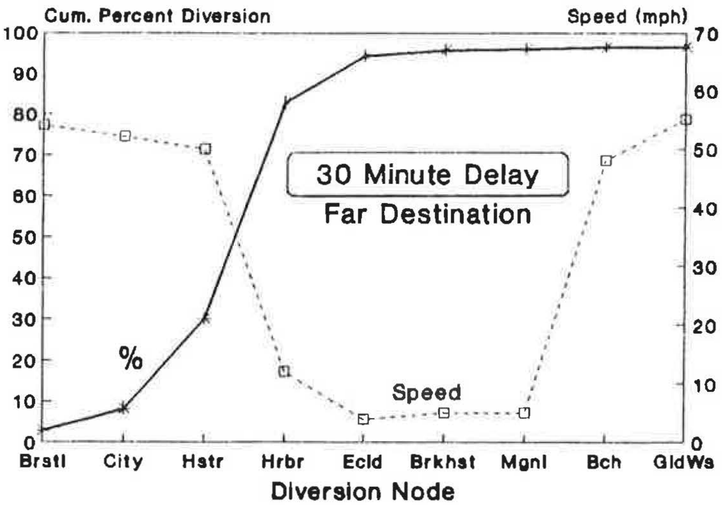
ALTERNATE ROUTE SELECTION, DRIVER DECISION MAKING, HEAD-UP DISPLAYS, IN-VEHICLE NAVIGATION, IVHS, ROUTE DIVERSION, ROUTE GUIDANCE, TRAFFIC CONGESTION, TRAFFIC DELAYS

REFERENCE

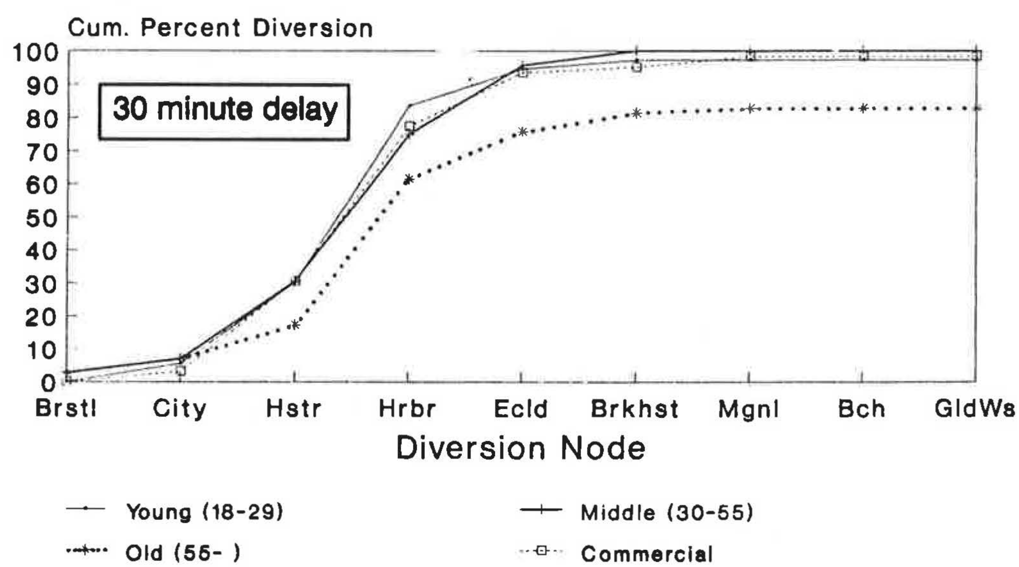
Shekhar, S., Coyle, M.S., Shargal, M., Kozak, J. J., Hancock, P. A. (1991). Design and validation of headup displays for navigation in IVHS. Warrendale, PA: Society of Automotive Engineers (SAE). *Vehicle Navigation and Information Systems Conference Proceedings, Part 1.* Publication No. P-253, pp.. 537-542. (October) (SAE Paper No. 912795).

DRIVER ALTERNATE-ROUTE-DIVERSION DECISION MAKING WITH IN-VEHICLE NAVIGATION

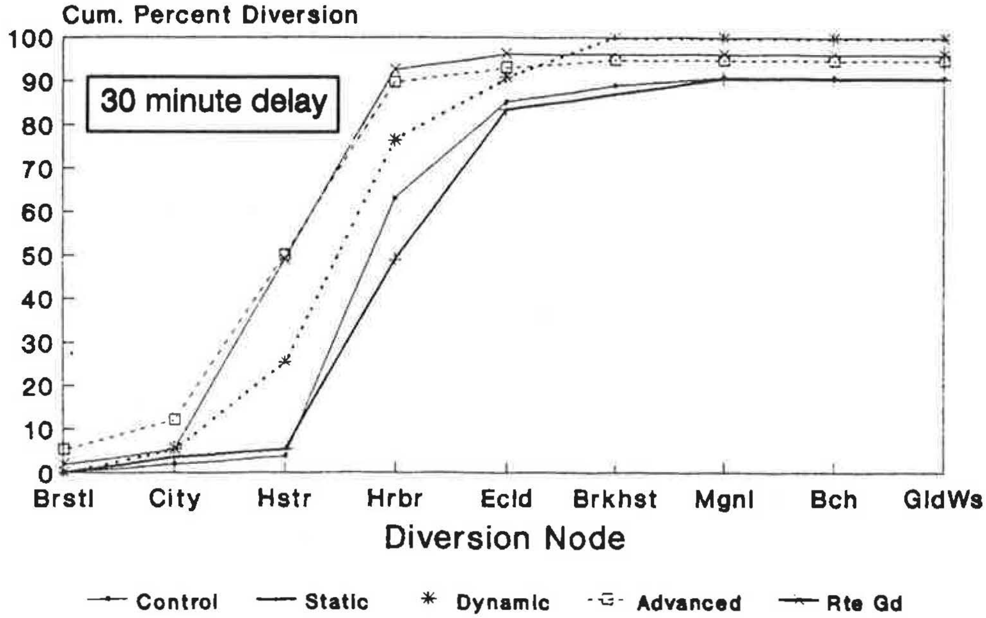
A. DIVERSION AS A FUNCTION OF MEAN TRAFFIC SPEED



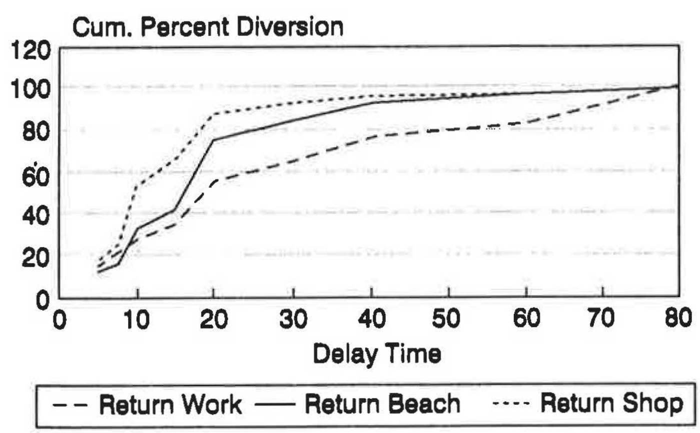
B. DIVERSION AS A FUNCTION OF AGE AND COMMERCIAL EXPERIENCE



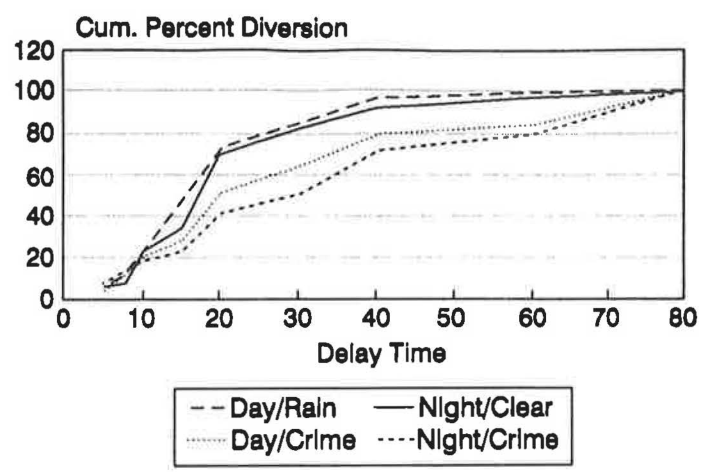
C. DIVERSION AS A FUNCTION OF TYPE OF NAVIGATION SYSTEM



D. DIVERSION AS A FUNCTION OF DELAY TIME AS INFLUENCED BY ENVIRONMENTAL AND TRIP PURPOSE FACTORS



(a)



(b)

RESULTS

A. The results show that drivers divert to an alternate route as mean traffic speed slows. In this graph the abscissa is the interchange order (from left to right by name). In this example a traffic incident has occurred at the Mgnl interchange causing a 30-minute delay.

Other results are presented for 11 and 18 minute delays, which show that slow-down is the major decision factor in diversion.

B. The results show that older drivers (55 and older) tend to be more reluctant to divert and that approximately 20 percent never divert. All other groups divert with approximately the same proportions as they approach the traffic incident interchange (at Mgnl).

Other results are presented in the paper for 11 and 18 minute delays. These results show similar trends, with older drivers more reluctant to divert.

C. The results show that the decision to divert is dependent on the type of navigation system used. Congestion information and navigation guidance provided by the more advanced systems (i.e. the dynamic, advanced, and route guidance systems) had a significant influence on route diversion decision making, with advanced map system and route guidance systems providing the best overall performance. Better systems encouraged drivers to divert sooner.

D. These results are from post-experiment questionnaire responses and show that the decision to divert is dependent not only on delay times but also conditions. Graph (a) shows in particular that if the alternate (diverted) route is through a high crime area, longer delay times must occur before drivers divert. Furthermore, drivers are even more reluctant to pass through a high-crime area at night. Graph (b) shows that drivers are more reluctant to divert when commuting from work, probably because delays during rush hours are a common occurrence. The results generally exhibit the factors that go into diversion decision making and are therefore highly relevant to IVHS traffic system design and system effectiveness evaluation.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 277
Age Distribution of Subjects: All ages, three age groups (young, middle, old), ages not given.
Subject Characteristics: 215 licensed American drivers equally distributed into 3 age groups with approximately equal numbers of males and females. Approximately half the drivers were familiar with the freeway route and the other half were not. In addition, there were 62 commercial drivers, most of whom were in the middle age group. A somewhat larger proportion than half were familiar with the route. Among all the drivers, average years of driving experience fell within the range of 11 to 20 years and average mileage fell in the range of 12 to 17 thousand per year. American drivers were used.
Subject Tasks: Drivers drove an open loop simulator consisting of projected slides, recorded auditory messages, and an in-vehicle navigation display system. Subjects indicated when they would divert based on conditions. (Training preceded data gathering; a post task questionnaire was also administered.)

KEY TERMS

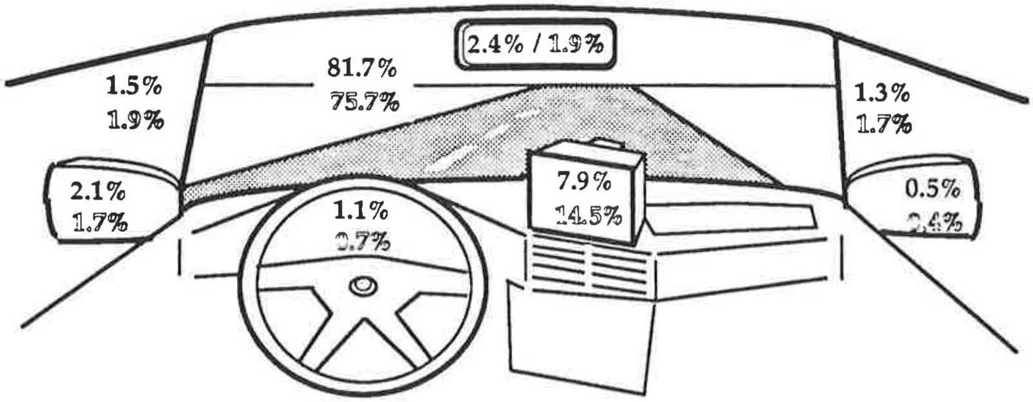
ALTERNATE ROUTE SELECTION, DRIVER DECISION MAKING, IN-VEHICLE NAVIGATION, IVHS, ROUTE DIVERSION, ROUTE GUIDANCE, TRAFFIC DELAYS, TRAFFIC CONGESTION

REFERENCE

Allen, R. W., Stein, A. C., Rosenthal, T. J., Ziedman, D., Torres, J. F., and Halati, A. (1991). A human factors study of driver reaction to in-vehicle navigation systems. In *IVHS and Vehicle Communications* (SP-877). Warrendale, PA: Society of Automotive Engineers (SAE). Paper No. 911680, August, pp. 83-102.

