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Research

Retroreflective Sheeting Materials on Highway Signs

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CENTER FOR
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STUDIES

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16. Abstract (Limit: 200 words)

In a road research project, older drivers were asked to read street names as soon as they were able as they were approaching an intersection. The signs were always on the far sides of the intersection but could be either on the right or left side. Intersections of three levels of complexity were used. A repeated measures design was used. All main effects and all but one of the interactions were significant. The legibility distances obtained from 864 trials using 18 subjects showed that Diamond Grade and VIP Diamond Grade sheeting were equivalent but that both were significantly superior to High Intensity Grade sheeting which was in turn significantly superior to Engineering Grade. The differences among sheeting grades were more apparent at the more complex intersections. The viewing conditions on some of the streets resulted in reduced visibility and conspicuity causing markedly reduced legibility distances. There were no performance differences based on gender. The implications for driving safety were discussed in the context of visual information processing workload, divided attention and multitasking.

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Retroreflective Sheeting Materials on Highway Signs

Final Report

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Executive Summary

The purpose of this project was to compare legibility distances for street name signs based on four different types of sheeting materials (Diamond, VIP Diamond, High Intensity, and Engineering Grades). Legibility distances were measured at three St. Paul, Minnesota intersections which varied in complexity: Como Avenue - Front Street - Dale Street (most complex), Grand Avenue - Avon Street (intermediate complexity), and Kent Street - Cottage Street (least complex).

All data was collected at night and all subjects were older drivers (nine males with an average age of 74 years and nine females with an average age of 68 years). Street name signs with invented and similar names, were placed on the far side of the intersection as the driver approached and they were on either the right or left side of the street at random. The driver approached the intersection and when they could read the sign they did so aloud. The distance from this point to the sign, corrected for response times, constituted the legibility distance. Each subject viewed each of the materials twice per street for each of the six streets for a total of 48 trials. Orders of intersection, street within intersection, sign materials and sign names were randomized.

Analysis of the data revealed that the use of Diamond Grade and VIP Diamond Grade sheeting materials resulted in similar legibility distances which were significantly greater than for High Intensity Grade which in turn were significantly greater than for Engineering Grade sheeting material. The data also showed the differences in legibility distances for the sheeting materials were of greatest importance for the more complex intersections and streets. At the simpler intersections and streets, the differences among the legibility distances for sheeting materials was greatly reduced. Pronounced differences in legibility distances based on side of the street could be explained by local differences in factors affecting visibility and conspicuity. There were no performance differences based on gender.

Performing tasks other than driving, while driving, (such as locating and reading street name signs) can lead to information processing overload and driving performance degradation. Information overload due to multitasking is specific to the procedure.

Introduction

Street name signs can pose serious problems for drivers who are trying to find a particular street address. The signs are sometimes obscured from the driver's view by trees, bushes, lamp posts, power poles, parked trucks and similar objects. The problem of finding and reading a street sign is made even more difficult by darkness and the problem is especially severe for older drivers. Only older subjects driving at night participated in the work reported here.

In this project we were not concerned with objects which might obstruct the driver's view of street name signs. Instead our attention focused on legibility distances for street name signs with four different sign sheeting materials. (The intersections we selected for study were free of solid obstructions to the driver's view of the signs). The idea behind the project was straightforward; the greater the legibility distance the better the signing material. The more difficult question, which we did not address in this project, concerned cost-benefit ratios. For example, if the best, but most costly sheeting material, yielded only a marginal improvement in legibility distance, the benefit might be deemed too small for the increase in cost.

In this study we have interpreted the data with the help of the Minimum Required Visibility Distance (MRVD) model. This model is related to legibility through letter size (MRVD = Required Legibility Index/Letter Size). Letter size was characterized by the height of the lowercase sign letters on the street name signs. The MRVD model is commonly used to estimate detection and legibility distances. This model assumes that a set of ordered driver responses occurs in the overall response to a sign. The first step is *Detection* of the sign followed by *Comprehension*, *Decision Making* and *Response Initiation*. Each of these steps requires time. During the time required to accomplish the steps in the model the driver approaches the intersection. If drivers are searching for a particular cross street at which they intend to turn (turning becomes the response in the model) they need to detect the sign and comprehend its meaning (read and understand the street name) before they come to a decision (this is or is not the searched-for street) before initiating the response (turn or continue through the intersection). We were not interested in this experiment in assigning times to each of the four steps in the model. In terms of the model we were directly interested in the first two steps and their contributions to legibility distances. However, in a general way we were interested in the complete model.

Performing the steps in the model took time. This had two important implications. First, as more time was required to perform these steps, less time was available to complete the response. That is, drivers might not realize until too late that they should have turned at the intersection. The second, and more important implication, was that as drivers were attending to street signs, in the sense described by the MRVD model, they were spending less time in attending to vehicle control tasks which were in turn dependent on frequent visual sampling of the environment outside the car. This is referred to as divided attention and is an important factor in performing many complex tasks such as driving a vehicle. Divided attention is described more completely as a subsection in the Discussion Section of this report. In general, if too much attention is spent in detecting, deciding, and comprehending signs, too little time is left for vehicle control no matter how efficiently the duty cycle for sharing time for vehicle control with time for MRVD activities is apportioned. Fortunately, in our experiment there was no penalty such as wasted time or getting lost so drivers could simply abandon the sign detection and sign reading tasks in favor of better vehicle control.

Division of attention as a forcing function for driving is related to circumstances which require drivers to do more than one task at a time. This is referred to as multitasking. Multitasking has an effect on our ability to process information. The greater the requirements imposed on drivers by multitasking, the greater the information processing workload. As information processing workload increases, so do performance errors. First, errors increase on tasks which are secondary to driving, such as the MRVD tasks. If workload continues to increase, the frequency of mistakes in the primary task of vehicle control will increase. This increase in workload greatly increases the likelihood of accidents. (Multitasking, Information Processing Workload, Primary and Secondary Tasks, and Performance are described in greater detail in the Discussion Section). These issues are not secondary to the question of whether drivers can easily find and read street name signs. Rather they are of equal importance since they directly address driving safety.

When we consider the many distractions which drivers impose upon themselves while driving, including searching for street name signs and then reading them, it is fair to ask why accidents are not more frequent than they actually are. Simulation and on-road studies such as those by Harms [1] and by Wierwille et al. [2] have shown that drivers usually behave in an adaptive way. If the primary vehicle control task was difficult, perhaps due to congestion or weather, drivers would not undertake secondary tasks. In this project the main secondary task was detecting and comprehending the street name signs.

One other issue needs to be introduced and that is our exclusive use of older drivers (over 60 years of age). Older drivers are slower in completing all four components in the MRVD model. This means that sign materials which increase legibility distances will be especially beneficial to older drivers. Visual system capability is the most important determinant in the cognitively simple task of sign detection and recognition. Aging results in diminished visual capability. Both static and dynamic acuity are negatively affected as are contrast sensitivity and the size of the visual fields. This means that older drivers will have more trouble resolving sign letters, that they will require greater luminance contrast ratios (contrast between the letters and their immediate surround) and that their peripheral vision will be restricted making sign detection more difficult. Other visual factors such as glare come into play as well and some of these are considered in the Discussion Section.

Methods

Introduction and General Procedure

This section of the report describes the methods used to collect the data and the sites used for data collection. The data was collected during the fall and early winter of 1995. The data was collected on nights when visibility was unlimited and snow had been removed from the streets and did not pose a driving problem. The general experimental method was designed to allow us to determine the legibility distance for the four sign sheeting materials used on the street name signs.

