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Driver Preferences for Instrument Panel Lighting Levels

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16. Abstract

This report identifies driver preferences for instrument cluster luminance/contrast levels. Thirty drivers (10 young Americans, 10 older Americans, and 10 Japanese) participated. Judgments (minimum, preferred, maximum, and dazzling) were obtained at nine sites along a 17-mile route in Ann Arbor, Michigan. Each driver provided judgments for 5 test conditions (daytime--electronic cluster, with and without sunglasses; nighttime--electronic, green analog, and white analog clusters).

An Analysis of Variance (ANOVA) of contrast ratios showed significant differences between the 3 clusters at night (electronic=178:1, green=82:1, and white=51:1). A t-test revealed significant differences between the electronic panel with (14:1) and without sunglasses (11:1). For the 5 conditions (with sunglasses, without sunglasses, electronic, green, and white), the preferred ratios were 14:1, 11:1, 186:1, 77:1, and 44:1, respectively. As expected, the order of the judgments from low to high contrast ratios was minimum (30:1), preferred (67:1), maximum (84:1), and dazzling (88:1). The maximum and dazzling judgments, however, were not significantly different. This was a function of the limited luminance range of the clusters, since 30% of the time the highest setting was not sufficient for the maximum judgment and 67% of the time it was not high enough for dazzling. Thus the contrasts for these two judgments were underestimated. Differences were found between young (64:1) and older (70:1) Americans, but not between American men and women or American and Japanese drivers. Prediction equations developed for contrast explain at least 84% of the variability for the preferred, maximum, and dazzling judgments.

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EXECUTIVE SUMMARY

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For instrument panels to be easy to use, the information on them must be legible and understandable. The purpose of this study was to determine the minimum, preferred, and maximum cluster lighting levels drivers identify as well as the point at which cluster lighting becomes a glare source. Legibility depends on characteristics such as display luminance levels and contrast, which were investigated in this study. Other factors examined include ambient illumination levels and driver characteristics (age, sex, ethnicity, and the use of sunglasses).

In the first part of the study, light transmission levels of three pairs of a popular brand of sunglasses (Bolle Irex 100 cateye and clip-on styles, as well as Bolle Acrylex) were measured. While the clip-ons and Irex 100 exhibited similar spectral transmission characteristics (parallel curves but different absolute levels), both differed somewhat from the Acrylex characteristics. All of them, however, transmitted red light while absorbing blue and green light (the color of the electronic display). Overall the Acrylex transmitted the smallest percentage of light (6%), the Irex 100 slightly more (7%), and the clip-ons the most (11%).

The second part of the study consisted of taking photometric measurements of the instrument clusters. Two versions of clusters were measured: production models from the 1989 Nissan Maxima and modifications of them with extended luminance ranges. The clusters consisted of three types: an electronic cluster (based on vacuum fluorescent technology), a standard analog cluster with black characters on white during the day (opposite of common practice) and white characters on black at night when cluster lighting is on, and a modified analog cluster identical to the standard cluster except that white (day) or green characters (night) are always shown on black. UMTRI's luminance levels of the production models were comparable to Nissan's for the green cluster (11% difference) and Kanto Seiki's for the white cluster (8% difference).

For the clusters with extended ranges (used in the driver preference experiment), measurements of luminance as a function of voltage, cluster reflectance, and veiling glare were recorded. The green and white analog clusters had similar luminance levels at low voltages (less than 12) while the green cluster had slightly higher levels than the white cluster at higher voltages. Luminance levels of the digital cluster were comparable to those of the white cluster at low voltages but exceeded even those of the green cluster at 12.7 volts (the maximum that could be measured). Character/background reflectances were 1.2/1.1%, 21.7/3.8%, and 5.1/38.2% for the digital, green, and white clusters, respectively. Finally, veiling luminance increased only slightly as voltage increased, with the white cluster having the highest level and the digital the least.

In the third part of the study, driver preferences for luminance levels for the three clusters with extended luminance ranges (electronic, green analog, and white analog) were obtained. As participants drove around a 17-mile route in Ann Arbor, Michigan, preferences for luminance levels (4 judgment types--minimum, preferred, maximum, and dazzling) were obtained at 9 sites that varied in ambient illumination levels. Data were collected both during the day (for the electronic cluster with and without sunglasses) and at night (for all three clusters). For each judgment, the experimenter recorded three illumination readings (instrument cluster, roof/ambient, and the driver's face) and the cluster voltage (which could be used to compute luminance). Thirty drivers [20 U.S. citizens (10 young, ages 25-41 and 10 older, ages 66-78) and 10 Japanese citizens (young, ages 29-43)] participated.

An Analysis of Variance (ANOVA) of contrast ratios (based on 5400 data points--30 drivers x 9 sites x 5 panels x 4 judgments) revealed statistically significant differences due to instrument cluster, judgment, and site. The three panels had different contrasts at night (digital=178:1, green=82:1, and white=51:1). For the digital cluster during the day, a t-test revealed significant differences due to sunglasses (with=14:1 and without=11:1). The preferred ratios were 14:1, 11:1, 186:1, 77:1, and 44:1 for the 5 conditions (with sunglasses, without sunglasses, electronic, green, and white, respectively). For judgments, the order from least to greatest contrasts was minimum (30:1), preferred (67:1), maximum (84:1), and dazzling (88:1). The maximum and dazzling judgments did not differ from each other but this was a function of the limited range of the panel. Drivers could not set the voltage high enough to be maximum and dazzling 30% and 67% of the time, respectively. For the maximum judgment, the highest voltage setting would have to be increased from 12.7 to 19.2 volts to be sufficient for 99% of the population.