COMPARISON OF COMMAND AND MAP NAVIGATION DISPLAYS

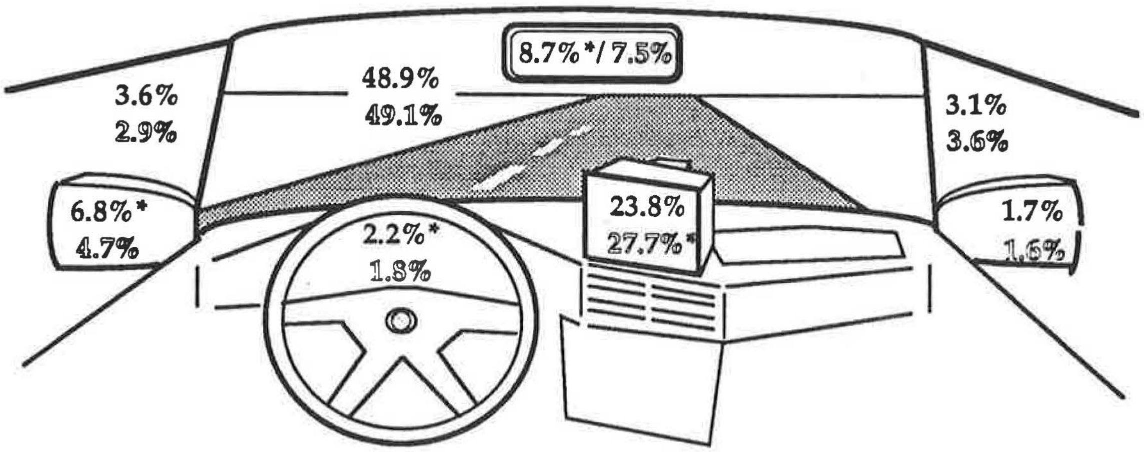
A. GLANCE DURATION COMPARISON



KEY:

Percentage of total visual attention allocation with LISB
Percentage of total visual attention allocation with Travelpilot

B. GLANCE FREQUENCY COMPARISON



KEY:

Percentage of total glance frequency allocation with LISB
Percentage of total glance frequency allocation with Travelpilot

RESULTS

A. The results show the percentage of total time that the drivers eyes were on the various components of the vehicle and the roadway. LISB is a command navigation system having both auditory commands and visual symbols (which, of course, includes route guidance). Travelpilot is a computer-generated map display (without route guidance). The results, as expected, show a greater proportion of total visual time on the roadway and a smaller proportion on the navigation display for LISB, when compared with Travelpilot.

   The results show that computerized map systems in which the driver must determine the route are more visually demanding.

B. The results show the percentage of glance occurrences (called frequencies) to the various components of the vehicle and the roadway. As can be seen the number of glances to the navigation display was somewhat larger for Travelpilot than for LISB.

   Other results in the study show that drivers experienced higher mental demands when using Travelpilot, and high time-pressure demands when using LISB.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 21
Age Distribution of Subjects: Approximately 60% were under 30 years. The remainder were over 55 years.
Subject Characteristics: Two had previous experience with LISB. Others had no experience with either system. (Gender of subjects unspecified.)
Subject Tasks: Drivers drove an instrumented vehicle from a start point to a destination in a city during off-peak hours. They were unfamiliar with the destination. Each driver experienced each of two routes, one with LISB and one with Travelpilot.

KEY TERMS

COMPUTERIZED NAVIGATION, IN-VEHICLE NAVIGATION, IVHS, MOVING MAP DISPLAYS, ROUTE GUIDANCE

REFERENCE

Parkes, A. M., Ashby, M. C., Fairclough, S. H. (1991). The effects of different in-vehicle route information displays on driver behavior. *Vehicle Navigation and Information Systems Conference Proceedings, Part I.* Warrendale, PA: Society of Automotive Engineers (SAE). Publication No. P-253, pp. 61-70. (SAE Paper No. 912734)

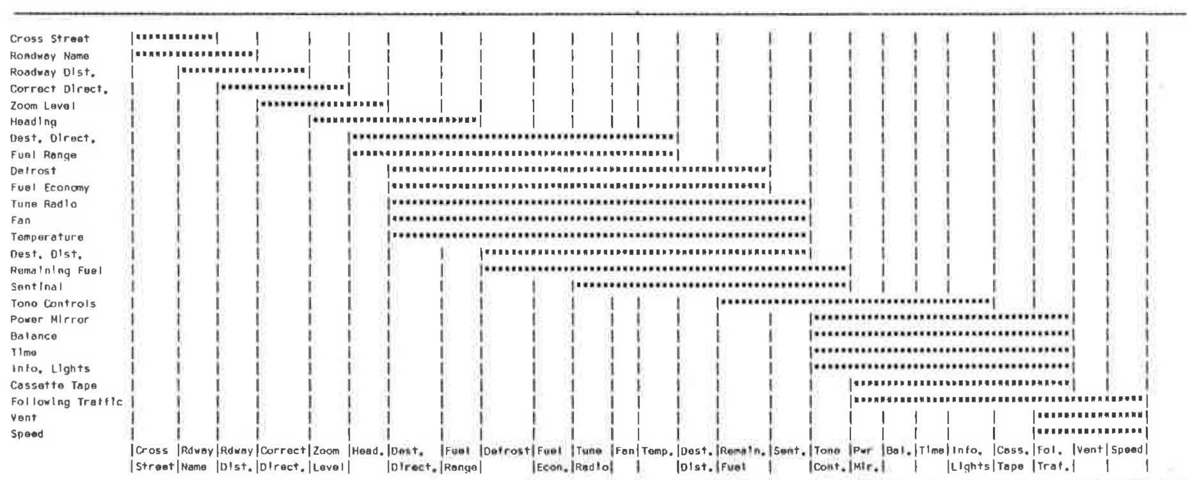
COMPARISON OF COMPUTERIZED IN-CAR NAVIGATION DEMANDS WITH CONVENTIONAL IN-CAR TASK DEMANDS

A. NUMBER AND LENGTH (seconds) OF TASK GLANCES

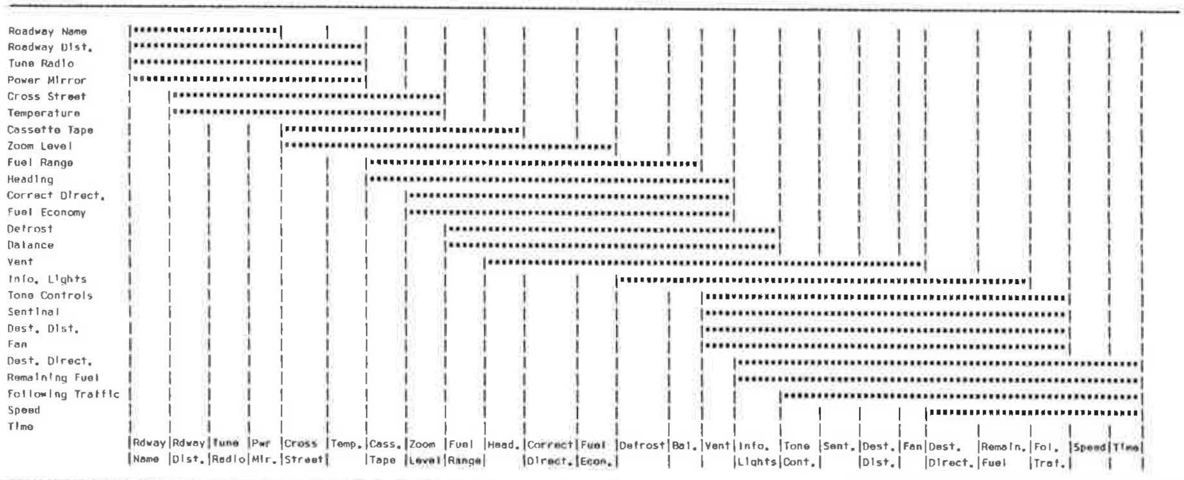
Task	Display single-glance length		Number of glances		Total display glance time (T_D)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Turn signal	0.30	0.39	0.63†	0.73	0.38	0.56
Speed	0.62	0.48	1.26	0.40	0.78	0.65
Following traffic	0.75	0.36	1.31	0.57	0.98	0.60
Time	0.83	0.38	1.26	0.46	1.04	0.56
Vent	0.62	0.40	1.83	1.03	1.13	0.99
Destination direction	1.20	0.73	1.31	0.62	1.57	0.94
Remaining fuel	1.04	0.50	1.52	0.71	1.58	0.95
Tone controls	0.92	0.41	1.73	0.82	1.59	1.03
Info. lights	0.83	0.35	2.12	1.16	1.75	0.93
Destination distance	1.06	0.56	1.73	0.93	1.83	1.09
Fan	1.10	0.48	1.78	1.00	1.95	1.29
Balance	0.86	0.35	2.59	1.18	2.23	1.50
Sentinal	1.01	0.47	2.51	1.81	2.38	1.71
Defrost	1.14	0.61	2.51	1.49	2.86	1.59
Fuel economy	1.14	0.58	2.48	0.94	2.87	1.09
Correct direction	1.45	0.67	2.04	1.25	2.96	1.86
Fuel range	1.19	1.02	2.54	0.60	3.0	1.43
Temperature	1.10	0.52	3.18	1.66	3.50	1.73
Cassette tape	0.80	0.29	2.06	1.29	1.59 + 1.64‡	0.96 (0.59)‡
Heading	1.30	0.56	2.76	1.81	3.58	2.23
Zoom level	1.40	0.65	2.91	1.65	4.00	2.17
Cruise control	0.82	0.36	5.88	2.81	4.82	3.80
Power mirror	0.86	0.34	6.64	2.56	5.71	2.78
Tune radio	1.10	0.47	6.91	2.39	7.6	3.41
Cross street	1.66	0.82	5.21	3.20	8.63	4.86
Roadway distance	1.53	0.65	5.78	2.85	8.84	5.20
Roadway name	1.63	0.80	6.52	3.15	10.63	5.80

†Drivers often did not glance at the turn signal.
‡Time required to search for and orient cassette tape.

B. MULTIPLE COMPARISONS OF SINGLE-GLANCE LENGTHS



C. MULTIPLE COMPARISONS OF TOTAL GLANCE TIMES, T_D.



RESULTS

A. The results show how mean single glance lengths, number of glances, and total task glance time vary with the task. As such they provide an indication of visual task demands for each task. Results are listed for 8 navigation tasks and 19 conventional (though many are contemporary) tasks. They are rank ordered according to total glance time, T_D, which is the sum of individual glance lengths.

The results show that mean single glance times ranged from 0.62 (excluding turn signal) to 1.66 seconds and that number of glances ranged from 0.78 to 10.63 seconds.

Of the tasks having total glance times above 5 seconds, 4 are navigation tasks. Similarly, all five tasks having single glance times at or above 1.40 seconds are navigation tasks. These results suggest that the visual demands of several in-car navigation tasks are relatively high when compared with conventional tasks, and also, that navigation using such a system draws heavily on visual (and possibly cognitive) resources.

B. The results show how various in-vehicle tasks may be grouped in terms of equivalent mean-single glance time demands. Tasks sharing common groups of asterisks do not differ significantly from one another ($\alpha = 0.05$), using T-test multiple comparisons. The "cross street" task, for example has a significantly longer mean single glance time than all other tasks except the "roadway name" and "roadway distance" tasks.

C. The results show a similar analysis of task total glance time. The results show that the tasks "roadway name" and "roadway distance" each have significantly longer total glance times than other tasks. However, it should be noted that the conventional task, "tune radio," also has a relatively long total glance time.

Additional results in the paper show that the number of lane exceedences while performing the tasks covaries with the total glance time.

The results taken together imply that additional human factors efforts should be directed toward reducing visual demands of in-car computerized moving map displays.

The results in A also provide an archival listing against which new tasks may be evaluated in terms of mean single glance times, number of glances, and task total glance times, that is, in terms of visual demands.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 32

Age Distribution of Subjects: 18 to 73 years in four equal-size groups: 18 to 25, 26 to 35, 36 to 49, and 50 or older.

Subject Characteristics: Equal numbers of males and females in each age group. Half of all subjects drove between 2000 and 10000 miles per year, and the other half more than 10000. Subjects were initially unfamiliar with the in-car navigation system and many of the more modern conventional in-vehicle systems. Drivers were Americans.

Subject Tasks: Drivers performed static practice on all tasks. They then performed all tasks while driving until proficient. Subsequently, data were gathered along three routes providing three replications for most tasks.

All runs were performed in a computerized navigator-equipped research vehicle on public roads.

KEY TERMS

COMPUTERIZED NAVIGATION, DRIVER ATTENTIONAL DEMAND, DRIVER WORKLOAD, IN-VEHICLE NAVIGATION, IVHS, MOVING MAP DISPLAYS, VISUAL DEMANDS

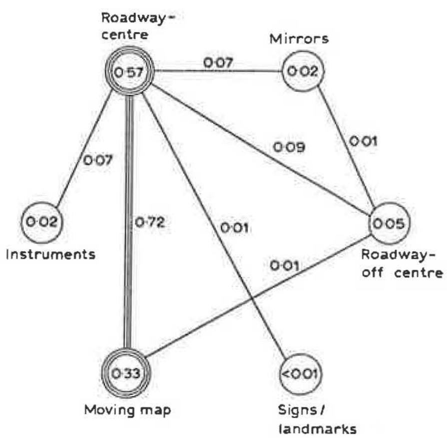
REFERENCE

Dingus, T. A., Antin, J. F., Hulse, M. C., and Wierwille, W. W. (1989). Attentional demand requirements of an automobile moving-map navigation system. *Transportation Research, 23A* (4), pp. 301-315.