The subjects, who were older drivers, were scheduled a week or so in advance of the day they were tested. By prearrangement we called subjects during the morning of the day of their test to confirm arrangements and to get instructions for finding their homes. Sometimes the weather was not satisfactory and the subject was then rescheduled. Occasionally subjects had forgotten their appointments with us, and these too were rescheduled. We then called for the subjects at their homes and delivered them to the first intersection for that evening. At the end of testing subjects were driven back to their homes.

Prior to the first trial, subjects read a description of the experiment and their roles in the experiment. Once they understood this, they signed a Consent Form. The subjects completed one or more practice trials. Then, if there were no questions, they began the experiment by driving toward the intersection from an initial distance that was much too great to permit them to read the street sign. As they approached the intersection at a speed of about 33 kilometers per hour (20 miles per hour), they searched for the sign which was always on the far side of the intersecting street but could be on either the right or left side (at random) of the driver's street. As soon as the subjects could read the sign they did so aloud. The distance from this point to the sign was defined as the uncorrected legibility distance. (The correction is described below.)

Subjects

The subjects were all older drivers with a mean age of 71 years. There were equal numbers of males (68 years to 83 years with a mean of 74 years) and females (62 years to 83 years with a mean of 68 years). All subjects drove frequently, drove at night, and were licensed Minnesota drivers. None had disabilities. None had significant cataracts and none were bothered excessively by glare while driving at night. All were familiar with driving a car similar to our Laboratory's car, with automatic transmission, power steering and power brakes. The subjects were all volunteers (not paid for their participation).

Signs

The sheeting material for the signs was donated by the 3M Company. The City of St. Paul's Sign Shop prepared the signs and supplied the posts for mounting the signs. The posts were 315 centimeters (124 inches) from the bottom of the standard to the top of the fixture which held the sign. The sign slats were 22.8 centimeters (9 inches) wide or high and 76.2 centimeters (30 inches) long.

The sheeting material was of four types. The brief descriptions which follow were supplied by 3M. More detailed information is available from them.

- Engineering Grade is an enclosed lens (specular) sheeting for use on traffic control signs.
- High Intensity Scotchlite™ is a high intensity grade sheeting using encapsulated lens retroreflective material for traffic control signs.
- Diamond Grade VIP is a Scotchlite™ retroreflective diamond grade VIP which is a bright, durable, prismatic lens retroreflective material for use on traffic control signs.
- Diamond Grade is a Scotchlite™ retroreflective diamond grade sheeting which is a bright, durable, prismatic lens material for use on traffic control signs.

Since some subjects would have prior knowledge of the names of the streets at the intersections, we used fictitious names. The first letter of theses names consisted of 152 mm (6 inch) uppercase "S" Series C letters followed by 114 mm (4.5 inch) lowercase Series C letters. The second letter was always "t". The names used were Strike, Strong, Stress, Straw, Story and Storm. Thus the subjects could not guess the street sign names by seeing only the first letter or two.

Sites And Routes

Three intersections in St. Paul were selected to represent differing complexity and traffic activity and these are described below.

Como Avenue - Dale Street - Front Street.

This was the most complex intersection with the greatest amount of activity. This intersection encompassed a large area. Immediately fronting the intersection were two bars, a pizza restaurant, a large sporting goods store, a gas station, a small used car lot and a convenience market. All were open for business at night. There were additional business establishments on Dale street but these did not directly front the intersection. Traffic through the intersection moved rapidly. Dale Street and Como Avenue have city buses with stops at this intersection. The streets were set at various acute angles to their neighboring streets. There were visually confusing conditions between the driver and street name sign. Lack of sign conspicuity was an additional problem for the drivers. All the businesses had lighted signs, there were street lights and 10 traffic signals in addition to the headlights of the vehicles passing through the intersection. These light sources, the large space occupied by the intersection and the confusing geometry all added to the conspicuity problem for the driver.

The subject drivers approached this intersection from the south on Dale Street and from the northwest on Como Avenue.

Avon Street - Grand Avenue.

This was the intersection of intermediate complexity and activity. This intersection was much smaller in area then the Como - Front - Dale intersection. Grand Avenue, but not Avon Street, was heavily traveled during the evening hours. There were two small businesses facing Grand Avenue on the eastern sides of Avon Street. On the opposite sides of Avon Street there were small apartment houses. The intersection was lighted by lantern style street lights and the modest amounts of light coming from the two businesses plus the headlights from passing traffic. There were two bus stops on Grand Avenue diagonally across Avon street from each other.

The drivers approached this intersection from the south on Avon Street and from the west on Grand Avenue.

Kent Street - Cottage Street.

This was the least complex and lowest activity intersection. This intersection was typical of a quiet residential area of one family homes. The intersection was lighted by two street lights.

The subject drivers approached the intersection from the east on Cottage Street and from the south on Kent Street.

Lab Car and Distance Measurement

The Human Factors Research Laboratory's (HFRL) car is a 1989 Honda Accord two door sedan with automatic transmission, power steering and power brakes. The headlight alignment was checked during the period of data collection. The windshield and headlights were cleaned prior to and during each data collection period as needed. The car had NuMetrics™ distance measuring equipment. The equipment was calibrated by using MN/DOT measured miles and checked by verifying the measured distances at the intersections.

Data Collection Procedure

At the intersections a starting location was marked for each of the routes described above. (The location for the sign standard was marked by paint on the pavement and in a textual description when the marks were obscured by snow.) The distances from the starting point and the sign location were measured and recorded. The subject approached the sign from the starting point. When the subject said the sign name aloud, the experimenter in the car pressed a button on the NuMetrics™ control box. The distance from the starting point to that point was displayed. Later, that distance was subtracted from the total distance to yield the legibility distance.

In this form of measurement there were two nearly constant sources of error. First, the subject had a time lag between recognizing the sign name and voicing the name. The experimenter had a lag between hearing the name and pressing the button. (If the subject stated the wrong name they then said the correct name as soon as possible and the experimenter again pressed the button to display the distance. That is the experimenter did not verify correctness before pressing the button thus reducing the potential response time. Misstating the street name by the subject rarely happened.) We estimate that these two response times totaled 0.75 to 1.25 seconds. At 20 mph this would yield a distance error of 6.71 meters to 11.2 meters (22 feet to 36.6 feet). The legibility distance was adjusted by the mean of the distance due to response times, 8.96 meters (29.3 feet). Making this adjustment for response times had no effect on the comparisons of sign sheeting materials but it did matter for the absolute values for legibility distance.

A third source of error was not constant. When a car followed the subject's car it sometimes added to the illumination of the street sign. We attempted to avoid this circumstance by waiting until traffic had passed the subject's car before leaving the starting place. This error did not occur at the Kent and Cottage intersection but it did happen on Grand Avenue, Como Avenue and Dale Street. We did not attempt a correction for this error source.

Experimental Design

We used a within subjects (repeated measures) experimental design in which all subjects in the experiment saw all conditions. This design eliminates between subject variation. The only between subjects variable which was of interest was gender. The conditions in this experiment were defined by:

- <u>Intersections</u>. The order in which each subject visited the three intersections was randomized with the constraint that the intersections were visited with equal frequency. This avoided a practice effect which might favor performance at the third intersection over the first two and the second intersection over the first visited if the order was always the same.

- Streets. At each intersection two streets were used with the subject always driving toward the sign from the same direction on a given street. The order in which the streets were used at a given intersection was randomized with each street used equally.
- Right - Left Sign Location. Right - left placement of signs was randomized with equal frequencies of right and left placements.
- Sign Names - Sheeting Materials. There were six sign names. Each occurred four times; one for each of the four sheeting materials. The order or presentation of the names and materials was randomized with the constraint that each of the materials was used one-fourth of the time. The order of presentation of the street names was randomized.