A simple t-test of contrast revealed statistically significant differences between young (64:1) and older (70:1) American drivers but not between American men and women or between Japanese and American drivers. An additional analysis of the dazzling judgment with respect to character luminance revealed results similar to those for contrast, except that the daytime conditions (with and without sunglasses) and young and older Americans did not differ.

A stepwise regression analysis was performed to predict the contrast ratios that drivers want. Separate equations were developed for each cluster-judgment combination, except when no differences in preferences were found in the ANOVA. Potential predictors included illumination levels (lux) on the roof/ambient (R), instrument panel (IP), and the drivers face (hat-H) as well as the driver's age. The 13 prediction equations are given in the report. At least 84% of the variability in contrast was explained by the factors included in the models for the preferred, maximum, and dazzling judgments (except for the green panel which could not be predicted, thus the mean provides an adequate prediction). The prediction equations for the preferred contrasts are:

<u>Day</u>
With Sunglasses=31.15 - 0.002 H - 0.0004 R
Without Sunglasses=30.35 - 0.004 R

<u>Night</u>
Digital=190.97 - 12.01 IP
Green Analog=77
White Analog=49.44 - 5.47 H

INTRODUCTION

Drivers want cars that are easy to use. Of particular importance to them is the ease of use of the driver-vehicle interface, the instrument panel. The panel must be designed so that it minimizes the time needed to obtain information, allowing drivers to keep their eyes on the road. Thus, the information provided must be both legible and understandable.

The legibility of text depends primarily upon character size, contrast, luminance, typeface, and color. For electronic displays, the key design problem is providing enough display luminance; that is, making the display bright enough so that it can be read when sunlit. But simply providing as much luminance as possible is not the answer. If a display is too bright, it will become a glare source and interfere with the driver's view of the road. Hence, the human factors problem is to decide how much light is required so the display can be easily read. This report examines the panel luminance levels that drivers prefer.

Other factors which may affect legibility (and are investigated in this report) include age and sex of the viewer, ethnic/cultural differences, ambient illumination levels, and the use of sunglasses. Ethnic origin, in particular, the difference between American and Japanese citizens, was examined because the sponsor of this research manufactures vehicles marketed in both countries. In addition, preferences were determined for three different panels manufactured by the sponsor. Finally, since it is presumed that drivers adjust panel brightness levels, why and how frequently they do so was examined. In particular, the following eight questions were investigated:

1. **What panel luminance/contrast levels do American drivers identify as minimally acceptable, preferred, maximally acceptable, and dazzling?**
2. **Do Japanese drivers prefer the same luminance/contrast levels as Americans?**
3. **How do these luminance/contrast level preferences vary as a function of ambient illumination?**
4. **For American drivers, how do these preferences vary as a function of age (young vs. old) and sex?**
5. **Do these preferences vary as a function of the type of instrumentation or its color?**
6. **How do sunglasses alter preferences for daytime levels?**
7. **What is the relationship between ambient and interior illumination levels and the illumination levels drivers experience?**
8. **How often and for what reason do American drivers adjust the panel brightness level?**

Previous studies have examined related topics such as the measurement of typical interior illumination levels, the legibility of characters, and in particular, the effect of sunglasses on legibility. A brief summary follows.

What are Typical Panel Illumination Levels?

Allen (1963)

The earliest reported survey of vehicle interior levels is that of Allen (1963). Sky, instrument panel (IP), and average scene illumination levels were measured in 56 cars manufactured in 1960 through 1962. The data were collected in Bloomington, Indiana (39 degrees North, 87 degrees West), where vehicles were measured once between 10 AM and 5:15 PM. The orientation of the cars relative to the sun varied from measurement to measurement. To provide a reference, the sun at 12:30 was due south and 70 degrees above the horizon.

Based on re-analysis of the data, the average sky illuminance was 5830 foot-candles (fc) (62,730 lux, where 1 fc=10.76391 lux). Figure 1 shows the cumulative distribution of levels. Notice that the distribution is not continuous; seven of the data points are for cloudy, not clear days.

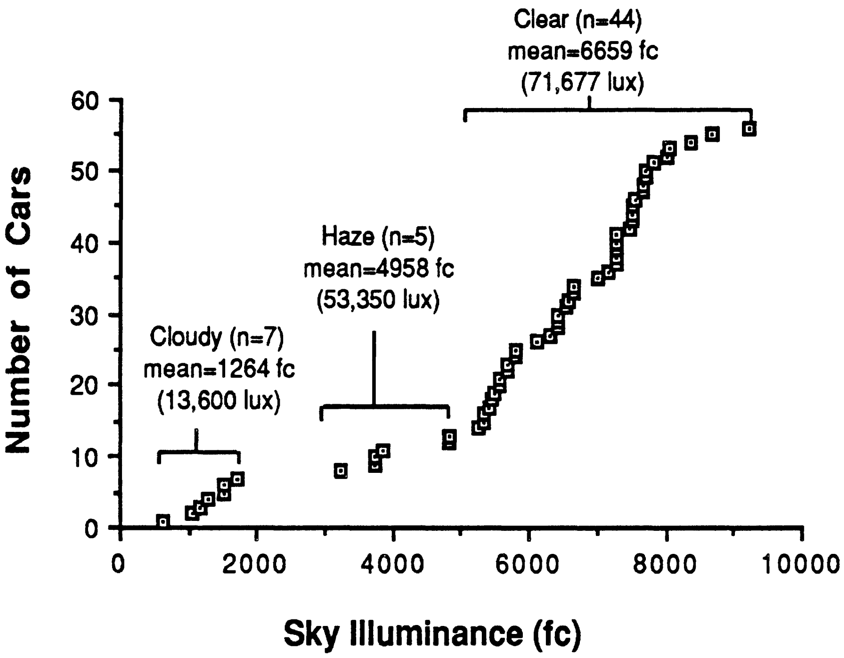


Figure 1. Sky Illuminance Levels from Allen (1963)