COMPARISON OF COMPUTERIZED IN-CAR NAVIGATION WITH PAPER MAP AND WITH MEMORIZED ROUTE

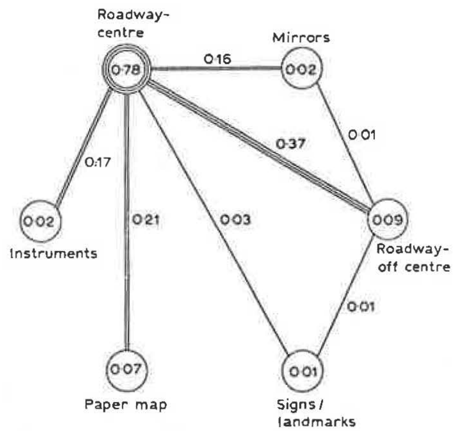
A. SCAN PATTERNS

NAVIGATOR



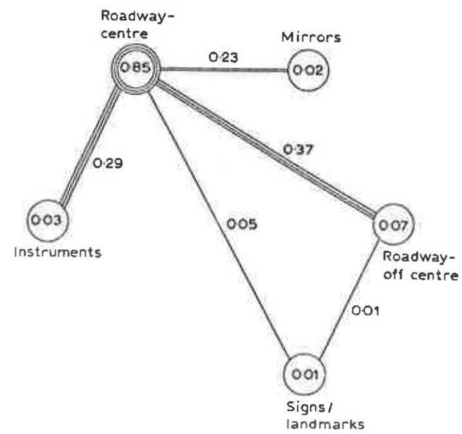
(a)

PAPER MAP



(b)

MEMORIZED ROUTE



(c)

B. TASK TIMES (Minutes)

Time Segment	Navigator	Paper Map	Memorized Route
Study Time	0.75	1.55	0.00
Drive Time	15.20	14.00	11.02
Total Time	15.95	15.55	11.02

RESULTS

A. The results show that drivers using a computerized moving-map in-car navigation system to reach an unfamiliar destination have scan patterns that are somewhat different from those when using a paper map, and that are quite different from those when the route is known and memorized. The diagrams show the visual link value probabilities (numbers alongside lines) and glance probabilities (numbers in circles) for the three situations. As can be seen, the probability that the eyes are on the forward roadway is lower when using the navigation system than when using a paper map, which in turn is lower than for memorized route.

The results show that scan patterns are heavily modified when using a complex in-car display for navigation. They are also modified when using a paper map. Questions arise as to the effects of this intrusion on driver performance and safety.

B. The results show the relative efficiency of in-car moving-map navigation, as compared with paper maps and memorized route. Drivers spent significantly more time studying the paper map than they did studying the navigator before beginning to drive. However, once underway, trip times with the paper map were slightly shorter. Total times for the navigator and paper map did not differ significantly from one another.

As expected, memorized route required no study time and produced significantly shorter trip times. (Memorized route represents a lower bound on trip time in noncongested areas.)

Other results show that the number of serious navigation errors for the navigation system and the paper map were very nearly equal.

Taken together, these results show that drivers can use complex moving-map displays about as effectively as paper maps. However, visual scan patterns are modified, and additional research needs to be done on the corresponding ramifications.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 32
Age Distribution of Subjects: 18 to 72 years, in four equal-size groups: 18 to 25, 26 to 34, 35 to 49, and 50 or older.
Subject Characteristics: Equal numbers of males and females in each age group. Half of all subjects drove between 2000 and 10000 miles per year, and the other half more than 10000. Subjects were initially unfamiliar with all destinations used. They had no previous experience with in-car computerized navigation and had not served as driver subjects previously. They were licensed American drivers.
Subject Tasks: Drivers drove to three different, counterbalanced destinations; one for each of the three navigation methods. For the in-car navigation run, subjects were trained until proficient. For the memorized route run, drivers were directed as they drove to the destination. They then drove back to the starting point. Finally, they then drove the route as data were gathered. For the paper map run, drivers were permitted to view the map as they drove.

All runs were performed in a computerized, navigator-equipped research vehicle on public roads.

KEY TERMS

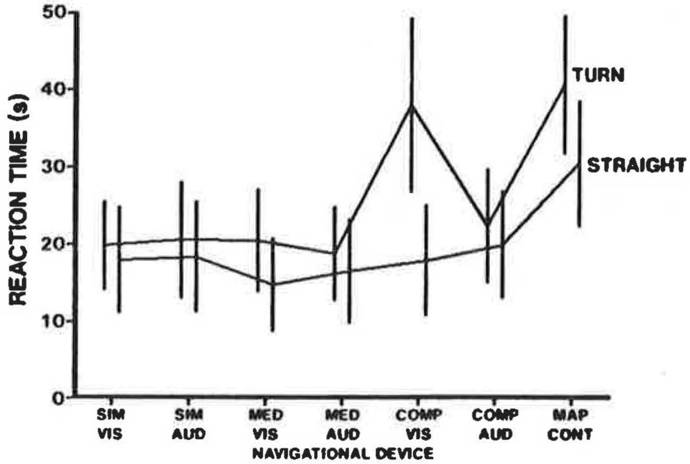
COMPUTERIZED NAVIGATION, IN-VEHICLE NAVIGATION, IVHS, MOVING MAP DISPLAYS, ROUTE GUIDANCE

REFERENCE

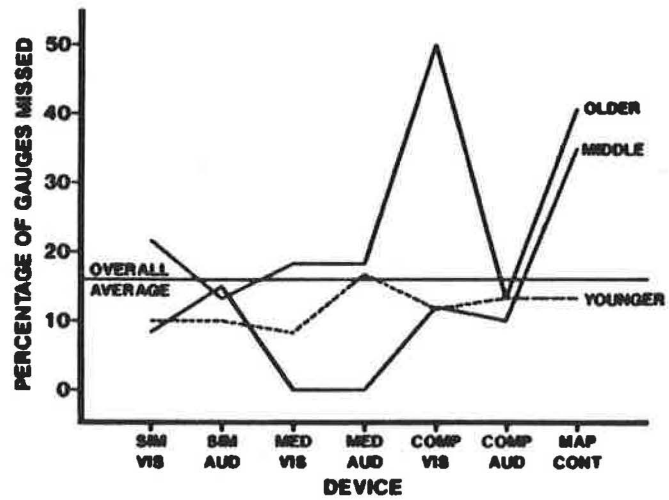
Antin, J. F., Dingus, T. A., Hulse, M. C., and Wierwille, W. W. (1990). An evaluation of the effectiveness and efficiency of an automobile moving-map navigation system. *International Journal of Man-Machine Studies, 33*, 581-594.

COMPARISONS OF DRIVER PERFORMANCE USING VARIOUS NAVIGATION DEVICES

A. RESPONSE TO GAUGE CHANGES

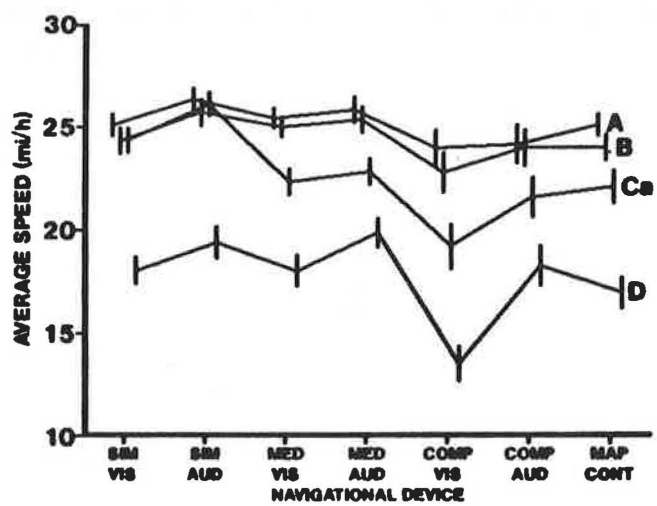


(a)



(b)

B. EFFECT ON SPEED



C. EFFECT ON NAVIGATION ERRORS

Complexity	Channel	
	Visual	Auditory
Simple	16	0
Medium	3	1
Complex	12	8
Map Control	14	

RESULTS

A. (a) The results show response times to detection of out of tolerance conditions on either of two instrument panel gauges as a function of type of navigation system. The navigation systems consisted of all combinations of simple, medium, and complex forms of visual- and auditory-modality devices. In addition strip-type (AAA) paper map navigation was also included.

The results indicate that complex visual navigation and paper map navigation methods increased response times to out-of-tolerance gauges on turns. The results are explained as follows: For the complex visual display, driver visual loading involved watching the display and performing the turn, which precluded being able to monitor the gauges. For the paper map condition, drivers had to read the maps and the road signs before and during the turns, which similarly precluded being able to monitor gauges.

(b) The results show that older drivers missed 50 percent of out-of-tolerance conditions for the complex visual displays. Also, for the paper map conditions, older- and middle-age drivers missed above average numbers of out-of-tolerance conditions. Younger drivers generally exhibited smaller decrements, as the graph shows.

B. The results show that drivers slowed as (primary) driving task difficulty increased in progression from A to D. (The letters A, B, Ca, and D represent combinations of increasing route and task difficulty designed to elicit differing amounts and types of driver resources needed.) In addition, greater speed reductions occurred for the complex-visual navigation system.

C. The tabled results show the number of navigation errors as a function of the complexity and modality, as well as for the paper map condition. As can be seen, the number of errors is much greater for the visual modality, except for the medium-complexity visual case.

The results are attributed to the following:

For the simple systems, the auditory command had greater attention-getting capability.
For the complex systems, drivers were able to hear and comprehend the street-sign names better than they were able to

glean navigation information from the visual display, or for that matter, the paper map.

These results, taken together, suggest that complex visual navigation displays and paper maps are more visually demanding than other types of navigation and may result in reduced detection performance, reduced trip speed, and increased navigation errors. Furthermore, older drivers are likely to have greater difficulty with complex visual navigation displays.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 126
Age Distribution of Subjects: Three groups: 20 to 25 years (mean of 22.8); 35 to 40 (mean of 37.6); and 55 or older (mean of 62.8).
Subject Characteristics: American drivers, 18 per navigation method, equal numbers from each age group, equal number of males and females in each age by navigation subgroup.
Subject Tasks: Drivers drove a fixed-based fully-interactive driving simulator under successively more difficult conditions, including decreases in lane width, increases in crosswind disturbances, increases in gauge detection difficulty and increases in difficulty of navigation. Subjects used a specified navigation method (one of seven) to reach a destination.

KEY TERMS

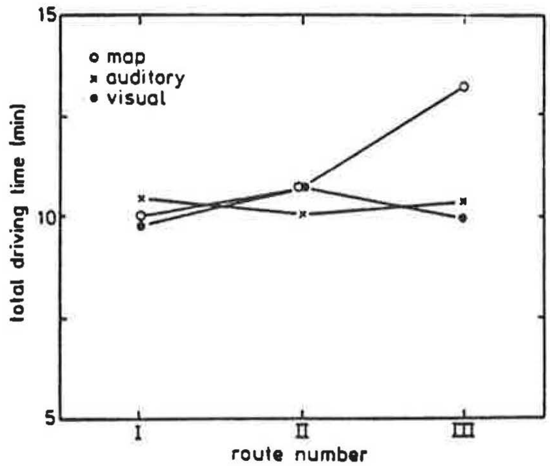
COMPUTERIZED NAVIGATION, DRIVER ATTENTIONAL DEMAND, DRIVER WORKLOAD, IN-VEHICLE NAVIGATION, IVHS, MOVING MAP DISPLAYS, VISUAL DEMANDS

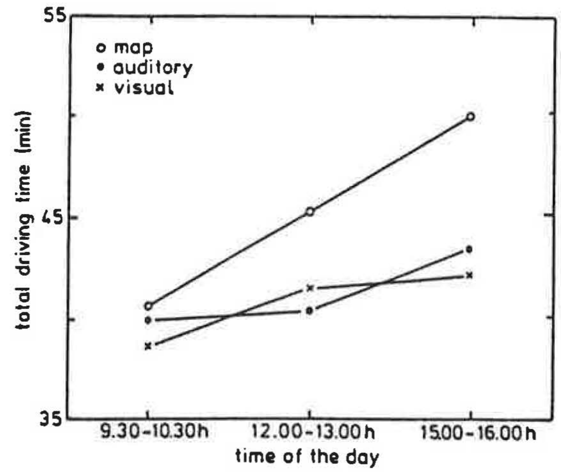
REFERENCE

Walker, J., Alicandri, E., Sedney, C., and Roberts, K. (1991). In-vehicle navigation devices: effects on the safety of driver performance. Warrendale, PA: Society of Automotive Engineers (SAE). *Vehicle Navigation and Information Systems Conference Proceedings, Part 1.* Publication No. P-253, pp. 537-542. (October) (SAE Paper No. 912793).

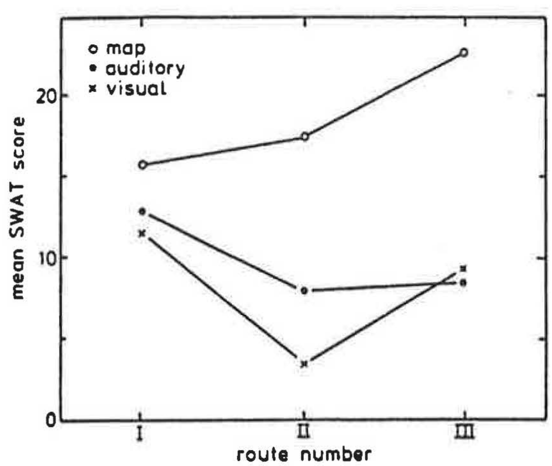
COMPARISON OF MAP NAVIGATION WITH SIMPLE AUDITORY AND SIMPLE VISUAL COMMAND NAVIGATION

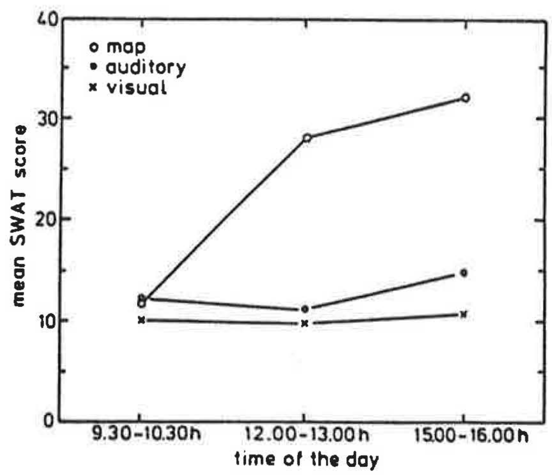
A. PERFORMANCE EFFECTS





B. DRIVER OPINION EFFECTS





RESULTS

A. The graphs show that drivers using maps had longer trip times for difficult routes (left graph) and for increasing traffic densities (right graph). Performance using a simple auditory command display and a simple visual command display were similar to one another. For auditory, the commands were "go left," "go left and then go right," etc. For visual, the commands were angled arrows showing present path as vertical and directed path as either vertical (for straight ahead) or left or right.