Each subject viewed each sign material twice for each street, thus there were eight trials on each street and 16 trials at each intersection for a total of 48 trials for each subject for the three intersections. The 864 legibility distances, 48 trials for each of the 18 subjects, were the data analyzed.

Results

Means

Tables 1 - 3 present mean legibility distances in feet for sheeting material, sheeting material by side of the street, by street, by side of each street, for each street by side of the street, and finally by sheeting material by street by side of the street. We are thus showing the detailed and informative data for streets rather than lumping the data by intersection. The reason for this mode of presentation is that viewing conditions for the streets within two of the intersections, Como - Front - Dale and Avon - Grand are not equivalent. This will be discussed in the following section.

Table 1 showed that Diamond Grade and VIP Diamond, over all conditions for a given street, resulted in nearly equivalent legibility distances (a graphical representation is presented in Figures 1a and 1b). These two sheeting materials resulted in greater legibility distances than the High Intensity Sheeting which was in turn superior to Engineering Grade. Table 1 also showed that this ranking was obtained for both sides of the street. However, when we examined the effect of sheeting material on legibility distance by street, we saw certain exceptions to this ranking.

Table 1 Mean Legibility Distances for Materials by Material, Street Side And Street

	Diamond	VIP Diamond	High Intensity	Engineer Grade
Material	170	172	142	130
Left Side	144	145	112	98
Right Side	196	199	172	162
Como	198	201	151	135
Dale	121	132	103	117
Grand	113	127	66	49
Avon	193	198	192	168
Cottage	200	194	171	165
Kent	195	180	170	148

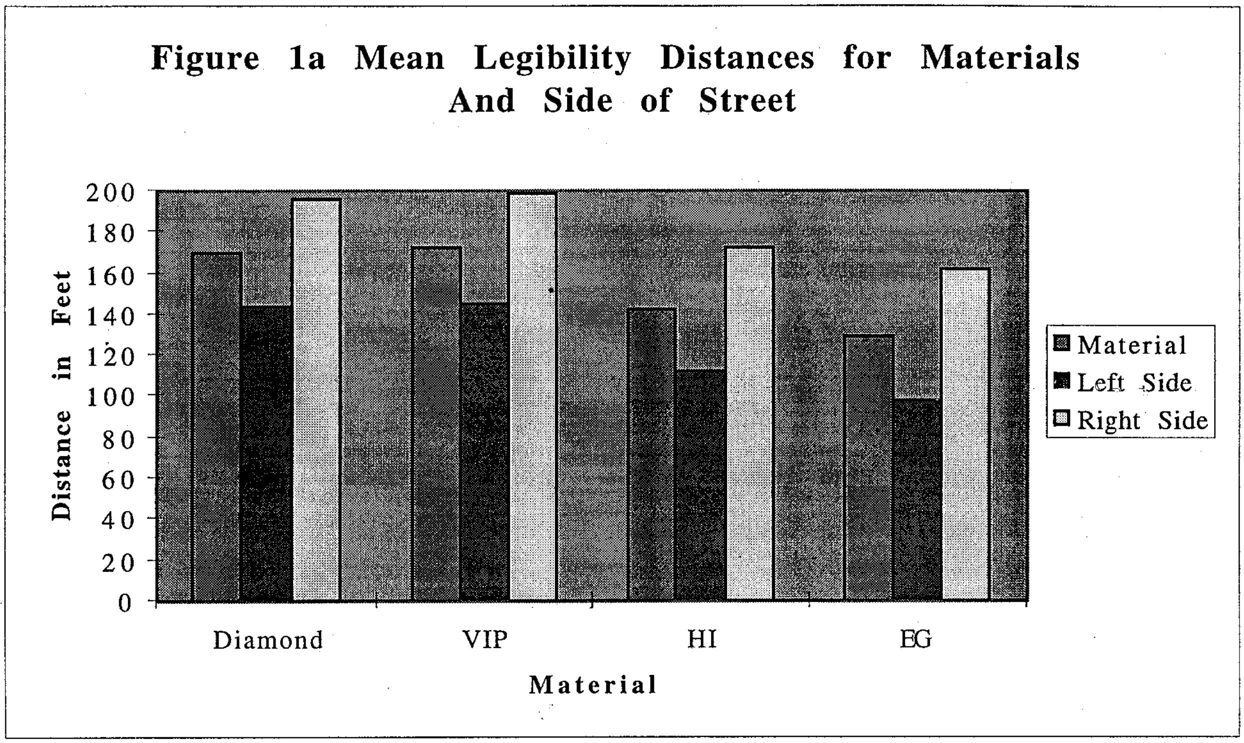


Figure 1a Mean Legibility Distances for Materials And Side of Street
Distance in Feet
200
180
160
140
120
100
80
60
40
20
0
Diamond
VIP
HI
EG
Material
Material
Left Side
Right Side

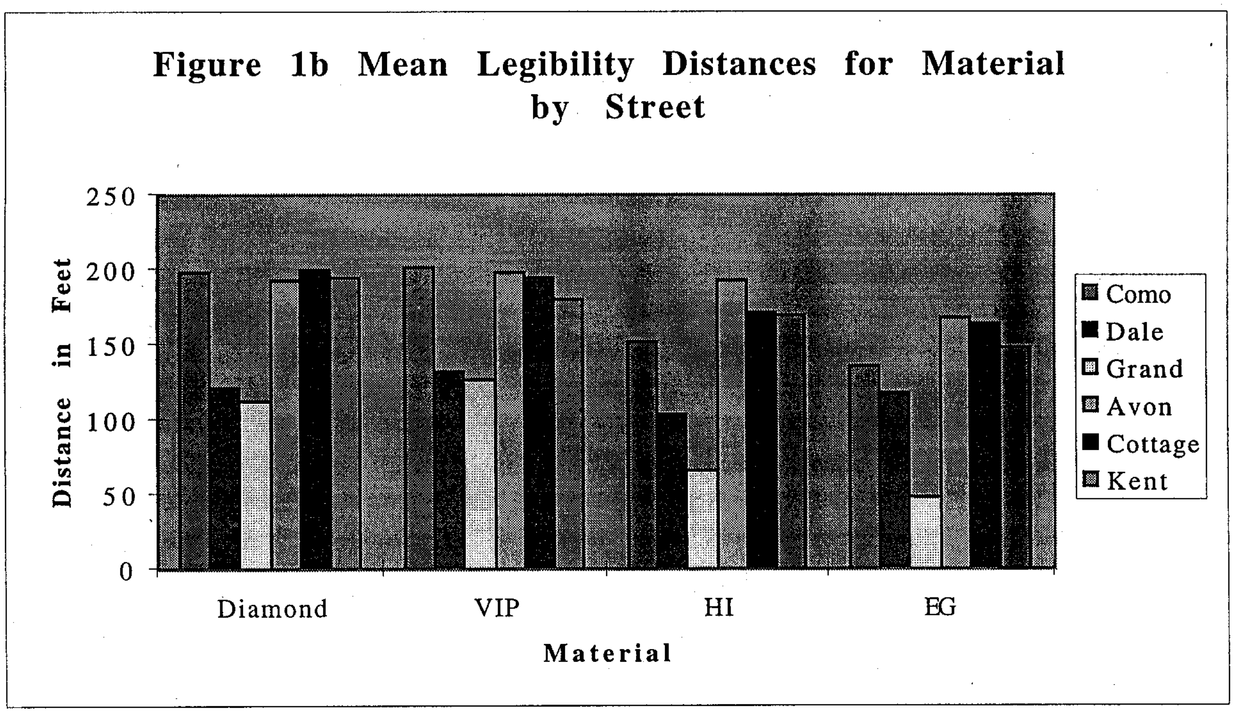


Figure 1b Mean Legibility Distances for Material by Street
Distance in Feet
250
200
150
100
50
0
Diamond
VIP
HI
EG
Material
Como
Dale
Grand
Avon
Cottage
Kent