Figure 2 shows the panel illuminance data. Notice the one outlier, 1640 fc (17,645 lux), which corresponds to the convertible in the study measured with its top down. The mean panel level without the outlier was 177 fc (1905 lux).

As shown in Figure 3, the ratio of panel to sky levels is reasonably constant if the data point for the convertible is discarded. While the ratio for the convertible was 0.225, the average ratio without this point was 0.038 (standard deviation=0.025). Thus, panel illumination levels are typically 4% of the ambient levels during the daytime.

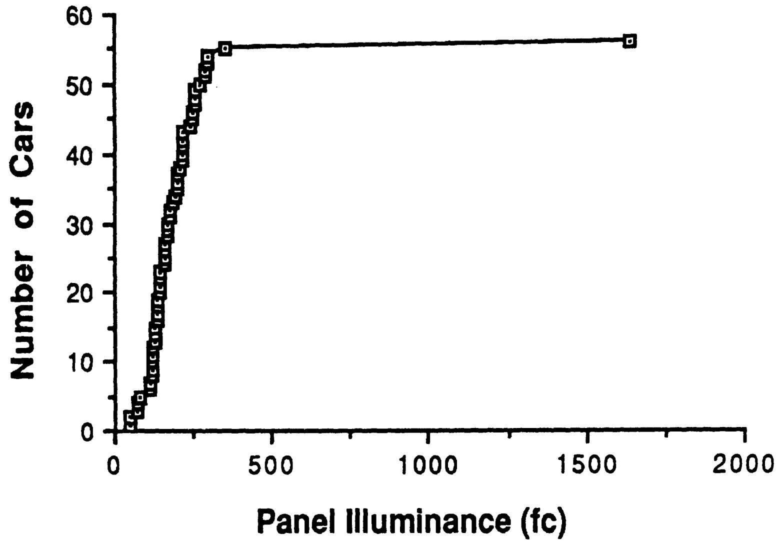


Figure 2. Panel Illuminance Levels from Allen (1963)

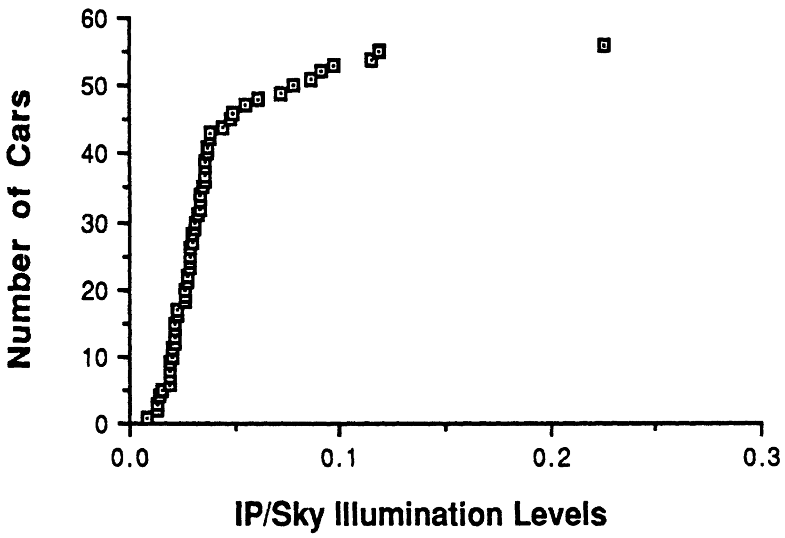


Figure 3. IP/Sky Illumination Levels from Allen (1963)

Yamaguchi, Kishino, and Dorris (1982)

As part of a study to examine the recognition of vacuum fluorescent displays, instrument panel illumination levels were measured for an unspecified four-door sedan. The sunlight conditions investigated were direct sunlight through the driver's side window and the rear window, as well as indirect sunlight through the windshield, the rear window (from a high position), and the front passenger side window. Although measurement details (e.g., vehicle sampled, etc.) are not given, it is presumed the measurements were taken somewhere in Japan.

The lowest illumination level, 1500 lux, was found when indirect sunlight entered the car through the windshield while the highest illumination levels, 60,000 and 48,000 lux, were obtained when direct sunlight entered through the open and closed driver's side window, respectively. Other illumination levels obtained were 5500 lux, 20,000 lux, and 2500 lux from light through a high position in the rear window, directly through the rear window, and through the passenger side window, respectively. The maximum values reported (direct sunlight illumination) are what one would expect based on the Allen (1963) data.