The results suggest that straightforward navigation aids can be helpful in improving driving performance when routes are complex and/or when traffic is heavy.

Other findings in the paper show that drivers spent more time standing still when using maps (they were not permitted to read maps while moving), and they made more navigation errors with maps.

B. Using the Subjective Workload Assessment Technique (SWAT), the results show that drivers provided higher workload ratings when using maps for all conditions. In addition, ratings of workload were highest when using the map for complex routes and for heavy traffic.

The results suggest that drivers do in fact feel that they are under heavier workload when using maps in complex routes and heavy traffic, as compared with the use of straightforward navigation aids.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 36
Age Distribution of Subjects: 22 to 45
Subject Characteristics: Dutch males, with at least 3 years of driving experience and driving at least 10000 km per year. Subjects were selected from a group of 52 on the basis of spatial ability (18 highest and 18 lowest selected). Normal vision.
Subjects Tasks: Drivers drove three different routes at three different times of day, corresponding to traffic conditions, counterbalanced. Performed ratings immediately following runs.

KEY TERMS

DRIVER PERFORMANCE, DRIVER WORKLOAD, IVHS, NAVIGATION AIDS, ROUTE GUIDANCE, ROUTE NAVIGATION

REFERENCE

Verwey, W. B. and Janssen, W. H. (1988) *Route following and driving performance with in-car route guidance systems*. (Report No. 1ZF1988C-14). Soesterberg, The Netherlands: TNO Institute for Perception.

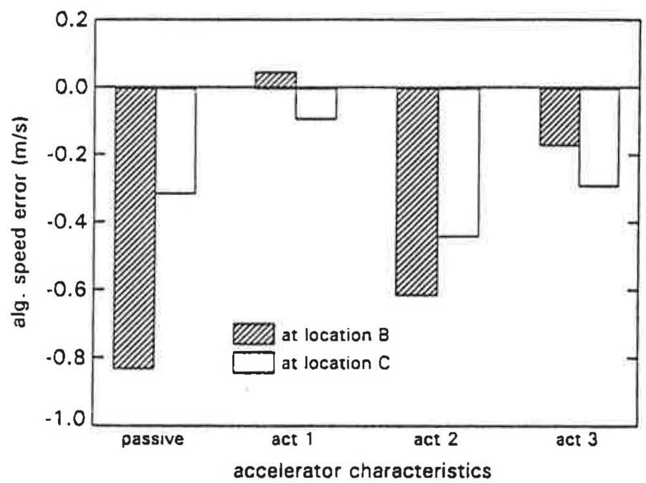
IVHS RELATED

Pre-Crash Behavior

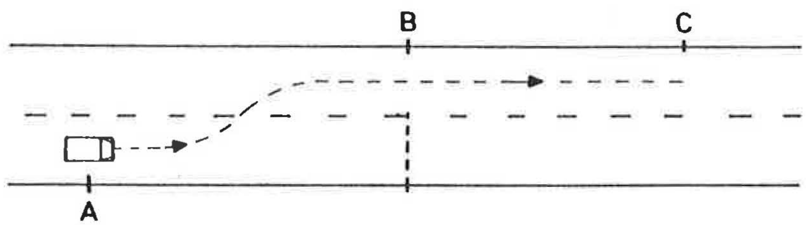
ACTIVE ACCELERATOR FOR SPEED CONTROL

SPEED ERRORS WHEN USING AN ACTIVE ACCELERATOR

(a)



(b)



Scenario Diagram

RESULTS

The results shown in (a) indicate that for practiced drivers, active accelerators can produce lower advisory speed errors than an ordinary (passive) accelerator.

The results for three types of active accelerators are compared with a passive accelerator at two simulated locations.

The drawing in (b) shows the scenario used in fixed base simulator runs. It included a lane barrier at B forcing a lane change. At the same time, drivers were provided with an advisory speed change which was to be achieved on reaching B.

The active accelerator configurations tested were:

active 1: force feedback linearly dependent on speed error

active 2: force feedback light (25N) if below goal speed, heavy (80N) if above goal speed.

active 3: passive plus accelerator vibration indicating point where accelerator should be released to advise goal speed.

Other findings in the paper show small differences in the number of glances to the speedometer as a function of accelerator configuration used (i.e., passive or active 1, 2, of 3.)

The results suggest that an active accelerator might be useful in improving control of speed for cooperative drivers. However, the results are preliminary and situation specific.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 8
Age Distribution of Subjects: 23 to 38 years.
Subject Characteristics: Dutch males with at least 5 years driving experience of 10000 km or more. All subjects had previous experience with the simulator.
Subject Tasks: Subjects repeatedly ran the instructed course containing the simulated barrier. All tests began with speeds of 100 km/h. If outside this speed by more than 5 km/h, the run was terminated and repeated. New instructed speeds (to be achieved on reaching B), were 100, 85, 70, and 55 km/h.

KEY TERMS

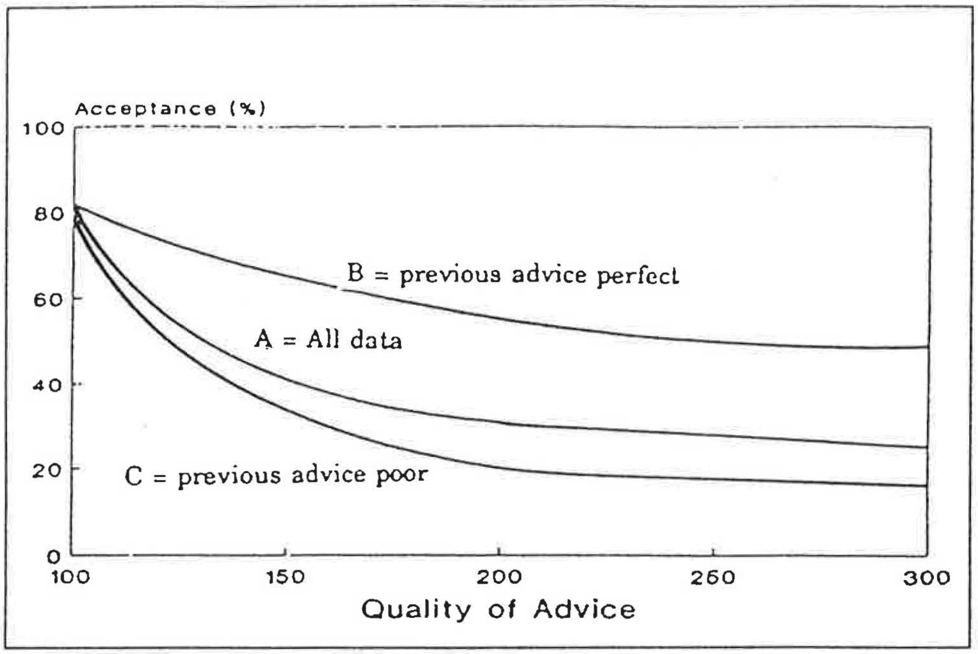
ACTIVE ACCELERATOR, ACTIVE CONTROLS, DRIVE-BY-WIRE, FORCE FEEDBACK, PROPRIOCEPTIVE FEEDBACK, SMART-CAR, SPEED ENFORCEMENT

REFERENCE

Godthelp, H. and Shumann, J. (1991). The use of an intelligent accelerator as an element of a driver support system. *Proceedings of the 24th ISATA Conference*, Florence, Italy, pp. 615-622. (See also Schumann, J., Godthelp, J. and Hoekstra, W. An exploratory simulator study on the use of active control devices in car driving. Soesterberg, Netherlands: TNO Institute for Perception. Report No. 1ZF1992 B-2, May, 1992.)

COMPLIANCE WITH ROUTE GUIDANCE INFORMATION

COMPLIANCE AS A FUNCTION OF QUALITY



RESULTS

The graph shows results of acceptance of route guidance information based on an objective quality measure. The abscissa in the graph is 100 times the ratio of the minimum time to the destination via the advised exit divided by the minimum time to the destination via the optimal exit. The ordinate is the percent of those accepting (heeding) the route guidance advise. Results are shown for three situations: A: all data, in which the accuracy (called quality) of the route guidance advice varied; B: data in which previous advice had always been correct, and C: data in which previous advice had been inaccurate (poor quality).

The results show that under the best conditions only about 80% of drivers will heed route guidance information. This percentage decreases as a function of quality of previous advice and assessed quality of present advice. The results are important for IVHS planning because they indicate that perceived quality of advice is extremely important in the driver's decision to divert to an advised route.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 350
Age Distribution of Subjects: Working-age individuals.
Subject Characteristics: (unstated). Subjects appeared to be ordinary drivers from England and France who drove to work. (Subjects were interviewed at their place of work.)

Subject Tasks: Subjects used "IGOR," an interactive route choice simulator designed for the study of drivers' compliance with route guidance advice. The simulator is PC based. The driver makes a series of journeys through IGOR's networks by indicating which exit he or she would take from each junction reached. Advisory guidance is displayed, which the driver may or may not heed.

KEY TERMS

ALTERNATE ROUTE SELECTION, DRIVER DECISION MAKING, IVHS, ROUTE DIVERSION, ROUTE GUIDANCE, TRAFFIC CONGESTION

REFERENCE

Bonsall, P. W. and Joint, M. (1991). Driver compliance with route guidance advice: the evidence and its implications. Warrendale, PA: Society of Automotive Engineers (SAE). *Vehicle Navigation and Information Systems Conference, P-253, Part 1* (October) (SAE Paper No. 912733), pp. 47-56.

DETECTING DROWSINESS AND B.A.C. USING OPERATIONAL MEASURES

A. DISCRIMINANT ANALYSIS RESULTS (DETECTION)

Alcohol

Six-minute interval data

	Predicted		
Actual	Impaired	Not Impaired	Total
Impaired	61	29 (32.22%)	90
Not impaired	13 (14.44%)	77	90
Total	74	106	180

Model variables: HRTRTM, HANTRAN, SMREV, LANDEVSQ
APER = 23.3%

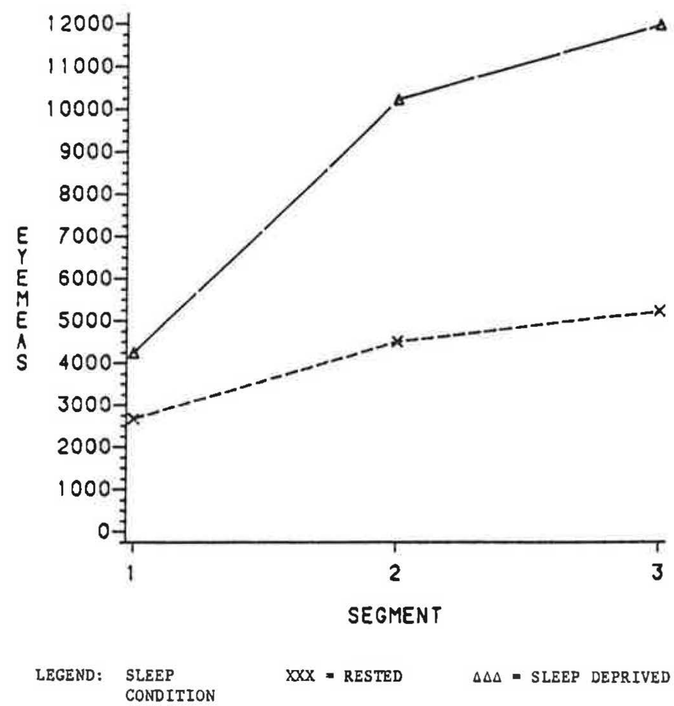
Drowsiness/Time on Task

Six-minute interval data

	Predicted		
Actual	Impaired	Not Impaired	Total
Impaired	20	8 (28.57%)	28
Not impaired	4 (2.63%)	148	152
Total	24	156	180

Model variables: LATPOSM, STEXEED, STVELVAR, SEATMOV, LGREV
APER = 6.7%

B. EYE CLOSURE



RESULTS

A. The discriminant analyses show the capabilities of detection algorithms to detect alcohol (0.05% BAC) and drowsiness. While alcohol produces an apparent error rate (APER) of 23.3%, the drowsiness produces an APER of 6.7%. The alcohol detector used a linear combination of heart rate, hand-off-wheel time, small steering reversals, and square of lane deviation. The drowsiness detector used lateral deviation, steering velocity exceedence, steering velocity variance, number of seat movements, and number of large steering reversals.

   The results show that *drowsiness detection* using operational measures is feasible. The relatively low APER indicates low misclassification rates using a linear combination of operational measures as the source of determination (detection) of drowsiness.

B. The graph shows that the eyelid closure measure is sensitive to time on task and that it is even more sensitive to sleep deprivation combined with time on task. The study used eye closure computed over six-minute intervals as the defining element for the discriminant analyses in A (Drowsiness/Time on task matrix).

   Other results in the paper show correlations in the range of 0.4 to 0.6 between eye closure measures and lane-keeping measures.