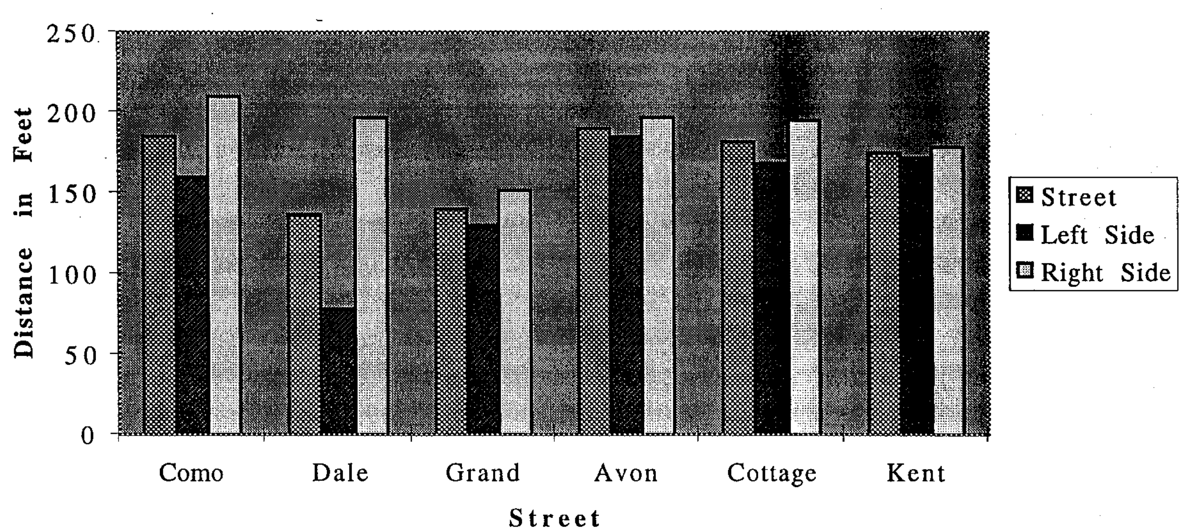
For Dale Street we saw that Engineering Grade outperformed the High Intensity sheeting and that for Dale and Avon Streets and for Grand Avenue, VIP Diamond resulted in greater legibility distances than did Diamond Grade. The explanation for most of these exceptions could be found in a closer inspection of the data for each side of the streets. That is, there were substantial differences in viewing conditions for the right vs. the left sides of certain streets. This observation was borne out by the data in Table 2 (see Figure 2 for a graphical representation). Table 4 showed which of the mean differences among sheeting materials were statistically significant.

Table 2 Mean Legibility Distances for Street And Side of Street

	Como	Dale	Grand	Avon	Cottage	Kent
Street	185	137	140	190	182	175
Left Side	160	78	130	185	169	171
Right Side	210	197	151	196	195	179

The effects on legibility distance caused by side of street for Como Avenue, Dale Street and Cottage Avenue are readily apparent in Table 2. In the Discussion Section we note various local conditions at these intersections which caused these differences.

Figure 2 Mean Legibility Distances for Street And Side Of Street



A striking feature in the data shown in Table 3 is the short legibility distances for the left sides of Dale Street and Grand Avenue (refer to Figures 3a and 3b for a graphical depiction). These are due to the same local idiosyncratic conditions which were seen in the Table 2 data. We could also note the relative uniformity of the legibility distances for both the right and left sides of Avon, Kent and Cottage Streets. Como Avenue is intermediate in this regard. This observation will become of more importance when we discuss the relative complexity of the three intersections. To anticipate this discussion, it would appear that the greater the retroreflectivity of the sheetings, the greater the importance as the intersections became more complex.

Table 3 Mean Legibility Distances for Materials by Street And Street Side

	Diamond	VIP Diamond	High Intensity	Engineer Grade
Left Side				
Como	172	174	116	88
Dale	41	72	23	33
Grand	86	71	22	17
Avon	178	202	185	164
Cottage	188	177	162	151
Kent	200	177	168	137
Right Side				
Como	223	229	185	181
Dale	201	193	184	201
Grand	140	184	110	81
Avon	207	194	200	171
Cottage	213	210	180	178
Kent	190	184	172	158

Figure 3a Mean Legibility Distances for Materials by Street Side (Left)

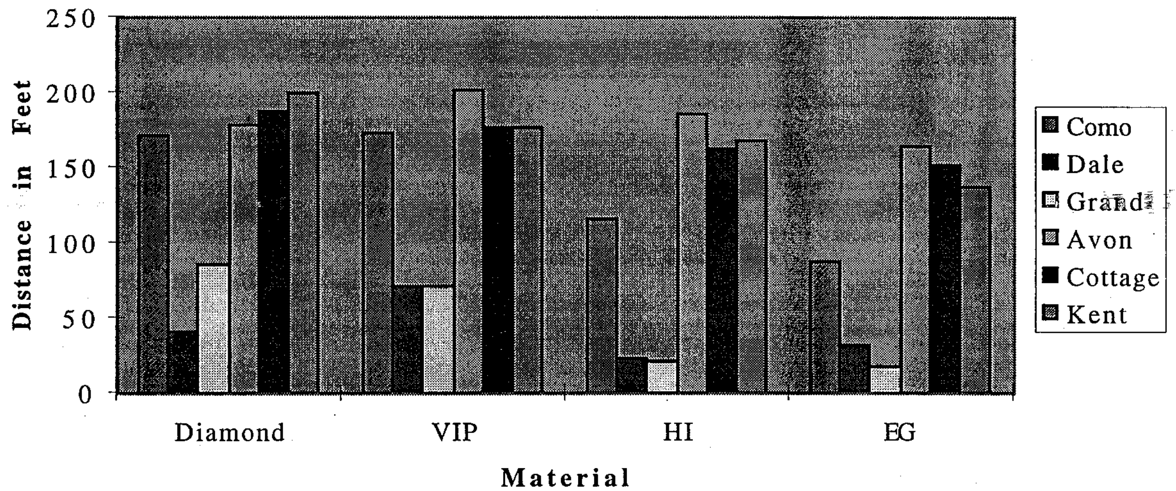
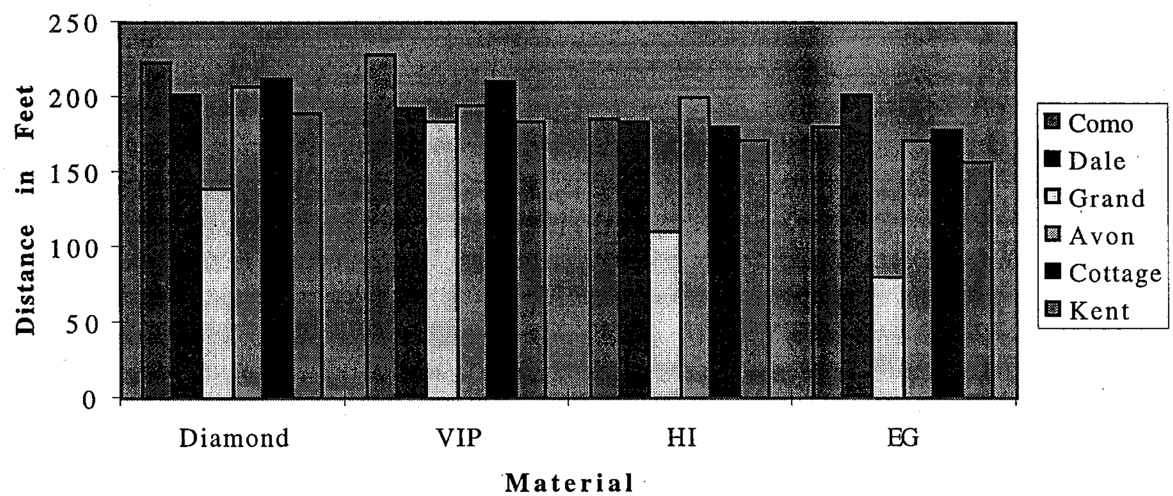