Kerst and Bos (1988)

Similarly, Kerst and Bos measured interior lighting levels to set conditions for subsequent studies of display legibility (Boreczky, Green, Bos, and Kerst, 1988; Bos, Green, and Kerst, 1988). They drove three small cars around a 9-mile loop in Ann Arbor, Michigan (42 degrees North, 83 degrees West). (Note: incorrect coordinates appear in the original study.) All cars had dark interiors and two had sunroofs with dot matrix glass, but no sun shades. At eight locations on the route, panel illumination levels were measured. (See Table 1.) Readings were taken between 10 AM and 1 PM on two days in mid-January. There was some snow on the ground but not a full blanket. One of the days was cloudy, the other clear. Readings were also taken late at night when it was cloudy. To check accuracy, each of the daytime conditions (location-cloud cover combinations) was taken twice, the nighttime readings three times.

Table 1. Panel Illumination Levels (fc) from Kerst and Bos (1988)

LOCATION DESCRIPTION	VEHICLE DIRECTION		SUNNY DAY	CLOUDY DAY	CLOUDY NIGHT
open, illuminated, no nearby buildings	205°	S-SW	299.3	283.2	0.007
suburban road, no street lights	105°	E-SE	302.7	276.5	0.008
city street, street lights, some buildings	15°	N-NE	462.7	452.0	0.049
expressway, no overhead lighting	160°	S-SE	266.8	266.3	0.002
5-lane street, commercial strip (well lit)	285°	W-NW	2032.5	434.0	0.127
5-lane street, commercial strip (well lit)	305°	NW	3019.3	490.5	0.547
boulevard, no street lights, few buildings	35°	NE	319.5	335.7	0.006
4-lane street, well illuminated	0°	N	509.3	382.0	0.149
MEAN			901.5	365.0	0.112

There were statistically significant differences between the three cars. The three light levels for the Z-24 (with a deeply recessed cluster) on the sunny day (400 fc) were half those of the Chevy Cavalier (820 fc) which in turn were about 60% of those in the Mazda 323 (1475 fc). (The 323 had considerable glass.) Even more significant were differences between locations, conditions, and their combination. (See Table 1.) The mean panel illumination levels were 902 fc (9705 lux) for the sunny day, 365 fc (3927 lux) for the overcast day, and 0.112 fc (1205 lux) for the overcast night.

Figure 4 shows panel illumination as a function of the orientation of the vehicle for the daytime sunny condition. Notice that orientation had a marked effect on the lighting level in this condition. When the test car was heading northwest, sunlight entered the car through the driver's side window and fell directly onto the cluster, leading to illumination readings of 2000-3000 fc. With those data points removed, the sunny day mean drops to 360 fc (3875 lux), about double that reported by Allen (1963).

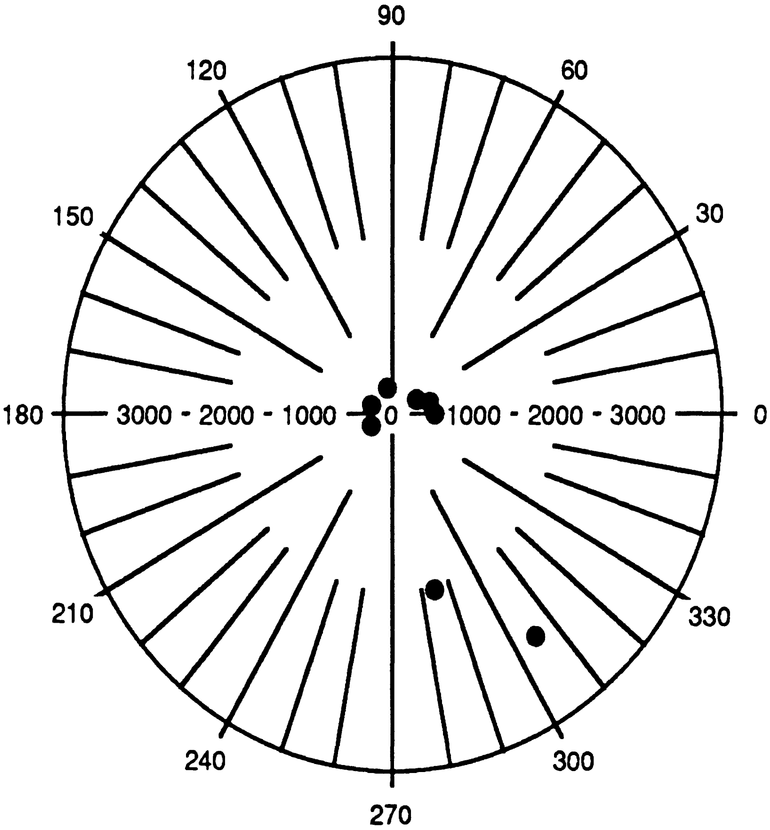


Figure 4. Polar Plot of Panel Illumination for Sunny Condition from Kerst and Bos (1988)

In summary, instrument panel illumination levels are determined primarily by ambient levels (Allen, 1963; Bos and Kerst, 1988; Yamaguchi, Kishino, and Dorris, 1982). Differences between vehicles tend to be small for contemporary cars, probably less than those of the past (except for cars with sunroofs) because of greater use of nonreflective interior treatments. During the daytime, panel levels depend primarily on cloud cover and sun angle. Levels on the order of 175-200 fc (1880-2150 lux) are common when lighting is indirect. However, when lighting is direct (as was the case for some of the conditions studied by Bos and Kerst), levels increase several orders of magnitude, especially for driver's side window exposures. Nighttime levels vary by about two orders of magnitude, with 0.11 fc (1200 lux) being typical.

What Are Typical Eye Illumination Levels?