   The results suggest that eye closure is a good measure of drowsiness, even though it may not be operationally detectable at present.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 6 each in four conditions: rested/sleep deprived and sober/alcohol (all combinations).
Age Distribution of Subjects: young adults
Subject Characteristics: licensed American drivers, currently driving at least 2000 miles per year.
Subject Tasks: Subjects drove a computer-controlled moving-base simulator in four different runs of 90 minutes each. Operational measures were computed along with computed level of eyelid closure for later discriminant analysis computations.

KEY TERMS

ALCOHOL, DRIVER PERFORMANCE, DRIVER STATUS, DRIVING TASK, DROWSINESS, FATIGUE, TIME ON TASK

REFERENCE

Dingus, T. A., Hardee, H. L., and Wierwille, W. W. (1987). Development of models for on-board detection of driver impairment. *Accident Analysis and Prevention, 19* (4), 271-283.

DETECTION OF DROWSY DRIVERS BY SUBSIDIARY TASKS

DISCRIMINANT ANALYSIS RESULTS

(a) AUDITORY TASK

		PREDICTED: IMPAIRED	PREDICTED: NOT IMPAIRED
ACTUAL	IMPAIRED	52	3
	NOT IMPAIRED	2	3

APER = 8.3%

MEASURES: NUMHIT, HRTRTV

(b) VISUAL TASK

		PREDICTED: IMPAIRED	PREDICTED: NOT IMPAIRED
ACTUAL	IMPAIRED	54	1
	NOT IMPAIRED	1	4

APER = 3.3%A

MEASURES: NUMHIT, HRTRTV

RESULTS

The results show that performance on a subsidiary task, combined with heart rate variance, produced an accurate classification of drowsiness. Drowsiness was defined in terms of amount of slow eyelid closure, a measure evolved in earlier research. For 60 classification intervals of six minutes each, only 5 were misclassified using an auditory subsidiary task and 2 were misclassified using a visual subsidiary task. The subsidiary task was a choice reaction time task in which the input to the driver was (a) auditory or (b) visual, and the output was by pushbutton activation, with buttons mounted on the steering wheel. The task measure used for the discriminant analyses was NUMHIT, the number of correct responses per six-minute interval. The independent variable for this discriminant analysis was a measure of slow eyelid closure.

The results are important to driver performance/status monitoring, because they show the feasibility of detecting impairment due to drowsiness by using a subsidiary task.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 12
Age Distribution of Subjects: (not specified)
Subject Characteristics: Ordinary American drivers with 20/30 far visual acuity and the ability to hear 40 dB tones presented to each ear. Half the subjects were male, the other half female.
Subject's Tasks: Subjects were kept awake until midnight and were not allowed to ingest stimulants. They then drove a moving-base computer-controlled driving simulator for 2 1/2 hours. (Data were gathered for the last two hours.)

KEY TERMS

DRIVER PERFORMANCE, DRIVER STATUS, DRIVING TASK, DROWSINESS, FATIGUE, SECONDARY TASK, SUBSIDIARY TASK, TIME ON TASK

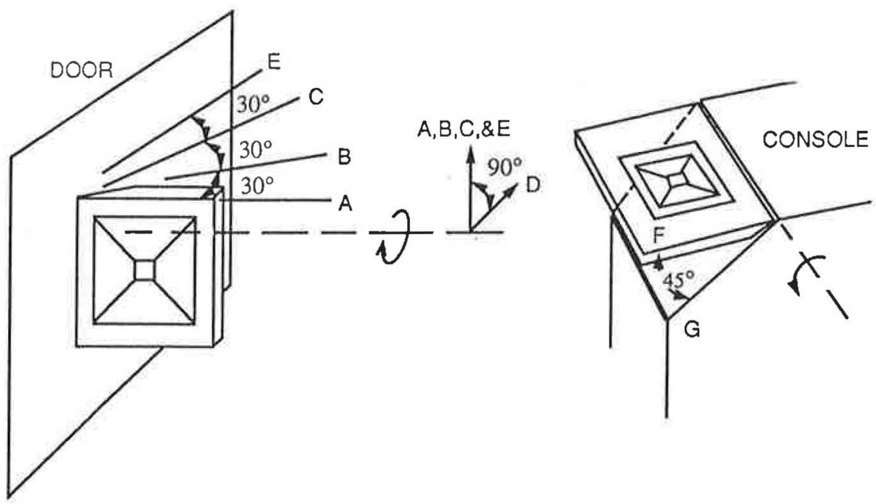
REFERENCE

Hardee, H. L., Dingus, T. A., and Wierwille, W. W. (1986). Driver drowsiness detection using subsidiary task and driving performance measures. Santa Monica, CA: Human Factors Society. *Proceedings of the Human Factors Society 30th Annual Meeting, 1986, Vol. 1*, pp. 398-402 (September).

DIRECTION-OF-MOTION STEREOTYPES
FOR IN-VEHICLE CONTROLS

PAD POWER MIRROR CONTROLS ON DOOR PANEL AND CONSOLE

Condition	Orientation of Control	Mirror Movement				Overall
		Down	Up	Left, Away from Subj.	Right, toward Subj.	
A	Vertical plane 90° to door plane	1.00B	0.98T	0.98L	0.98R	197/200 = 0.99
B	Vertical plane 60° to door plane	1.00B	0.94T	0.98L	0.96R	194/200 = 0.97
C	Vertical plane 30° to door plane	0.96B	0.94T	0.98L	0.98R	193/200 = 0.97
D	Horizontal plane extending from door (e.g., arm rest)	0.80A	0.82F	0.88L	0.94R	172/200 = 0.86
E	Vertical plane flush with door	0.82B	0.86T	0.70L	0.72R	155/200 = 0.78
F	Horizontal plane on console	0.94A	0.96F	0.98L	1.00R	194/200 = 0.97
G	Console plane sloping 45° down and away from driver	0.52F*	0.58F*	0.94L	0.92R	148/200 = 0.74



Chosen Direction Key
- B : Bottom Quadrant of Pad
- T : Top Quadrant of Pad
- L : Left Quadrant of Pad as Viewed by Driver
- R : Right Quadrant of Pad as Viewed by Driver
- A : Aft Quadrant of Pad
- F : Fore Quadrant of Pad
- * : Indicates Conflict in Chosen Directions

RESULTS

The results show the stereotype strength (degree of agreement) on power mirror pad switch control directions. A numerical value of 1.00 indicates perfect agreement among subjects (and the strongest possible stereotype strength) whereas a value of 0.50 indicates the weakest strength in a dichotomous-choice situation.

The results show that conditions A, B, C, and F produce strong stereotypes. These are believed to be a result of one-to-one geometric mapping of the pad switch control motions with the mirror itself (that is, good display-control compatibility). Condition G, in which the switch is on the console and slanted away from the driver results in a weaker stereotype.

The paper also presents stereotype strength results for a variety of other in-vehicle controls, including:

1. Door-mounted joystick controls for power mirrors.

2. Door-mounted controls for power windows, including

   (a) 2 x 2 toggle switches,
   (b) 1 x 4 toggle switches,
   (c) 2 x 2 rocker switches, and
   (d) 2 x 2 push-pull switches

3. Door-mounted (left and right) crank controls for manual windows.

4. Left and right multipurpose steering wheel stalk controls.

5. Thumbwheel, toggle switch, linear slide, rotary, and rocker switch controls mounted on the instrument panel in a variety of orientations, and

6. Power door lock toggle switches mounted on the door panel.

The results presented in the paper are important to the design of in-vehicle controls and their corresponding displays because they indicate for a wide variety of situations the degree of movement consensus in the driving population. As a result, control type, mounting position, and direction of motion can in most cases be selected so that there is little or no confusion in use.

TEST CONDITIONS/PROCEDURES

Number of subjects: 200, four groups of 50
Age Distribution of Subjects: Two equal-size age groups: 18 to 45 years, and 46-86 years.
Subject Characteristics: Licensed American drivers, selected to match the car-buy public. Seventy percent in each group drove domestic nameplate vehicles, and thirty percent drove foreign nameplate vehicles. Each group had approximately equal numbers of males and females.
Subject Tasks: Subjects selected a direction (and in some cases, the type) of movement after being requested to perform a certain task (e.g., lower the passenger side front window). They performed these tasks in a buck (static simulator) in which the controls could be easily changed in terms of type, location, and orientation.

KEY TERMS

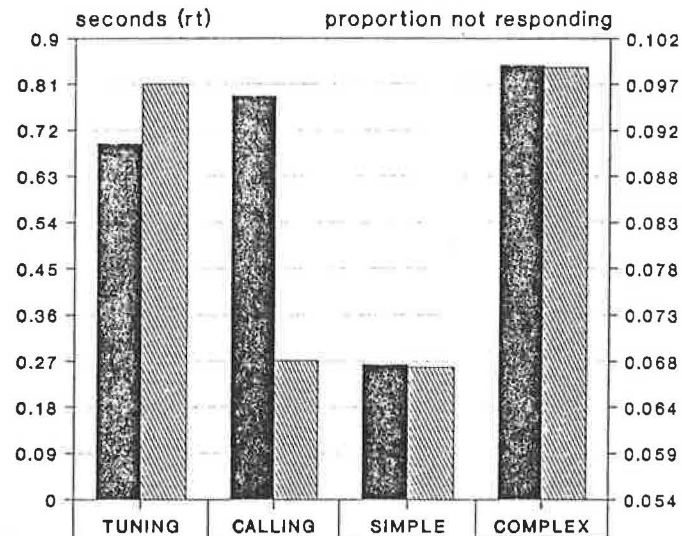
ACTUATION ERRORS, CONTROL DESIGN, CONTROL-DISPLAY COMPATIBILITY, DIRECTION-OF-MOTION STEREOTYPES, INSTRUMENT PANEL DESIGN, IN-VEHICLE CONTROLS, POPULATION STEREOTYPES

REFERENCE

Wierwille, W. W. and McFarlane, J. (1991). Overview of a study on direction-of-motion stereotype strengths for automobile controls. Warrendale, PA: Society of Automotive Engineers (SAE). Paper No. 910115, presented at the International Congress and Exposition, Detroit, MI (February).

DISTRACTION EFFECTS OF CELLULAR PHONING AND RADIO TUNING

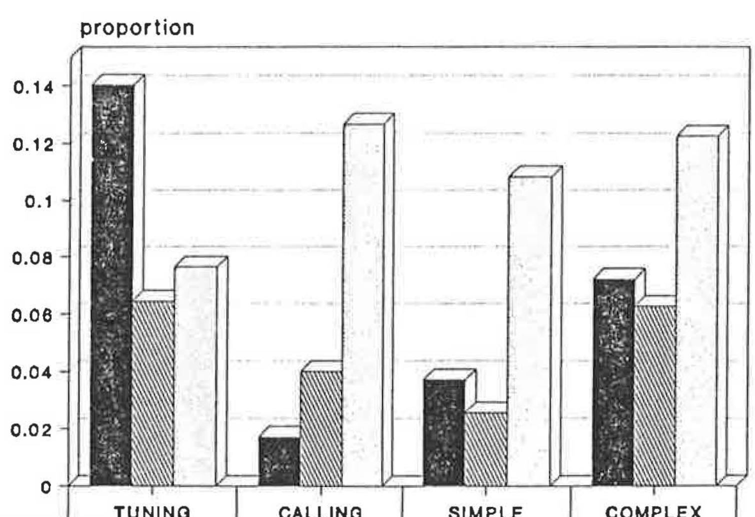
A. INCREASES IN RESPONSE TIMES AND PROPORTIONS OF NON-RESPONSES



	TUNING	CALLING	SIMPLE	COMPLEX
response time	0.694	0.787	0.264	0.847
not responding	0.097	0.068	0.068	0.099

DISTRACTION TYPE

B. PROPORTIONS OF NON-RESPONSES AS A FUNCTION OF AGE



	TUNING	CALLING	SIMPLE	COMPLEX
17-25	0.14	0.017	0.037	0.072
26-49	0.064	0.04	0.026	0.063
50-80	0.077	0.127	0.108	0.123

DISTRACTION TYPE

RESULTS

A. The results show mean increases in response times and proportions of non-responses to traffic events. The study was performed using edited videotapes of roadway events played back and displayed while subjects performed various cellular telephoning tasks. For comparison, a radio tuning task and a "no-task" segment were also included. The three telephone tasks were dialing a number, holding a simple conversation, and holding a complex (math and short-term memory problems) conversation. Note that for purposes of graphing, the response times for each cell *include* the non-response data by substituting the longest response time for the cell.

The results show that driver's attention to details in the forward driving scene is decreased when cellular phoning or radio tuning are performed. The results suggest that complex in-vehicle tasks do in fact increase the response time and likelihood of hazard detection.

B. The results show that for cellular phoning older drivers missed more traffic events than did middle-age or young drivers. Radio tuning did not have the same effect. In fact, younger drivers missed more events.

Additional results show that older drivers had large increases in response times while dialing.

The results suggest that older drivers are less able to handle the additional task of cellular phoning, probably because of slowing cognitive processes and decreases in visual performance.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 151
Age Distribution of Subjects: 45 subjects 25 and under; 57 subjects 26 to 49; 49 subjects 50 and over.
Subject Characteristics: Licensed American drivers without overt problems. No other qualifications, so that a typical cross section would be obtained.
Subject Tasks: Drivers drove an open-loop simulator using a steering wheel, accelerator, and brake. They performed instructed telephoning and radio tuning tasks. Measures were computed from the steering, braking, and accelerating responses (or lack thereof) of the drivers.