Figure 3b Mean Legibility Distances for Material by Street Side (Right)



Analysis of Variance

We completed the analyses of variance for the main within subject effects (Street, Side of Street, and Sheeting Material), pairwise interactions and the triple interaction. The F values for all within subjects main effects and all but one of the interactions were significant at $P<0.01$. The one non-significant F value was for the Side of Street by Sheeting Material interaction which, in any event, has little meaning within the design of this experiment, suggesting only that type of sheeting material cannot substitute for difficult local viewing conditions. The single between subject variable was gender and this was not significant. There were certain paired comparisons for gender by street which were significant, especially for Grand Avenue, but there was little consistency to these findings.

Paired Comparisons

The data for the paired comparisons for sheeting materials are shown in Table 4. Significance was calculated using the Tukey Honest Significant Difference (Tukey HSD) method. The paired comparison results for streets showed only one significant difference and that was for the difference between Como Avenue and Dale Street. This finding could have been anticipated by inspecting the results in Table 3, especially those for the left side of the street. The criterion level in the Tukey method guarded against alpha inflation thus making this a conservative method for comparing paired differences among variables. The analysis of variance for side of street (right vs. left) confirmed that these variables were significantly different. In Table 4 and other paired comparison tables an asterisk indicated a statistically significant difference ($P<0.05$) between members of the pair of variables or interactions.

Table 4 Sheeting Material Paired Comparisons

Material	Diamond	VIP	HI	Eng
Diamond				
VIP				
HI	*	*		
Eng	*	*		

Table 4 showed that Diamond Grade and VIP Diamond Grade were significantly different from both High Intensity Grade and Engineering Grade. Table 5 shows the significance of the interaction of street by sheeting material.

Table 5 Comparisons of The Interaction of Street by Material

	Diamond Grade						VIP Diamond					
DIA	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como												
Dale	*											
Grand	*											
Avon		*	*									
Cottage		*	*									
Kent		*	*									

VIP	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como		*	*									
Dale	*			*	*	*	*					
Grand	*			*	*	*	*					
Avon		*	*					*	*			
Cottage		*	*					*	*			
Kent		*	*					*	*			

HIGH	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como	*		*	*	*	*	*			*	*	
Dale	*			*	*	*	*			*	*	*
Grand	*	*	*	*	*	*	*	*	*	*	*	*
Avon		*	*					*	*			
Cottage		*	*					*	*			
Kent		*	*					*	*			

ENG	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como	*			*	*	*	*			*	*	*
Dale	*			*	*	*	*			*	*	*
Grand	*	*	*		*	*	*	*	*	*	*	*
Avon		*	*						*			
Cottage		*	*						*			
Kent	*			*	*	*	*			*	*	

Table 5 Continued Comparisons of The Interaction of Street by Material

	High Intensity						Engineering Grade					
DIA	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como												
Dale	*											
Grand	*	*										
Avon	*	*	*									
Cottage		*	*									
Kent		*	*									
VIP	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como												
Dale												
Grand												
Avon												
Cottage												
Kent												
HI	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como												
Dale	*											
Grand	*	*										
Avon	*	*	*									
Cottage		*	*									
Kent		*	*									
ENG	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
Como			*	*								
Dale			*	*	*	*						
Grand	*	*		*	*	*	*	*				
Avon		*	*					*	*			
Cottage		*	*					*	*			
Kent		*	*	*					*			

Table 5 confirmed the earlier observation that Diamond Grade and VIP Diamond Grade provided a significant benefit only when viewing conditions were complex and difficult for subjects. This was borne out by the lack of significant paired comparisons for Avon, Kent and Cottage Streets.

Table 6 Comparisons of The Interaction of Street by Side

	Left						Right					
	Como	Dale	Grand	Avon	Cottage	Kent	Como	Dale	Grand	Avon	Cottage	Kent
LEFT												
Como												
Dale	*						*					
Grand	*	*					*	*				
Avon	*	*	*				*		*			
Cottage		*	*				*	*	*	*		
Kent		*	*				*	*	*	*	*	
RIGHT												
Como	*											
Dale	*	*										
Grand		*					*	*				
Avon		*	*						*			
Cottage	*	*	*		*							
Kent		*	*				*					

Table 6 confirmed the significance of the difference between the right side vs. left side placements for Dale Street and Grand Avenue and to a lesser extent for Como Avenue as well.

Discussion

Introduction

Our results will be discussed first in terms of legibility distances. Next we briefly discuss some relevant aspects of visual performance, especially visual function in older drivers. We then discuss some of the broader implications which these results have for driving safety. This latter discussion centers on the issues of divided attention, multitasking, workload and secondary tasks, and information processing workload. While these concepts apply widely to human task performance in complex real world situations such as driving, they are not specific to the experimental situation reported here. However, they focus attention on safety as well as the legibility aspects of performing the tasks used in this project.

Legibility Distances

The legibility distances formed a surprisingly well-ordered set of data for a road research experiment. Tables 1 - 3 which showed the means for the various material configurations suggested that:

- Diamond Grade and VIP Diamond Grade were similar in terms of legibility distances;
- High Intensity sheeting was inferior to Diamond and VIP but superior to Engineering Grade;
- There were some pronounced differences between the left and right side locations of the street name signs which were not compensated by type of sheeting material;
- That type of sheeting material was of less importance in determining legibility distance on the less complex streets (Avon, Kent and Cottage);
- That the left sides of both Dale Street and Grand Avenue had features which resulted in reduced legibility distances for all sheeting material types.

Table 4 confirmed the observation that Diamond Grade and VIP Diamond were not significantly different from each other but that both Diamond Grade and VIP Diamond resulted in significantly greater viewing distances than High Intensity and Engineering Grade sheeting materials.

The most important feature shown by Table 5 (Interaction of Street by Material) was that type of sheeting material was of less importance in determining legibility distances for the least complex streets (Avon, Kent and Cottage). Otherwise, Table 5 confirmed the observations made in the discussion of the means for the legibility distances.

The street name signs on the left side of Dale street were particularly difficult for subjects to locate and read. The sign locations on Dale Street were opposite each other. However, there was a great deal of background visual clutter on the left side of Dale Street including a traffic signal and gas station lights which reduced sign conspicuity. On the left side of Grand Avenue the street name sign was in front of and below a street lantern. The light from the street lantern served to reduce the luminance contrast of the street name sign against background thus reducing legibility distances.

Overall the data showed that type of sheeting material had statistically significant effects on legibility distances, particularly for the more complex streets. The data also showed that certain local conditions can override the effect of sheeting materials leading to a shortening of legibility distances.