As part of a large study of instrument panel legibility, Mourant and Langolf (1976) measured the light level falling on a driver's eyes inside a 1973 Buick LeSabre, using low-beam headlights on a dark night with no moon and no street lighting. The level reported was 0.053 lux (0.0049 fc).

Allen (1963) found that illuminance for a variety of scenes averages 11.7% of sky illuminance. Scenes of interest include green fields, city streets, dirt roads, concrete roads, and gravel roads which have illumination levels that are approximately 6%, 9%, 13%, 16%, and 17% of sky illuminance, respectively.

How Are Glare Levels Computed?

One of the consequences of external illumination of a vehicle interior is that some of the light may not be desired. One form that light might take is as a glare source. There are two types of glare, disability glare and discomfort glare.

Disability glare is a decrease in visual performance produced by stray light. This light produces a veiling luminance which interferes with seeing. The apparent luminances of the background and object are given by the following equations:

Background Luminance = $L'_b = L_b + L_v$
Object Luminance = $L'_o = L_o + L_v$

where L_v = added luminance due to the stray light

since contrast = $C = (L_b - L_o)/L_b$

replacing L_b and L_o with L'_b and L'_o

apparent contrast = $C' = (L_b - L_o) / (L_b + L_v)$

for multiple glare sources

$$L_v = 10\pi[E_1 a_1^{-2} + E_2 a_2^{-2} + \ldots + E_n a_n^{-2}]$$

where:

L_v = equivalent veiling luminance (ft-L)
E_i= illumination along the line of sight contributed by each glare source (fc)
a_i= angular displacement between each glare source and line of sight (degrees)

(Illuminating Engineering Society, 1972)

For motor vehicle design, there are two concerns with disability glare--do oncoming headlights interfere with detecting roadway objects or reading signs and does the panel interfere with seeing them? Generally, panel luminance does not create a problem.

Fry (1975) describes an analytic method for measuring the luminance of a glare source. In brief, he developed an integrating lens that can be attached to the end of a photometer. That lens weights sources based on their luminance and deviation from the line of sight.

Discomfort Glare is the "subjective impression of discomfort from bright lights" (Sivak, Olson, and Zeltner, 1989, p. 391). Boyce (1981) describes three methods that are used primarily to assess discomfort glare from overhead office lighting, the Visual Comfort Probability (VCP) Method (Guth, 1963), the Glare Index System (Petherbridge and Hopkinson, 1950), and the European Glare Limiting Method (Sollner, 1965, 1974).

According to the Visual Comfort Probability (VCP) method (from Boyce, 1981):

Glare Sensation Index = $M = 0.5L_sQ/(PF^{0.44})$

where:

L_s = Luminance of the glare source (candela per square meter (cd/m^2))
$Q = 20.4W_s + 1.52W_s^{0.2} - 0.075$
W_s = solid angle subtended at the eye by the glare source (steradians)
P = index of the position of the glare source with respect to the line of sight (Boyce does not identify the units)
F = mean luminance of the entire field of view, including the glare source (cd/m^2)

For multiple sources:

Disability Glare Rating = $DGR = (\sum_n M)^a$

where:

$a = n^{-0.0914}$

n = the number of glare sources

Using a figure, DGR values can be converted into VCP values, the percentage of people who will find the cumulative glare sensation acceptable. Boyce (1981) notes that the experimental evidence on which it is based is limited and somewhat removed from application, though the method seems to work in practice.

Another expression used is the Glare Index System of Petherbridge and Hopkinson (1950). According to Boyce, the glare from a single source is:

Glare Sensation = $G = 0.48 L_s^{1.6} W_s^{0.8} / (L_b P1.6)$

where:

L_s = luminance of the glare source (cd/m^2)
W_s = solid angle subtended by the glare source at the eye (steradians)
L_s = mean luminance of the field of view excluding the glare source (cd/m^2)
P = index of the position of the glare source with respect to the line of sight

For multiple glare sources the Glare Index is:

Glare Index = $10 \log_{10}(\Sigma G)$

This expression was based on people responding to simulations of schoolrooms. Boyce (1981) believes the data are more reliable than the VCP method.

The third approach used is the European Glare Limiting Method (Sollner, 1965, 1974). During its development, one-third scale models of an office were viewed by 10-15 observers. A total of 750 different lighting variations were examined. Those results, generally presented in a graphic form, were examined by Fischer (1972) and represented as equations. For luminaires with luminous side panels viewed crossways:

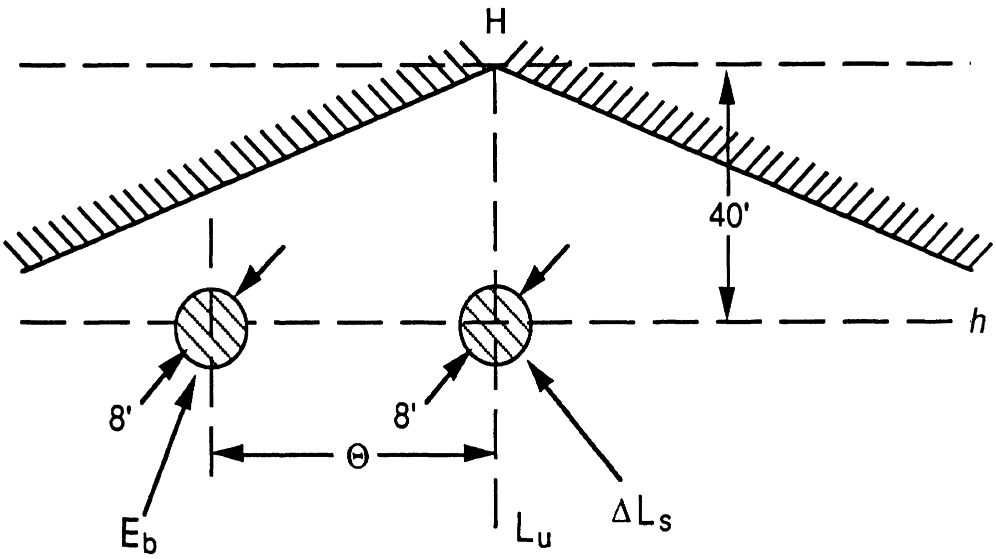
$$\log_{10}(L_{75\text{-}90}) = 2.93 + 0.07(G - 1.16\log_{10}(E/1000))^2$$