KEY TERMS

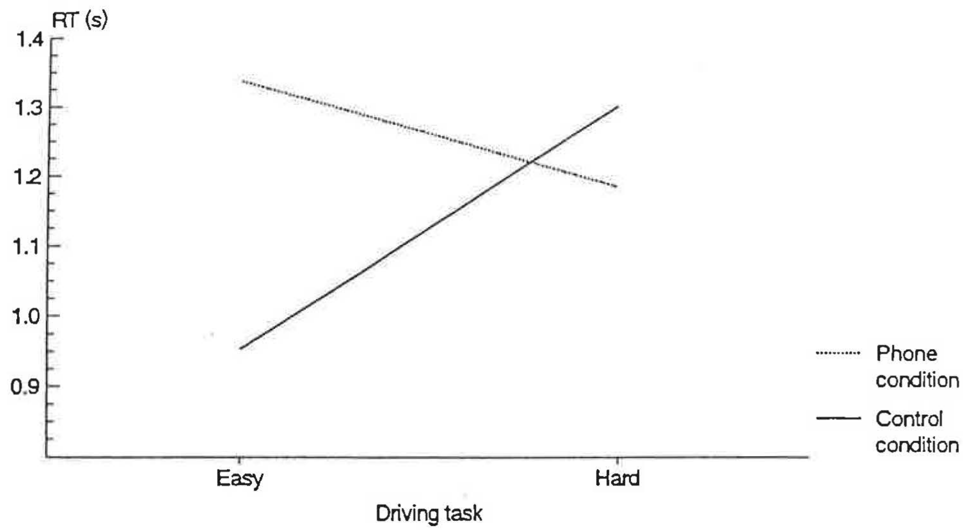
CELLULAR TELEPHONING, DRIVER DISTRACTION, DRIVER WORKLOAD, IVHS, PERCEPTION-RESPONSE TIME, TASK DEMANDS, TARGET DETECTION

REFERENCE

McKnight, A. J. and McKnight, A. S. (1991). The effect of cellular phone use upon driver attention. Landover, MD: National Public Services Research Institute (8201 Corporate Drive, Suite 220, Landover, MD 20785). (Sponsored by AAA Foundation for Traffic Safety, Washington, DC 20036.) (January) (No Report Number.)

EFFECTS OF CELLULAR PHONE USE ON DRIVER BEHAVIOR AND WORKLOAD

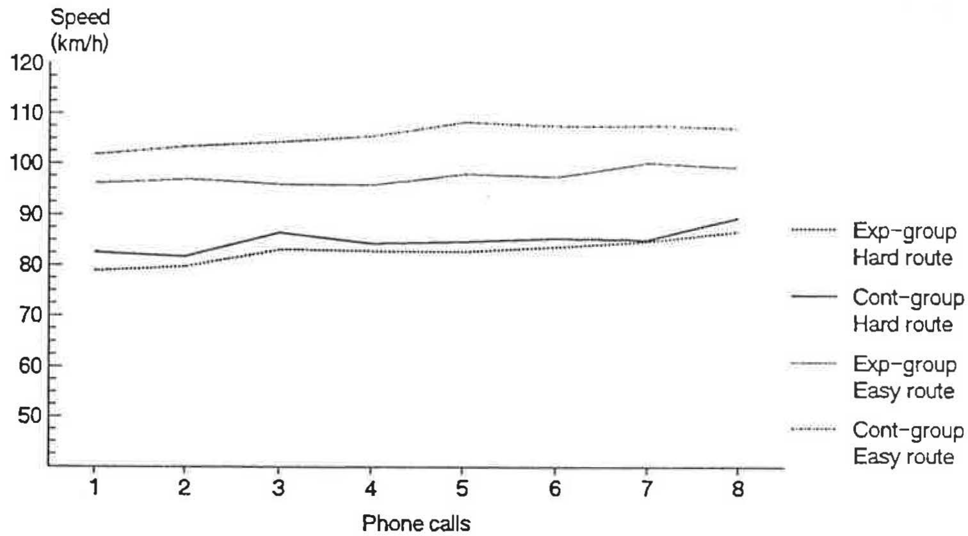
A. INTERACTIVE EFFECT OF DRIVING TASK AND PHONE USAGE ON EMERGENCY REACTION TIME



B. SIGNIFICANT PHONE USAGE EFFECTS ON DRIVING RATING SCALES

Factor	Source	df	F	p
Mental demand	RTI	1,36	30.40	.0001
Physical demand	RTI	1,36	5.18	.0289
Time pressure	RTI	1,36	6.72	.0137
Operator performance	RTI	1,36	7.01	.0119
Operator effort	RTI	1,36	5.05	.0308
Frustration level	RTI	1,36	6.62	.0143
Frustration level	RTI*ROU	1,36	5.95	.0198

C. EFFECTS OF PHONE USE ON SPEED



RESULTS

A. The graph shows an interactive effect in which brake reaction time to a simulated emergency at the roadside increases with phone usage, but only when the roadway is easy to drive. Under more demanding (heavily curved) road conditions, there is no effect.

The results suggest that drivers adapt to difficult conditions, that is, they do not allow internal (phoning) and external (difficult driving) conditions to increase their response to emergencies beyond specific limits.

B. The table shows that phone usage caused significant increases in workload-component rating scales (NASA-TLX), as well as a significant interaction of phone use and route difficulty for the "frustration" component scale. (In the table RTI represents the absence/presence of phone usage and ROU represents the easy/hard driving task scenarios.)

The results indicate that drivers experienced greater workload when using a cellular phone and that they experienced greater frustration when using the phone under difficult roadway conditions.

C. The graph shows the interactive effect of phone use and route difficulty on vehicle speed. Drivers slowed (to approximately the same speed) under difficult route conditions, whether or not they were using the cellular phone. On the other hand, for the easy route, drivers showed a bit when using the cellular phone (as compared with non-usage), but not as much as when driving the difficult route.

The results again suggest that phone use influences performance, but only under easy driving conditions. In other words, drivers adapt to difficult driving conditions and do not allow phone use to cause additional effects.

Other findings suggest that phone use may influence selection of mean lane position. However, such effects could have numerous causes.

In regard to IVHS, the results of the experiment suggest that driver behavior under complex combinations of workload may not be readily predictable.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 40
Age Distribution of Subjects: 23 to 61 years; mean age: 32, standard deviation of age: 9.5.
Subject Characteristics: 20 males, 20 females. Experienced Swedish drivers (at least 5 years and 10000 km/year).
Subject Tasks: Subjects drove a moving base computer controlled simulator (VTI) in four counterbalanced runs: two roadway conditions (easy/hard) x two phone conditions (present/absent). In the phone runs, subjects answered questions (yes/no) from "The Working Memory Span Test" using a hands-free telephone, and had to memorize the last word of each presentation for later recall. They also responded by braking to a red square marker appearing at the right edge of the roadway scene.

KEY TERMS

CELLULAR TELEPHONING, DRIVER DISTRACTION, DRIVER OPINION RATING, DRIVER WORKLOAD, IVHS, PERCEPTION-RESPONSE TIME, TASK DEMANDS

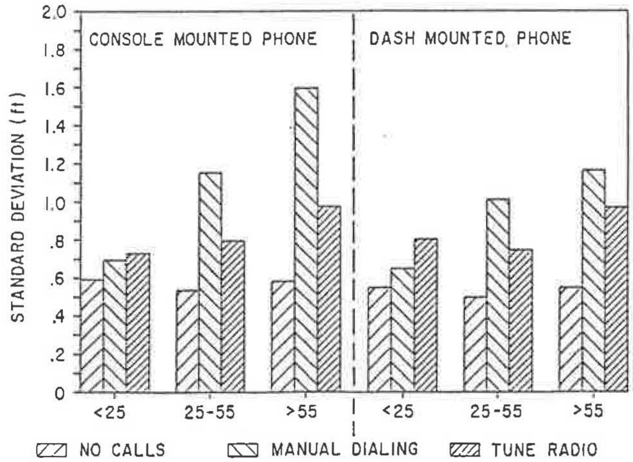
REFERENCE

Alm, H. and Nilsson, L. (1991). Changes in driver behavior as a function of hands-free mobile telephones - a simulator study. Linkoping, Sweden: Swedish Road and Traffic Institute. Paper No. 175 (ISSN 0347-6049). (Also appearing as Report No. 47, DRIVE Project V1017 (Bertie), Changes in Driver Behavior Due to the Introduction of RTI Systems, October, 1990.)

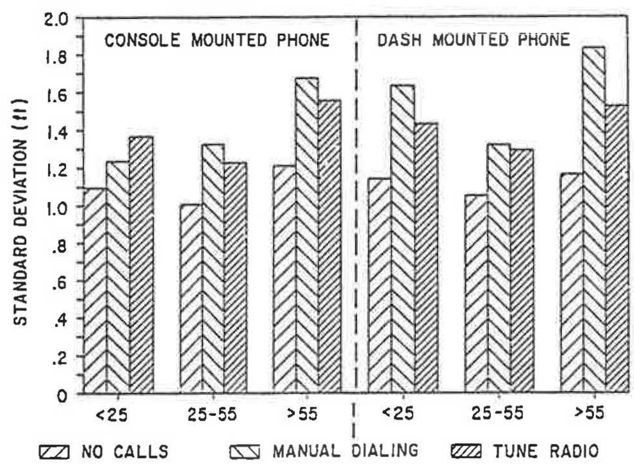
EFFECTS OF CELLULAR PHONE USE ON DRIVING PERFORMANCE

A. LANE POSITION DEVIATION FOR MANUAL DIALING

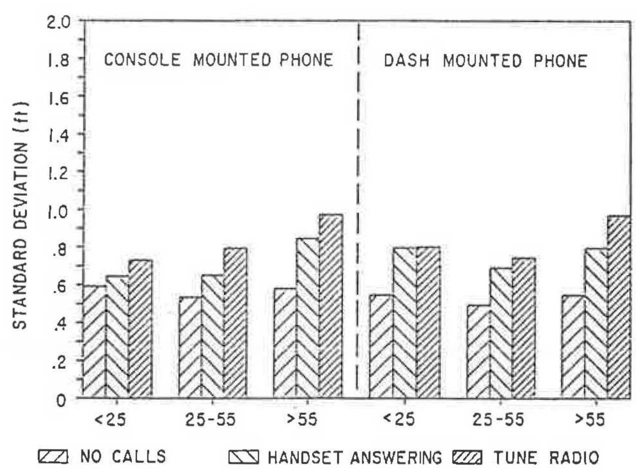
(a)



(b)



B. LANE POSITION DEVIATION FOR HANDSET ANSWERING



C. INCREASE IN PROBABILITY OF OBSTACLE COLLISION AND LANE EXCEEDENCE

TASK	AGE GROUP	PHONE LOCATION	INCREASE IN PROBABILITY OF: HITTING OBSTACLE	EXCEEDING LANE BOUNDARY
CALL ORIGINATION Manual	Young	Console	---	---
	Middle		5x	---
	Older		5x	---
Memory	Young		---	---
	Middle		---	---
	Older		---	---
Voice	Young		---	---
	Middle		---	3x
	Older		---	---
Manual	Young	Dash	---	---
	Middle		1.6x	---
	Older		1.5x	---
Memory	Young		---	---
	Middle		---	---
	Older		---	---
Voice	Young		---	---
	Middle		1.5x	---
	Older		---	---
CALL RECEIVING Handset	Young	Both	---	---
	Middle		---	---
	Older		---	---
Hands Free	Young	Both	---	---
	Middle		0-3x	---
	Older		0-5x	0-2x
RADIO TUNING	Young	---	---	---
	Middle		---	---
	Older		5-7x	---

RESULTS

A. (a) The results show that for straight road situations, standard deviation of vehicle position in lane increases when manually dialing a cellular phone. Furthermore, the task interacts with age and with phone position in the vehicle. Older drivers and console mounting (as opposed to dash mounting) caused increases in deviations. The effects are greater than those obtained when manually tuning a radio to a given frequency.

(b) The results were obtained under similar conditions, except that road sections were curved (instead of straight). They show that drivers had greater lane position deviations even when not performing additional tasks. Nevertheless, manual dialing still results in an increase in deviation.

B. The results show that straight-road phone answering, whether by handset or hands-free mode, generally causes an increase in deviation of the vehicle. However, the increased deviation is not as great as when dialing, nor as when tuning the radio manually.

C. The results show the estimated increases in the probability of colliding with an obstacle moving into the roadway and in the probability of lane exceedence as a function of the type of in-vehicle (phone or tuning) task.

All of these results demonstrate clearly that dialing a cellular telephone manually while driving can be hazardous, and that console mounting with its large angular disparities between the forward scene and the keypad increases the hazard. Furthermore, older drivers are more susceptible to the hazard than younger drivers.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 72
Age Distribution of Subjects: three equal size groups: under 25, 25 to 55, and over 55 years.
Subject Characteristics: American drivers. Half of each group were females, and half were males. In the young and middle age groups, half the males and half the females were cellular phone users. In the older age group only a few cellular phone users were included (because a sufficient number could not be found.)
Subject Tasks: Subjects drove a fixed-base computer controlled simulator while heeding traffic signs. They performed various cellular phone tasks and also occasionally had to avoid an obstacle that moved from the road edge into the travel lane.