Visual Performance And Older Drivers

Establishing a causal link between accidents and reduced visual performance has been elusive. Recounting the successes and failures of these research efforts provides insight into the difficulties of establishing a correlational link between deficits in visual performance and the likelihood of accidents [3], [4], [5], [6], [7], [8], [9], [10], [11]. The task of driving is mostly visual (Hills [8] and Shinar & Shreiber [12]). However, the occurrence of a driving accident is only partially accounted for by loss of certain aspects of visual function (Owsley, Ball, Sloane, Roenker, & Bruni [13]). There was a weak link between the loss of dynamic and static visual acuity and the incidence of accidents within a population of California drivers. These correlations typically did not account for more than five percent of the variance. Keltner and Johnson [10] established a difference between drivers with peripheral field-of-view loss in both eyes and a control group on both accidents and convictions. Other studies have suggested that mental status, structural and pathological degeneration of the eye, cardiovascular disease, and prescribed and unprescribed medications may contribute to the pool of variance that accounts for accidents[8], [13]. As the visual system ages, there are changes in visual function, specifically, static and dynamic acuity, perception of angular movement, movement in depth, visual field, tracking movement of the eyes, glare sensitivity, color vision, contrast sensitivity, and scotopic vision (Keltner & Johnson, [10]; Council and Allen [14]; Danielson [15]; Johnson and Keltner [16]; Lovsund, Hedin and Tornos [17]; and North [18]). Sturgis and Osgood [19] studied the effects of glare and background luminance on visual acuity and contrast sensitivity on nighttime driving. In the previously cited studies, loss of visual function was more prevalent in older populations. Even studies done on older drivers with clinically significant eye diseases such as retinitis pigmentosa (Fishman et al.

[20]; and Szlyk et al. [21]), and various abnormalities of the central visual pathways (Freytag and Sacks [22]) did not provide correlations with accidents.

In spite of the large amount of work, there is surprisingly weak evidence connecting the loss of visual function to accident incidence even with loss of visual function with aging and disease. These findings and the findings of Harms [1] and Wierwille, et al. [2] at least partially account for the fact that older drivers do not consistently have accidents while searching for and reading street name signs. Thus age alone is not a good predictor of performance on tasks such as locating and reading street name signs. Some better predictors of such performances are shown in Table 7.

Table 7. Predictors of Visual Performance

Opthamalogical Function	**Visual Function**	**Attentional Function**	**Mental Function**	**Motor Function**
Clinical Ratings	Static Acuity	Detection	Information	Musculoskeletal
<u>Disorders</u>				
Ocular Media	Dynamic Acuity	Localization	Abstraction	Reaction Time
Central Vision	Disability Glare	Selection	Digit Span	Choice Reaction Time
Peripheral Vision	Contrast Sensitivity	Switching	Orientation	Movement Time
Color Discrimination	Division	Verbal Memory		
<u>Diagnosis</u>	Stereoacuity	Sustained Attention	Speech	
Cataracts	Movement Detection			Naming
Diabetic Rentinopathy				
Glaucoma				
Macular Degeneration				
Normal				
Retinitus Pigmentosa				

Divided Attention Issues in Driving

The issue of divided attention is relevant to an understanding of the data presented in the preceding section. One of the critical problems of driving, centers on the question of distributed attention. Simply stated, if we as drivers are searching for or reading a sign we are only imperfectly controlling our car. While it is clear that the present trend is for providing drivers with increased information in the driving environment, we must also be alert for possible deficits in driving performance. (Besides street name signs there are devices for use inside the car such as navigational devices and personal information devices as well as information presented outside the car via ordinary signs as well as variable message signs all of which place greater attentional demands on the driver.) Also, we are aware that division of attention among multiple tasks leads to degradation of primary performance (steering, speed maintenance, headway and braking), especially in high demand (i.e., congested traffic) conditions. The seminal work done by Brown and Poulton in 1961 [23] at the Applied Psychology Unit in Cambridge, England attests to these performance changes. What remains unknown is the relationship between division of attention and safety in terms of collision avoidance. We do know that attention is implicated far more in driving safety than simple visual function. This accounts for the poor correlation between visual function, as measured in driver screening and licensing tests, and subsequent driving accident records. As divided attention is clearly a critical factor in safety, it is central to an understanding of how we may safely divide our attention between such tasks as locating and reading street name signs and controlling the headway and velocity vector of the car.

Attention takes a finite time to switch. However, models of drivers' capabilities show that intermittent sampling of the forward view, i.e., repeatedly glancing at the road and then glancing back at the sign or other display, does provide the capability for vehicle control. Problems only arise in unusual or emergency conditions. Quite simply, this is why we can glance at signs or tune radios without a collision each time. However, increasing the time attention is directed to a task other than driving the vehicle increases the opportunity of collision. Fortunately drivers may behave in an adaptive manner when confronted with increasing amounts of information. Wierwille and colleagues in 1991 [2] experimentally determined that drivers adaptively shifted their attention from an in-car navigation display to the outside driving world as outside visual demand increased. In partial confirmation of this finding, Harms in 1991 [1] showed that as visual demand outside the car increased while simultaneously cognitive demand inside the car increased, drivers reduced their speed and devoted more attention to the outside world while reducing attention to the in-car cognitive task. Even though a display such as a street name sign may be presented at optical infinity, drivers must still distinguish information from a constantly changing background which may be quite complex as at the Como - Front - Dale intersection and to a lesser extent at the Avon - Grand intersection. At these intersections where more attention must be devoted to the sign locating and reading task, there is also the need for more attention to be devoted to the driving task at these busy and complex intersections. In short, information locating and acquisition is a trade-off with vehicle control and thus with driving safety.

Workload And Secondary Tasks

Ivan Brown and his colleagues at Cambridge University [23] showed in 1961 that doing two things at once degraded driving performance as a function of traffic density. There are also published studies using subsidiary tasks in realistic driving situations (such as those at the Traffic Research Center, University of Gronigen). Also there are experiments such as those done by Hancock, Wulf, Thom, and Fassnacht in 1990 [24] which use a secondary task paradigm to estimate the mental workload (as contrasted to physical workload) caused by a primary task. The primary task in the present context is driving a car. The general finding is that as the driver devotes more and more attention to an increasingly difficult driving task, performance on the primary task of driving the car, up to some difficulty level, does not change but performance on the secondary task deteriorates. However, eventually the increasing difficulty of the tasks will degrade primary task performance. This is the basis for the hypothesis that secondary tasks will increase the mental workload of the driver until the driver becomes overloaded and driving performance fails. If traffic is heavy or the weather is bad, overload (exceeding the driver's attentional bandwidth) may happen with very little secondary task loading. In the experiment reported here, the secondary task was locating and reading the street name sign. Usually there was no impact on the primary task but occasionally vehicle control was degraded (see below).

Multitasking

The simultaneous performance of multiple tasks is called *multitasking*. At the HFRL we are concerned with the effect of multitasking on driving performance. The objective of an experiment directly related to multitasking was done by Stackhouse and Dewing in 1995 [25]. This study evaluated the impact on driving of performing representative non-driving tasks during simulated driving. The experiments were performed in the HFRL's driving simulator.

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

The results demonstrated that age but not gender was statistically significant and that doing some of the tasks significantly degraded driving performance. The task which caused the greatest problem was the task which required drivers to use the visual display showing a map and the text of a traffic message. In this experiment drivers were free to allocate their attention among both in-car tasks and outside-car tasks. The visual display of map and text is somewhat analogous to reading written directions and searching for a street name sign while controlling the car. For both experiments the MRVP model would apply. The above multitasking study showed that there were objective reasons for considering the evaluation of trade-offs between traffic safety and providing drivers with information requiring a high degree of visual attention.