where:

G = glare rating
E = illuminance on the horizontal plane (lux)
$L_{75\text{-}90}$ = luminance of the luminaire at an angle of 75-90 degrees

Because the nature of the experimental context in which these three methods were developed is so different from that of driving, it is not clear how applicable these expressions are to instrument panel lighting.

The preferred expression is based on the work of Schmidt-Clausen and Bindels (1974). Their work examines both disability and discomfort glare. In their research, people were shown two lights against a background (with a uniform adaptation level) that resembled a driver's view of a road. (See Figure 5.) During the experiment, a glare source was present at a known angle from the line of sight to a target in the center of the field of view. At random times the target luminance was either increased or not increased above the threshold for 1 second. The subject's task was to rate the glare on the 9-point DeBoer scale shown in Table 2.



where E_b = glare illumination
Θ = angle of glare
L_u = adaptation luminance
ΔL_s = luminance of test object

Figure 5. Test Conditions of Schmidt-Clausen and Bindels (1974)

Table 2. Discomfort Glare Scale

Assessment	Glare Rating (W)
Unbearable	1
	2
Disturbing	3
	4
Just Admissible	5
	6
Acceptable	7
	8
Noticeable	9

In this research, disabling was defined as a doubling of the detection threshold. According to their work:

Disability Glare = $\Delta L_s = \Delta L_{soo}$ [1 + L_u/Cl + E_b/(C_{eoo} $a^{2.2}$)]

where:

L_u = background adaptation level (cd/m^2)
E_b = background illuminance (lux)
a = glare angle (degrees?)
$\Delta L_{soo} = 1.3 \times 10^{-2}$ cd/m^2
Cl = 3.5×10^{-1} cd/m^2
$C_{eoo} = 3.8 \times 10^{-6}$ lux/$min^{-2.2}$

Discomfort Glare = W = 5.0 + 2log[1 + sqrt(L_u/Cpl)]
- 2log[E_b/(Cpooa$^{0.46}$)]

where:

Cpl = 4.0×10^{-2} cd/m^2
$C_{poo} = 3.0 \times 10^{-3}$ lux/$min^{-0.46}$

The difficulty with applying these expressions of glare to instrument panel lighting is that there are significant differences in the test conditions. For example, the glare sources examined in these studies all tend to be fairly small, a fraction of a degree. On the other hand, an instrument panel might cover eight degrees if thought of as a single glare source rather than multiple sources with glare from each instrument. Sivak, Simmons, and Flannagan (1988) have shown that for small targets (0.3 to 0.6 degrees in diameter) having equal illuminance, those with smaller diameters were rated as significantly more glaring.

Mourant and Langolf (1976) measured panel glare levels using a Fry lens in three cars, with the panel brightness set to maximum. The highest level recorded was 0.001 cd/m^2 (0.34 footlamberts), an order of magnitude below the level they cite as being required for disability glare.

Also important are cultural differences in response to glare, an issue investigated by Sivak, Olson, and Zeltner (1989). In this study, as a test vehicle approached a parked car with its headlights on, people rated the glare from the parked car on a DeBoer scale (1-9). There were 18 drivers, nine from the U.S. and nine from West Germany who had recently arrived in the U.S. The West Germans consistently rated the oncoming headlamps as being more glaring than did the U.S. drivers. One explanation of this is that Europeans might be less tolerant of glare because they are normally exposed to lower levels; European low-beam headlamps deliver about 1/3 to 1/2 the light of U.S. headlights to the eyes of oncoming drivers. Because the context is preserved, similar differences are likely for instrument panel lighting levels.

Does Wearing Sunglasses Affect Visual Performance?

One of the factors examined in this research is the effect of wearing sunglasses on preferred panel brightness levels. People often wear sunglasses while driving during the daytime, but their effect on the legibility of electronic displays has not been investigated. From simple observation it is obvious that they reduce panel brightness at the driver's eyes enough that panel output must be increased considerably if the displays are to be legible. The effect of sunglasses is important because the common complaint about electronic displays is that they are difficult to read when sunlit. For American drivers, it is common for them to be wearing sunglasses when that occurs.

Qualities of sunglasses that need to be considered in relation to a viewer are light transmission, gradient, polarization, photochromaticity, and shape (Consumers Union, 1988). The most important quality is the percentage of light they transmit. As shown in Table 3, most sunglasses do not transmit all visible and UV light bands equally. This is very important for electronic displays because their light output tends to be highly spectral. For example, vacuum fluorescent (VF) displays tend to be blue-green, whereas LED displays are often red. Thus, sunglasses that were tinted red would pass relatively more of the light from an LED display than a VF display (and make the VF display more difficult to see).