KEY TERMS

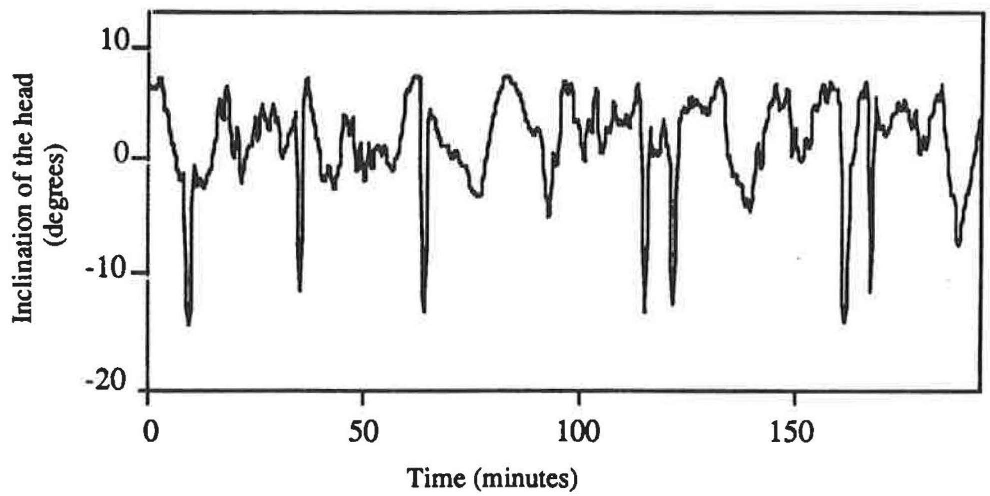
CELLULAR TELEPHONING, DRIVER DISTRACTION, DRIVER WORKLOAD, LANE KEEPING, OBSTACLE AVOIDANCE, TASK DEMANDS

REFERENCE

Stein, A. C., Parseghian, Z., and Allen, R. W. (1987). A simulator study of the safety implications of cellular mobile phone use. Hawthorne, CA: Systems Technology, Inc. Paper No. 405 (March). (See also *31st Annual Proceedings, American Association for Automotive Medicine*, New Orleans, LA, Sept., 1987.)

HEAD INCLINATION ANGLE AND VIGILANCE

TYPICAL INCLINATION ANGLE WHILE DRIVING



RESULTS

The study consisted of measuring head inclination and comparing it with a derived EEG-related measure of vigilance. The EEG measure (which included a derived relationship between alpha and beta wave amplitudes) was divided into three categories, one being high vigilance, one being average vigilance, and one being low vigilance. Measures were taken for 15 second intervals.

The results show a statistically significant relationship between absolute head inclination and vigilance, namely, inclination increased with decreased vigilance.

Additional analysis in the paper showed that reverse inclination (head backward) was strongly related to low vigilance.

TEST CONDITIONS/PROCEDURES

Number of Subjects: (unspecified, but more than 1)
Age Distribution of Subjects: (unspecified)
Subject characteristics: (unspecified, French drivers)
Subject Tasks: drivers drove a total of four hours on a motorway in an instrumented vehicle.

KEY TERMS

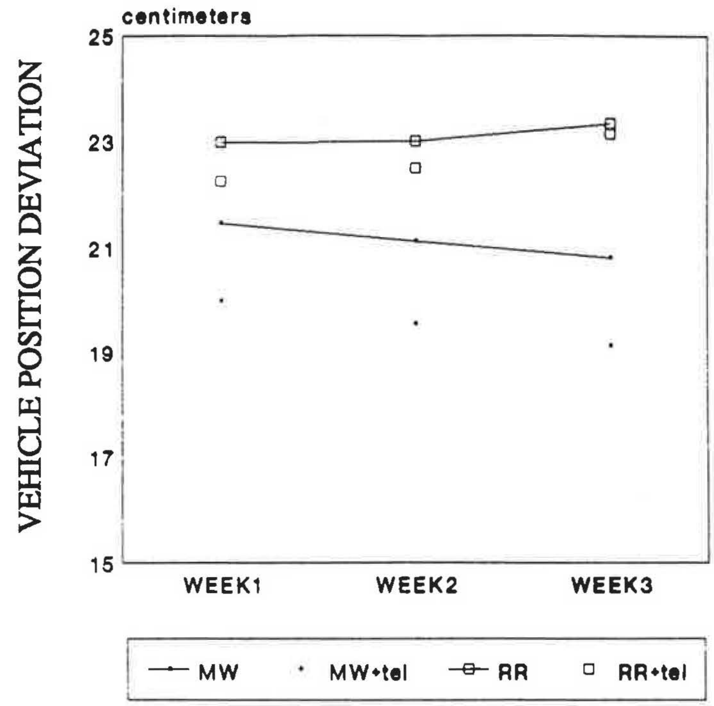
DRIVER PERFORMANCE, DRIVER STATUS, DRIVING TASK, DROWSINESS, FATIGUE, TIME ON TASK, VIGILANCE

REFERENCE

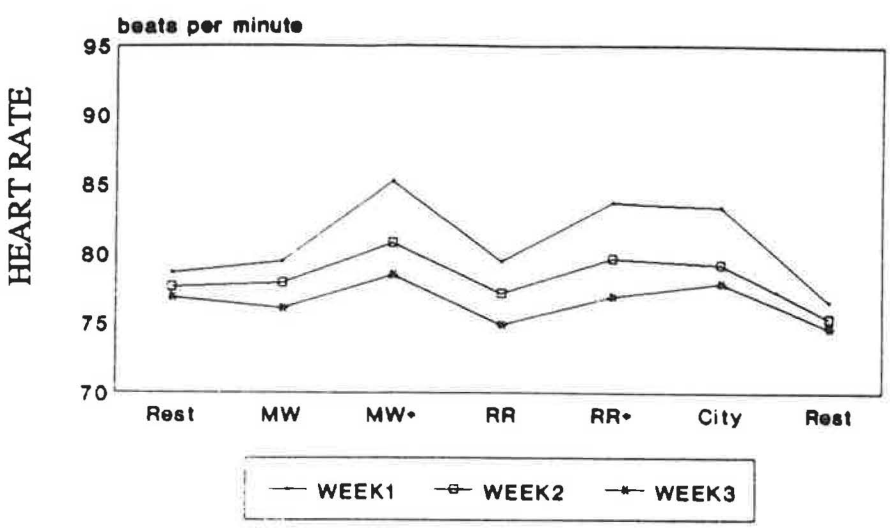
Vallet, M., Fakhar, S., Olivier, D., and Baez, D. (1991). Detection and control of the degree of vigilance of drivers. Bron cédex, France: INRETS (Institut National de Recherch sur les Transports et Leur Sécurité Laboratoire Energie Nuisances). Paper No. 91-52-0-10, October.

PERFORMANCE EFFECTS OF CELLULAR TELEPHONING

A. EFFECTS ON LANE DEVIATION



B. EFFECTS ON HEART RATE



RESULTS

A. The results show that the standard deviation of lateral position in the lane appears to be reduced when using an in-car phone. Results are shown for a motorway (MW) and for a ring road (RR). The act of mobile communication appears to have a favorable effect on lane keeping.

The results suggest a facilitative effect. However, it is possible that drivers exerted extra effort while telephoning to compensate for any potential loss of control. In any case, telephoning did not affect lane keeping adversely.

B. The results show how heart rate was affected by the task and by acclimatization. In the cases where telephoning took place (MW+ and RR+), heart rate increased slightly.

The results suggest that telephoning while driving induces a slightly higher level of autonomic activity or arousal. Time on task has the opposite effect (which is in agreement with many previous research studies.)

Other results of the research indicate that there were no age effects and no effect of hands-free vs. hand-held operation.

TEST CONDITIONS/PROCEDURES

Number of subjects: 12 (10 male, 2 female)
Age Distribution of Subjects: 3 equal-size groups, 23-35, 35-50, and 50-65 years.
Subject Characteristics: Dutch drivers with at least five years driving of at least 5000 km/year. No previous experience with mobile telephones.
Subject Tasks: Subjects drove each weekday for three weeks. Performance was tested with and without mobile phone usage under three conditions: light traffic on a quiet motorway, heavy traffic on a four-lane ring road, and in city traffic. Subjects performed paced-addition over the telephone. Half of the subjects used a hand-held unit, and half used a hands-free unit.

KEY TERMS

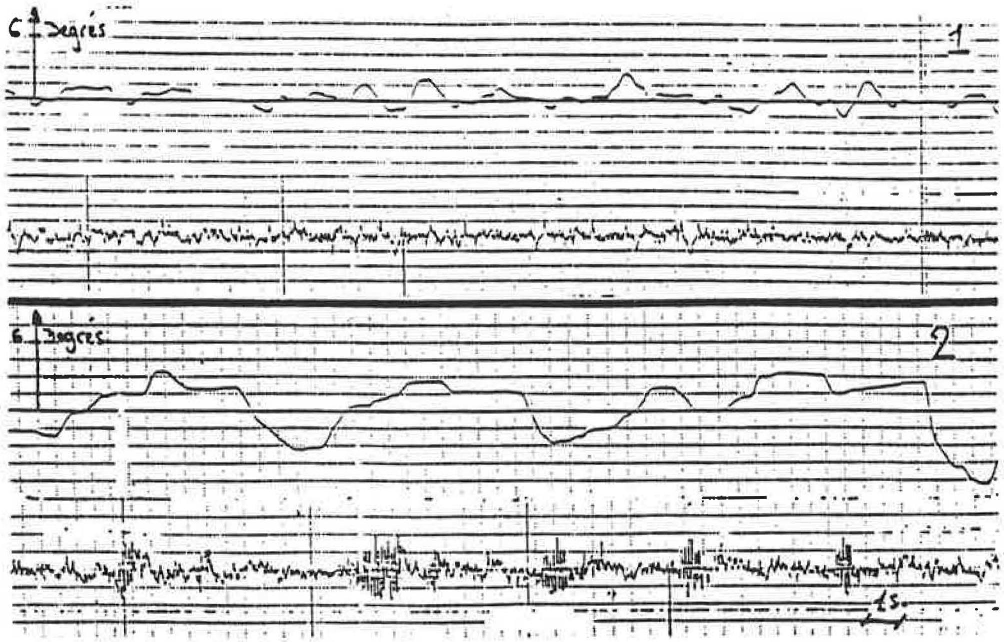
CELLULAR TELEPHONING, DEMANDS, DRIVER DISTRACTION, DRIVER WORKLOAD, PHYSIOLOGICAL MEASURES, TASK DEMANDS, LANE KEEPING

REFERENCE

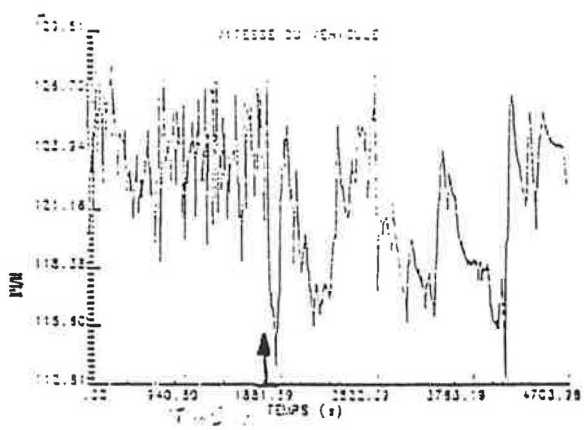
Brookuis, K. A., deVries, G., and deWaard, D. (1991). The effects of mobile telephoning on driving performance. *Accident Analysis and Prevention, 23*(4), 309-316.

RELATIONSHIPS BETWEEN DRIVER ALERTNESS, EEG, STEERING ANGLE, AND SPEED

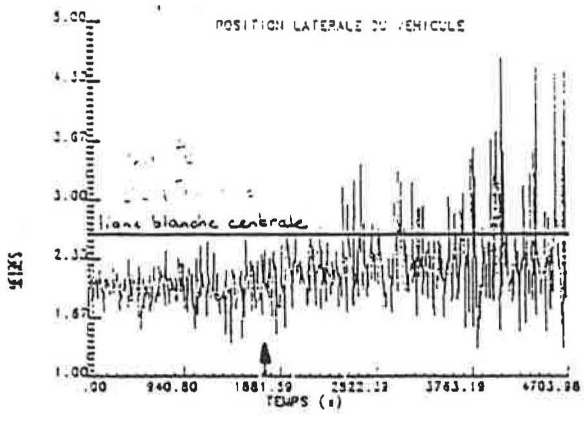
A. STEERING ON STRAIGHT SECTIONS AND EEG FOR ALERT (1) AND DROWSY (2) CONDITIONS



B. SPEED (a) AND LATERAL POSITION (b) CHANGES WITH DROWSINESS

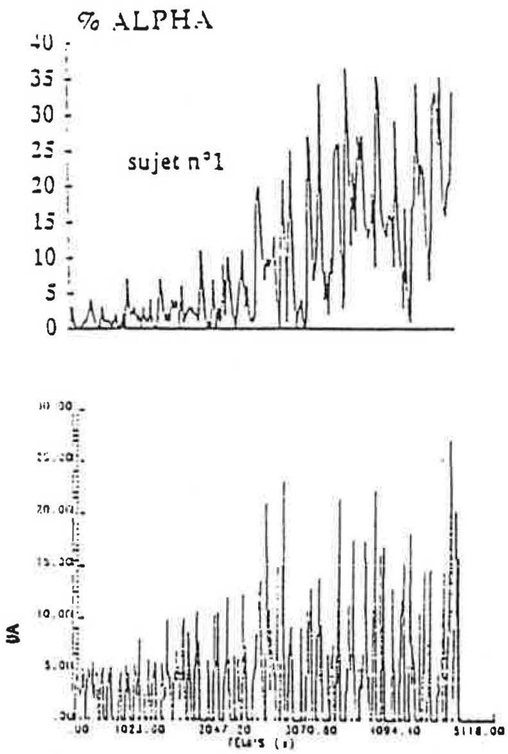


(a)

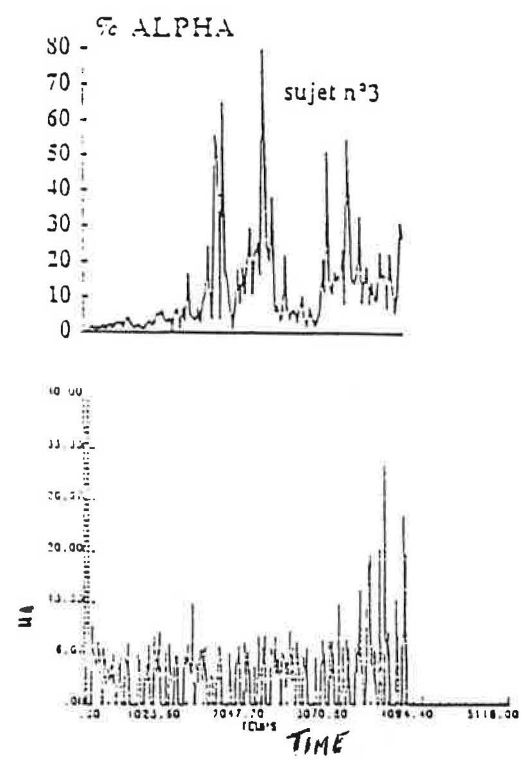


(b)

C. EEG ALPHA AMPLITUDE AND STEERING AMPLITUDE FOR SUBJECT WITH CORRESPONDENCE (a) AND FOR SUBJECT WITHOUT CORRESPONDENCE (b)



(a)



(b)

RESULTS

A. The results show that for certain subjects, there is a close correspondence between bursts of alpha waves in the EEG (bottom) trace and larger, coarser steering control (second from bottom trace). The top two traces show results of the same subjects under alert conditions.