In the case of human performance, each of the individual tasks such as those described in the above HFRL experiment, is called a *loading task* because it imposes a load on attention, cognitive function and often on motor function as well. Theories of human information processing generally predict that cognitive and motor performance will decrease as a function of the number of tasks being processed concurrently. However, there is disagreement as to the precise nature of this performance decrement. The classic single channel theories of attention developed by Broadbent in 1958 [26], and further refined in 1971 [27] and 1982 [28]; as well as similar theories by Treisman in 1960 [29], and 1969 [30] and Treisman and Gelade in 1980 [31] and by Deutsch and Deutsch in 1963 [32] and Moray in 1967 [33] and in 1969 [34] predicted substantial performance decrements in multitasking situations, arguing that human attention can concentrate on only a single task at any given time. The multiple resource theories of Allport, Antonis & Reynolds in 1972 [35] and Gopher, Brickner and Navon, in 1982 [36] often predicted much more modest decrements, since they endowed humans with the capacity for parallel processing of multiple tasks, provided that the tasks were not competing for similar cognitive resources.

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

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

The most conservative position to take is to assume a default viewpoint that drivers *cannot* engage in multitasking unless empirical research demonstrates otherwise. Furthermore, an empirical demonstration of the relative safety of one particular combination of loading tasks should not be taken to generalize to any other combination which has not yet been tested. One theoretical way around the problem, would be to prevent drivers from performing loading tasks while driving. Effective means to achieve this abstinence have not been suggested.

Prior research on multitasking while driving has often centered around the use of loading tasks chosen more for their experimental and theoretical convenience than for ecological validity. For example, Brouwer and his colleagues in 1991 [37] had subjects count the number of dots displayed in an on-screen rectangle while driving. In 1990 Liao [38] had subjects respond to colored squares, do mental arithmetic, and track cosine waves with a joystick while driving. Dewar, Ells, and Mundy in 1976 [39] had subjects respond to integers between 1 and 99 flashed on-screen. In a subsequent paper in 1993 Dewar [40] suggested that reading road signs added attentional load which could result in hazardous driving. Stephens and Michaels in 1964 [41] had subjects keep a point of light centered on a CRT display.

While such tasks may have served a theoretical purpose of loading the perceptual, cognitive, and motor systems, they are not the kinds of multiple tasks in which motorists routinely engage. Assuming that one wants to study multitasking during driving, it makes sense to use independent variables (loading tasks) and dependent variable performance measures with ecological validity in a plausible driving situation. This was the situation provided by this project on street name sign evaluation

In the study reported here, drivers had no accidents in nearly 1000 trials. However, overload caused by locating and reading street name signs was frequently observed by the experimenter who was in the car with the subject. For example we observed a subject repeatedly confusing the accelerator and brake pedals. The response was momentary but under some traffic conditions the results could have been serious. Similarly, we observed subjects repeatedly turning off the headlights when their actual intent was signaling a turn. We observed subjects so preoccupied with trying to read the street name sign that they ventured into the intersection without stopping at the stop sign or traffic signals. The point is not to relate a set of such anecdotes but to point out that under the conditions of this ecologically valid experiment, the increased potential for accidents was abundantly apparent. The attempt in this part of the discussion is to consider the kinds of simple behaviors in which motorists routinely engage while driving, in order to assess the effects of these behaviors on various critical aspects of actual driving behavior.

Both McKnight and McKnight in 1993 [42] and Brookhuis, De Vries and De Waard in 1991 [43] examined the effects of using hand-held and hands-free cellular telephones. The former used a form of driving simulation while the latter group collected data during actual driving. McKnight and McKnight [42] found that driving performance was affected slightly, but statistically significantly, in subjects over 50 years of age by both casual and intense phone conversations but performance was only decreased in younger subjects by intense conversations. Placing the call (dialing) required the subject to remove one hand from the steering wheel, but this decreased performance less than intense conversation on the phone or tuning the radio. Tuning the car radio resulted in about the same performance decrement as intense conversation but for this task younger drivers showed a greater decrement than older drivers. However, not all investigators have similar performance decrements.

Brookhuis, De Vries and De Waard [43] had subjects drive in both heavy and light traffic while placing phone calls and talking on the phone. Lateral position control (swerving and steering movements) decreased when subjects were talking on the phone but car following (maintaining spacing and sudden stopping) was not changed due to talking on the phone. There was no change in frequency of checking the rearview mirror when talking on the phone. There was no difference attributable to hand-held versus hands-free phone types. There were no age-related effects in these experiments. In summary this work showed that use of a cellular phone resulted in only slight changes in driving performance This contrasted with the findings (above) of McKnight and McKnight [42] and Stackhouse and Dewing's 1994 study [25].

Information Processing Workload

Just as the prolonged performance of a physically demanding task results in fatigue and an increasing number of task errors, information processing can overload an operator resulting in errors. Ivan Brown and E.C. Poulton [23] contributed the idea of secondary task performance as a method for measuring information processing workload. For a physically demanding task we can measure oxygen consumption or carbon dioxide production and use this measure to quantify the difficulty of the task. For information processing workload there are no such directly available and measurable variables. However, Brown and Poulton found that if a subject was asked to perform as well as possible on a task of primary importance, then when the subject was asked to perform a task of secondary importance, the number of errors on the secondary task served as a reliable measure of the information processing workload imposed by the primary task. A recent application of this idea to simulated car driving was discussed by Hancock and his coworkers [44].

The idea underlying this observation is that we can process information up to some maximum rate. Increasing the processing demand beyond that rate results in an increasing number of performance errors. Said differently, as task demand increases, thus imposing an increasing information processing workload, performance deteriorates. There is a confusion here that we strive to avoid and that is the potential confusion between performance and workload as discussed by Hancock and Caird [44]. If we measure a subject's ability to keep the car between the lane stripes, we might find that we can make this task increasingly harder to do but that up to some difficulty level there is no increase in performance errors but only an increase in workload. At some level both performance errors and workload will increase. At the lower levels of task demand, performance errors do not measure demand or task difficulty. At these levels we can use secondary task errors to measure information processing workload (task difficulty). A pertinent implication of this finding might be, that when drivers are in congested traffic in conditions which reduce visibility, drivers may maintain complete control of the car. The driver's workload in this instance would be high although driving performance may give no indication of the difficulty of the task. However, if we added to the driver's workload with one more task, such as locating and reading a street sign, performance might suffer severely. This would be true even though locating and reading a street sign under nominal conditions might cause no performance decrement whatsoever. This is the set of conditions which could lead to driver overload as described above with is potential for causing accidents. An alternative and more hopeful speculation is that as workload becomes heavy, drivers will not undertake an additional secondary task. This speculation is supported by the findings of Wierwille [2] and Harms [1] which were discussed above.

Conclusions

- The use of Diamond Grade and VIP Diamond Grade sheeting materials resulted in similar legibility distances which were greater than High Intensity Grade which in turn was greater than Engineering Grade sheeting material.
- The differences in legibility distances for the sheeting materials were of greatest importance for the more complex intersections and streets. At the simpler intersections and streets the differences among the legibility distances for the different sheeting materials was greatly reduced.
- Pronounced differences in legibility distances based on side of the street could be explained by local differences in factors affecting visibility and conspicuity.
- There were no performance differences based on gender.
- Performing tasks other than driving, while driving, (such as locating and reading street name signs) can lead to information processing overload and driving performance degradation. Information overload due to multitasking is specific to the procedure.