Table 3. Sunglasses Test Data from Chase (1987)

Model Name	Visible Light Transmittance %	Light Spectrum Transmittance %							
		UV	Violet	Blue	Green	Yellow	Orange	Red	IR
Revo Venture	16	0	4	5	2	19	23	10	2
Serengeti Vermillion 7999SS	17	0.5	7	10	9	22	35	42	48
Bolle Irex 100 Madras	6	0	X	X	5	8	9	12	0.5
Smith Grayhawk	38	4.5	31	38	38	37	36	38	78
Vuarnet Skillynx	6	0	X	X	4	7	9	1 2	31
Oakley Blades	13	0	12	27	14	33	53	58	42
Scott Graphite I	14	0	3	2	10	17	18	25	40
Jones Magic	27	0	12	27	14	33	53	58	74
I Ski Suncloud Rose	8	1	4	5	2	12	20	25	37
Bolle Irex 90+ Cateye	40	0	2	6	37	46	49	52	10
Style Eyes Pro Rose III	6	0.5	2	3	2	8	13	16	27
Carrera Extreme 100 Top	5	0	X	X	2	9	7	3	1
Gargoyles	20	0	11	15	20	20	21	25	47
Uvex Sportstyle 78	33	0	10	24	31	33	39	61	84
Ray-Ban Wayfarer	14	X	9	10	14	14	11	17	10
Sid Optiks Hicon Killy	6	0.5	2	3	2	9	14	16	23
I Sid Lites	7	0	5	5	2	13	12	17	51
Martin IR	6	0	X	X	4	8	9	8	1
Brand X	9	0.5	7	10	9	7	9	22	43
Brand Y	4	2	12	4	5	2	3	22	92

A second quality of sunglasses is their gradient, of which there are three types: plain, single gradient, and double gradient. For plain or nongradient sunglasses, the color density is uniform. For gradient or single gradient sunglasses, the top section of the lens is darker than the bottom. They may be desired for daytime driving because they reduce the sky light levels and make reading the instrument panel easy (when head movements do not occur). Double gradient glasses are darkest both at the top and bottom, lighter in the middle.

Polarized lens are designed to filter out light that becomes horizontally polarized when reflected off smooth surfaces such as pavement or water. It is believed they are well suited for driving. Many types of electronic displays, however, have polarizing layers so their output is partially polarized. If the polarization angle of the sunglasses differs sharply from that of the display, the light level the driver sees is considerably reduced.

Sunglasses can be photochromatic; that is, their transmission characteristics can change with the ambient light level and often with ambient temperature as well. Decay half lives for photochromatic lenses vary from half a minute to several minutes and are not the same going from dark to light (fast change) as from light to dark (slow change).

Photochromatic lenses can be a complicating factor when driving. For example, when entering a tunnel from bright sunlight, an adaptive electronic display would decrease its light level, but because the sunglasses had not changed, would be too dark to read. However, in a car, the roof and window glass filter out much of the UV light (which causes the lenses to darken), so they do not respond very much to changes in interior light levels. Of course, that is not true in a convertible with the top down. The effect is reduced in a car with an open sunroof and the windows rolled down since the windshield still absorbs much of the light.

Finally, the shape of the sunglasses must be considered. Obviously wraparound sunglasses or sunglasses with side shades (as in glasses used for sailing or mountaineering) will do more to block peripheral glare than sunglasses without them.

Despite their popularity, the scientific literature on sunglasses and visual performance is not very extensive. Questions about sunglasses frequently arise in the context of traffic signals, night driving, polarized headlights, and tinted windshields. One interesting view is that tinted sunglasses can make drivers behave as if they had color-defective vision (Berggren, 1970). Not only have sunglasses been found to affect visual performance, but the effect may vary depending on the type of sunglasses worn and the lighting characteristics of the environment.

In one of the first studies to appear in the literature (Allen, 1964), two people sat in fifty 1963 American automobiles and signaled when they could read the speedometer after being cued to do so. This was done both with and without sunglasses (25% transmission). A total of 40 responses were collected per car, with the sequence of cars being the same for both participants. It was found that wearing sunglasses increased response time approximately 12.5%.

Another typical study is Allen (1979). He had 29 people drive a 58-mile course while wearing photochromatic sunglasses. The participants' task was to press a button when they saw transverse white stripes in the road. The route was driven both during the day and at night. Prior to testing, the sunglasses were irradiated to bleach them, except for some of the nighttime tests. Figure 6 shows the response functions. Shown in Table 4 are the detection times. Notice that bleaching the sunglasses did have a marked effect on detection performance.