   The results show promise in using the EEG alpha wave as a defining indicator of drowsiness. However, the relationship only holds for certain subjects. (See C below. Thus other aspects must be included for a driver status alertness monitoring system.)

B. The results show that vehicle speed maintenance and lateral position deteriorate more or less at the same time as a result of drowsiness. The arrow in the graph shows the point of drowsiness onset, at which time vehicle speed variation (a) increases and lane position variation (b) also begins to increase.

   The results suggest that, at least for some drivers, longitudinal and lateral directional control deteriorate more or less simultaneously with drowsiness; such results could be useful in development of a driver status/alertness monitoring system.

C. The results show that a steering wheel amplitude measure is related to occurrence of alpha bursts in some subjects, for example (a) but not others (b). Here the % of alpha waves in the EEG is shown in the upper traces, and steering amplitude measure in the lower traces.

The results suggest that alpha waves alone are not sufficient to predict steering performance deterioration in all subjects.

Other results suggest that there is a relationship between percent of alpha waves in the EEG and facial expression of drowsiness. Thus, some drowsy drivers can maintain control better than others. All results in the paper are considered by the authors to be preliminary and exploratory.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 27 (16 males, 11 females)
Age Distribution of Subjects: 22 to 56 years (mean of 30.5, standard deviation of 8.18).
Subject Characteristics: Subjects were selected for their tendency to emit alpha waves with their eyes closed. Subjects were Swedish drivers.
Subject Tasks: Subjects drove a 4-degree of freedom moving-base simulator using a monotonous two-lane roadway with no intersections or other vehicles. Straight and small-radius curve sections were interspersed. Data were processed only during straight sections. Subjects were instructed to maintain a speed of 100 to 120 km/h and to remain in the right lane. (Subjects were not sleep deprived.)

KEY TERMS

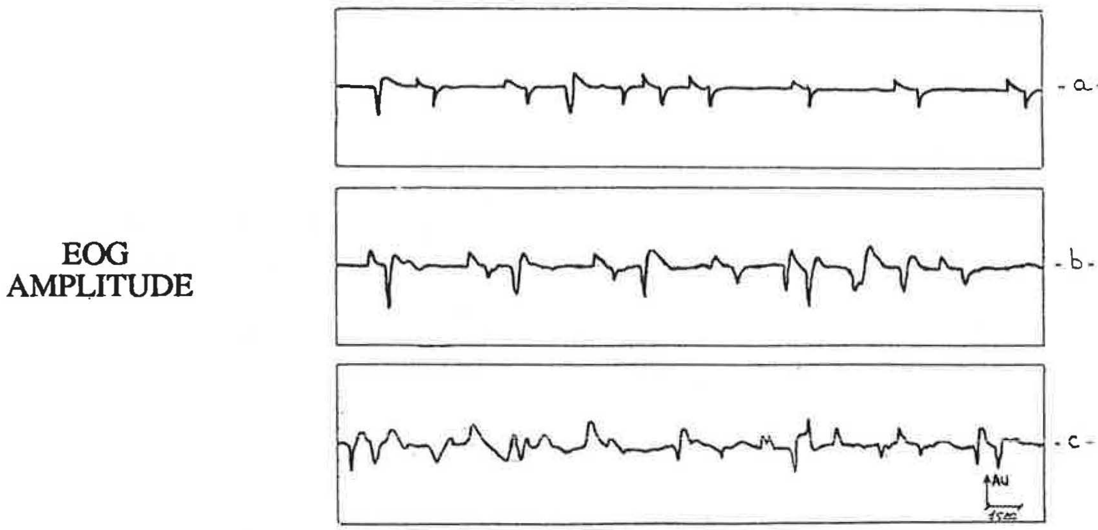
DRIVER PERFORMANCE, DRIVER STATUS, DRIVING TASK, DROWSINESS, EEG, FATIGUE, LANE KEEPING, STEERING BEHAVIOR, TIME ON TASK

REFERENCE

Planque, S., Petit, C., Chapüt, D., and Tarriere, C. (1991). A system for identifying lapses of alertness when driving. Nanterre, France: Renault (Motor Company). (Unpublished paper available from the authors. Department of Environmental Sciences, 132 rue des Suisses - 92000 NANTERRE, France.

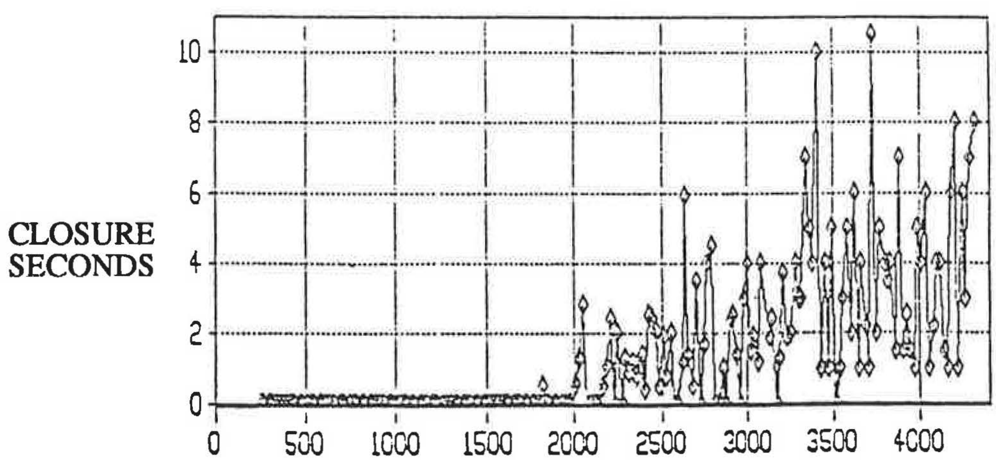
RELATIONSHIPS BETWEEN DRIVER ALERTNESS, EOG, AND EYE CLOSURE TIME

A. EOG (ELECTRO-OCULOGRAM) AS A FUNCTION OF TIME ON TASK (AND ASSOCIATED DROWSINESS). (a, 6 min; b, 30 min; c, 68 min into driving task, with subject falling asleep at 69 min.)



TIME
(Each trace is 21.5 sec in duration.)

B. EYE CLOSURE TIME PER INTERVAL AS A FUNCTION OF TIME ON TASK



INTERVAL NUMBER
(Each interval is 21.5 sec in duration.)

RESULTS

A. The graphic result shows changes (for one subject) in the EOG as the subject goes from a fresh to a drowsy state. The bottom line shows the condition just prior to falling asleep. The EOG no longer contains crisp blinks, but instead shows an irregular decreasing ramp pattern.

The results suggest that EOG which is closely related to eye closures can serve as a definitional measure in driver status/performance monitoring, as earlier investigators have found.

B. This graph shows that eye closures between 6 and 10 seconds in total length occur as precursors to falling asleep. Each point on the graph represents information from a 21.5 second interval.

The results are in agreement with previous investigations showing that slow and prolonged closures are a good indicator of drowsiness onset. Also, there is sufficient time to detect and alarm prior to loss of vehicle control. These results show that slow closure may be used as an independent variable in driver status/performance monitoring.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 27 (16 males, 11 females)
Age Distribution of Subjects: 22 to 56 years (mean of 30.5, standard deviation of 8.18).
Subject Characteristics: Subjects were selected for their tendency to emit alpha waves with their eyes closed. Subjects were Swedish drivers.
Subject Tasks: Subjects drove a 4-degree of freedom moving-base simulator using a monotonous two-lane roadway with no intersections or other vehicles. Straight and small-radius curve sections were interspersed. Data were processed only during straight sections. Subjects were instructed to maintain a speed of 100 to 120 km/h and to remain in the right lane. (Subjects were not sleep deprived.)

KEY TERMS

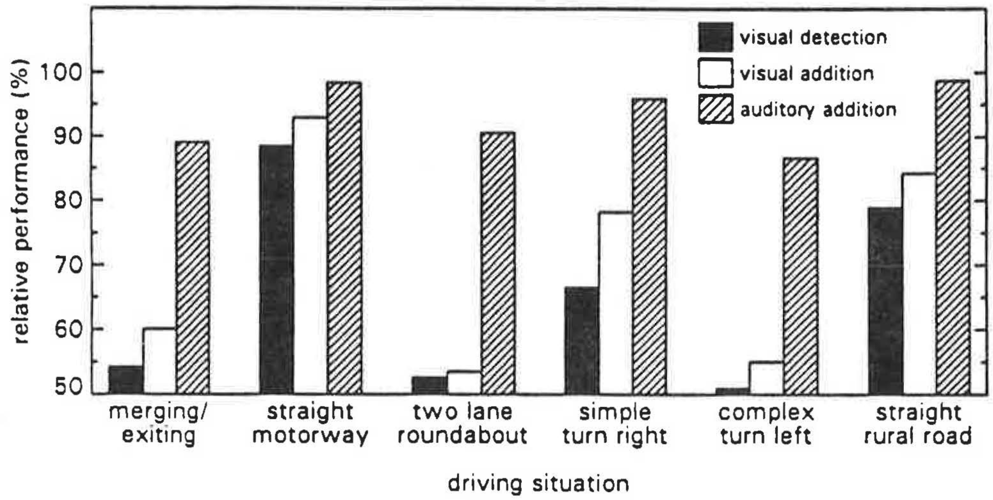
DRIVER PERFORMANCE, DRIVER STATUS, DRIVING TASK, DROWSINESS, EEG, FATIGUE, LANE KEEPING, STEERING BEHAVIOR, TIME ON TASK

REFERENCE

Planque, S., Chapüt, D., Petit, C., Tarriere, C. and Chabanon, C. (1991). Analysis of EOG and EEG signals to detect lapses of alertness in car simulation. Paper presented at the 13th Experimental Safety Vehicle (ESV) Conference, Paris, France (November), Paper No. 91-54-W-17.

SECONDARY TASK PERFORMANCE AS A FUNCTION OF DRIVING TASK

SECONDARY TASK PERFORMANCE



RESULTS

The results show the percent of change from baseline for three different kinds of secondary tasks as a function of driving task. Baseline performance consisted of performing the corresponding secondary task by itself. The three secondary tasks employed were:

visual detection (presented on an in-car plasma display, but otherwise not specified in the paper),

visual addition (presented on the plasma display consisting of adding 12 to presented numbers; response was verbal), and

auditory addition (presented by a digitally recorded male voice, consisting of adding 12 to presented numbers; response was verbal.)

The results indicate that auditory secondary tasks are affected very little by changes in the driving task, whereas visual secondary tasks are affected. Thus, addition of tasks to the driving environment can be expected to result in differing levels of additional task performance, depending on the type of resource needed to service the additional tasks.

TEST CONDITIONS/PROCEDURES

Number of Subjects: 24
Age Distribution of Subjects: 20 to 30 years
Subject Characteristics: 12 drivers were experienced, having driven for five or more years and more than 10000 km per year. The other 12 were inexperienced, having possessed their license less than one year and having driven less than 10000 km. Half of each group were male, the other half females. Drivers were Dutch.

Subject Tasks: Subjects drove an instrumented vehicle on public roads while performing the secondary tasks. They also performed the secondary tasks by themselves to establish baselines.

KEY TERMS

DISPLAY DESIGN, DRIVER ATTENTIONAL DEMAND, DRIVER DISTRACTION, DRIVER WORKLOAD, IN-VEHICLE DISPLAYS, LANE KEEPING, MULTIPLE RESOURCE THEORY, SECONDARY TASKS, SUBSIDIARY TASKS, TASK DEMANDS, VISUAL DEMANDS

REFERENCE

Verwey, W. B. (1991). Adaptive interfaces based on driver resource demands. In Y. Queinnec and F. Daniellou (Eds.), *Proceedings of the Eleventh Congress of the International Ergonomics Association; Designing for Everyone*, Paris. Taylor & Francis, pp. 1541-1543.