REFERENCES

1. Harms, L. (1991). Experimental studies of variations in cognitive load and driving speed in traffic and in driving simulation, 71-78. In Vision in Vehicles - III. New York: North-Holland.

2. Wierwille, W. W., Hulse, M. C., Fischer, T. J., and Dingus, T. A. (1991). Visual adaptation of the driver to high-demand driving situation while navigating with an in-car navigation system, 79-87. In Vision in Vehicles - III. New York: North-Holland.

3. Charman, W.N. (1985). Visual standards for driving. Ophthalmic Physiological Opticians Journal, 5(2) 211-220.

4. Committee on Medical Aspects of Automotive Safety (June 1969). Visual factors in automobile driving, and provisional standards. Archives of Ophthalmology, 81, 865-871.

5. Davison, P.A. (1985). Inter-Relationships between British drivers' visual abilities, age and road accident histories. Ophthalmic Physiological Opticians Journal, 5(2) 195-204.

6. Fonda, G. (1986). Suggested vision standards for drivers in the United States with vision ranging from 20/175 (6/52) to 20/50 (6/15). Annals of Ophthalmology, 18(2) 76-79.

7. Hales, R.H. (November 1982). Functional ability profiles for driver licensing: Exemplification by visual profile. Archives of Ophthalmology, 100, 1780-1783.

8. Hills, B.L. (1980). Vision, visibility, and perception in driving. Perception, 9, 183-216.

9. Keeney, A.H. (September-October, 1968). Opthalmic pathology in driver limitation. Paper presented at the Seventy-Second Annual Session of the American Academy of Ophthalmology and Otolaryngology, October 29-November 3, 1967, Chicago. In Trials of the American Academy of Ophthalmology and Otolaryngology, 72, 737-740.

10. Keltner, J.L. and Johnson, C.A. (September 1987). Visual function, driving safety, and the elderly. Ophthalmology, 94(9) 1180-1188.

11. Taylor, J.F. (1987). Vision and driving. Ophthalmic Physiology Opticians Journal, 7(2) 187-189.

12. Shinar, D. and Schieber, F. (1991). Visual requirements for safety and mobility of older drivers. Human Factors, 33(5) 507-519.

13. Owsley, C., Ball, K., Sloane, M.E., Roenker, D.L. and Bruni, J.R. (1991). Visual/Cognitive correlates of vehicle accidents in older drivers. Psychology and Aging, 6(3) 403-415.

14. Council, F.W. and Allen, J.A.Jr. (1974) A study of the visual fields of North Carolina Drivers and the relationship to accidents. University of North Carolina, Chapel Hill.

15. Danielson, R.W. (1956). The relationship of fields of vision to safety in driving with a report of 680 drivers examined by various screening methods. Transcripts of the American Ophthalmology Society, 54, 369-416.

16. Johnson, C.A. and Keltner, J.L. (March 1983). Incidence of visual field loss in 20,000 eyes and its relationship to driving performance. Archives of Ophthalmology, 101, 371-375.

17. Lovsund, P., Hedin,A. and Tornros, J. (1991). Effects on driving performance of visual field defects: A driving simulator study. Accident Analysis and Prevention, 23(4) 331-342.

18. North, R.V. (1985). The relationship between the extent of visual field and driving performance—A review. Ophthalmic Physiology Opticians Journal, 5(2) 205-210.

19. Sturgis, S.P. and Osgood, D.J. (1982). Effects of glare and background luminance on visual acuity and contrast sensitivity: Implications for driver night vision testing. Human Factors, 24(3) 347-360.

20. Fishman, G.A., Anderson, R.J., Stinson, L. and Haqaue, A. (1981). Driving performance of retinitis pigmentosa patients. British Journal of Ophthalmology 65, 122-126.

21. Szlyk, J.P., Fishman, G.A., Master, S.P. and Alexander, K.R. (1991). Peripheral vision screening for driving in retinitis pigmentosa patients. Ophthalmology 98, 612-618.

22. Freytag, E. and Sacks, J.G. (June 3, 1968). Abnormalities of the central visual pathways contributing to traffic accidents. Journal of the American Medical Association, 204(10) 119-874.

23. Brown, I. D. & Poulton, E. C. (1961). Measuring the spare "mental capacity" of car drivers by a subsidiary task. Ergonomics, 4. 35-40.

24. Hancock, P. A., Wulf, G., Thom, D. and Fassnacht, P. (1990). Driver workload during differing driver maneuvers. Accident Analysis and Prevention, 22, 281-290.

25. Stackhouse, S .P. & Dewing, W. L. (1995). Interaction of non-driving tasks with driving. Minnesota Department of Transportation, Report Number 95-20.

26. Broadbent, D E. (1958). Perception and communications. London: Pergammon Press.

27. Broadbent, D. E. (1971). Decision and stress. New York: Academic Press.

28. Broadbent, D. E. (1982). Task combination and selective intake of information. Acta Psychologica, 50, 253-290.

29. Treisman, A. (1960). Contextual cues in selective listening. Quarterly Journal of Experimental Psychology, 12, 242-248.

30. Treisman, A. (1969). Strategies and models of selective attention. Psychological Review, 76, 282-299.

31. Treisman, A. & Gelade, G. (1980). A feature integration theory of attention. Cognitive Psychology, 12, 97-136.

32. Deutsch, J. & Deutsch, D. (1963). Attention: some theoretical consideration. Psychological Review, 70(1), 80-90.

33. Moray, N. (1967). Where is capacity limited? A survey and a model. Acta Psychologica, 9, 401-412.

34. Moray, N. (1969). Attention: Selective processes in vision and hearing. London: Hutchinson.

35. Allport, D. A., Antonis, B., & Reynolds, R. (1972). On the division of attention: A disproof of single channel hypothesis. Quarterly Journal of Experimental Psychology, 24, 225-235.

36. Gopher, D., Brickner, M., & Navon, D. (1982). Different difficulty manipulations interact differently with task emphasis: Evidence for multiple resources. Journal of Experimental Psychology: Human Perception and Performance, 8, 146-157.

37. Brouwer, W. H., Waterink, W., Van Wolffelaar, P. C. & Rothergatter, T. (1991). Divided attention in experienced young and old drivers: lane tracking and visual analysis in a dynamic driving simulator. Human Factors, 33(5), 309-316. Divided attention in experienced young and old drivers: lane tracking and visual analysis in a dynamic driving simulator. Human Factors, 33(5), 573-582.

38. Liao, J. (1990). A simulation study of human performance deterioration and mental workload. Unpublished doctoral dissertation, University of Toronto, Toronto.

39. Dewar, R. E. Ells, J. G., & Mundy, G. (1976). Reaction time as an index of traffic sign perception. Human Factors, 18, 381-392.

40. Dewar, R. (1993). Hazardous Road Signs Ahead, Ergonomics and Design, July Issue., pp. 26-31.

41. Stephens , B W. & Michaels, R. M. (1964). Timesharing between two driving tasks: Simulated steering and recognition of road signs. Public Roads, 33, 81-88.

42. McKnight, A.J. and McKnight, A.S. (1993). The effect of cellular phone use upon driver attention. Accident Prevention And Analysis 25, 259-265.

43. Brookhuis, K.A., Devries, G. and De Waard, D. (1991). The effects of mobile telephoning on driving performance. Accident Analysis and Prevention 23, 309-316.

44. Hancock, P. A., Caird, J. (1993). Experimental evaluation of a model of mental workload. Human Factors, 35, 413-429.