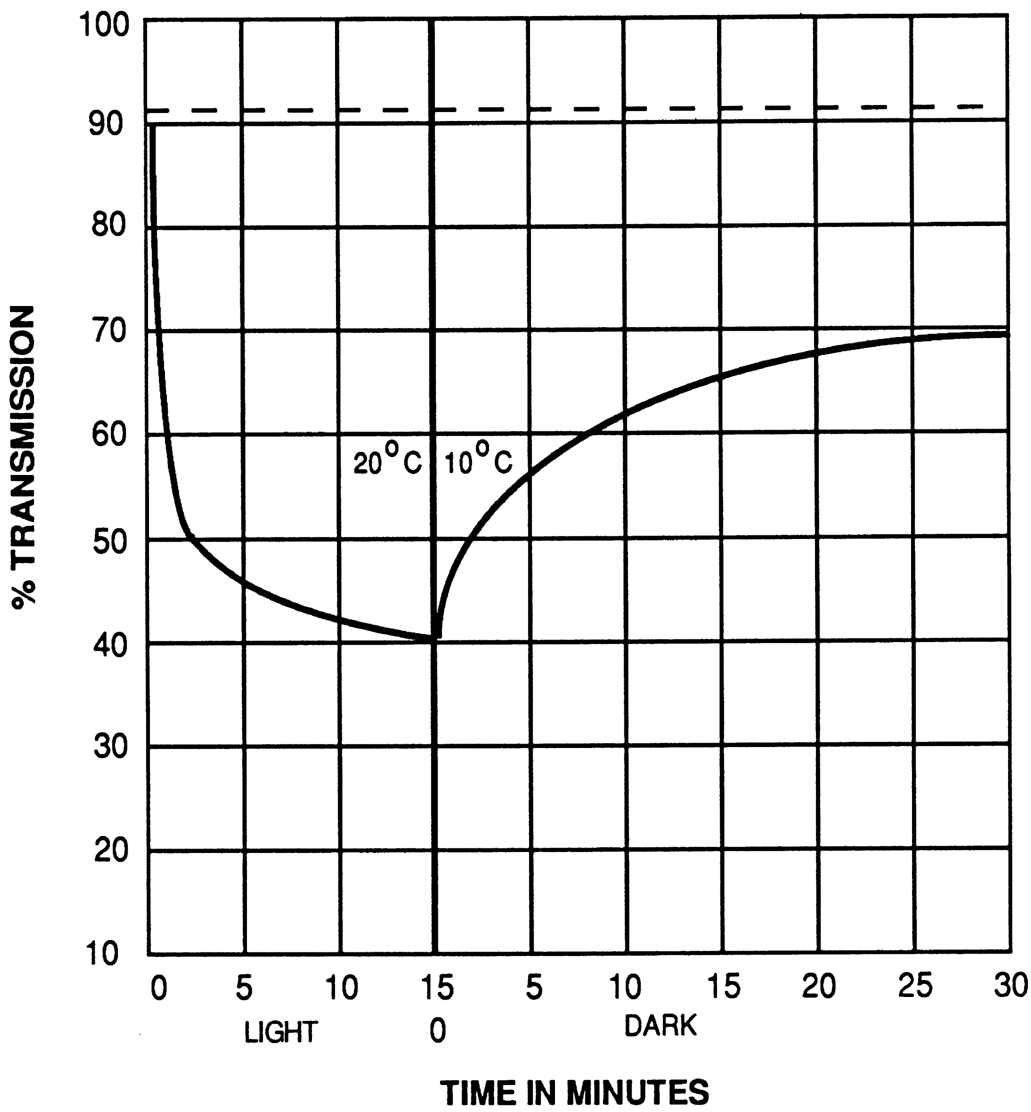


Figure 6. Response Curve for Photochromatic Sunglasses from Allen (1979)

Table 4. Detection Times (Sec) from Allen (1979)

Glasses	Day	Night	Night (kept in dark)
single coated	5.61	2.38	2.13
multicoated	5.62	2.46	2.08
crown glass (uncoated)*	5.48	2.61	2.01
neo multicoated**	5.57	2.59	2.21

* transmission = 92%
** transmission = 95%

Mehan and Bennett (1973) summarize several visual performance studies, which in sum indicated that wearing sunglasses will only have a small effect on performance since they primarily reduce overall luminance, but not contrast. This is not quite the case for polaroid sunglasses where glare reduction can lead to significant improvements in performance. They investigated the effect of sunglasses on visual acuity with and without a 1000-footlambert glare source. In the experiment, plain (20% and 30% transmission) and polaroid sunglasses (15% transmission) were used to view targets with a background luminance of 100-footlamberts. They found that while sunglasses did not affect visual acuity in the no-glare condition, polaroid sunglasses led to significant improvements in performance with glare. In fact, performance with polaroid sunglasses for the glare condition was similar to that for the no-glare condition.

Thus, the literature suggests that wearing sunglasses during the daytime makes it easier for drivers to see objects in the roadway but difficult for them to see characters on the instrument panel. However, the costs and benefits of sunglasses, especially of various types, have not been systematically investigated.

How Can Character Legibility Be Predicted?

There are literally hundreds of studies that have examined how big characters need to be so they can be read. (See Green, Goldstein, Zeltner, and Adams,1988 for a recent review.) Of the numerous studies, three are particularly pertinent.

Howett (1983) presents a series of expressions that are based on studies of visual acuity and thus represent the minimum requirements, not levels that are easy to see. In brief, he recommends that character heights be calculated as follows:

$$\text{Height} = H = (H{:}Sw) * 1.45 * 10^{-5} * S * D$$

where:

H:Sw = Height:Strokewidth Ratio
D = Viewing Distance (m)

S= Effective Snellen Acuity = $Sd * (85/L_b)^{.213} * (90/C)^{.532}$

where:

Sd = Denominator in the Snellen ratio. (If a viewer has 20/40 visual acuity, use 40.)
L_b = Background Luminance (cd/m^2)

Contrast = $C = ((L_b - L_t)/L_b) * 100$

where:

L_b = Background Luminance
L_t = Target Luminance

Payne (1983) investigated how accurately people read seven-segment liquid crystal displays. He reports:

Error Rate (%) = 1.52 + .02Bl - 1.4Ca + .02Va - .0006Ea

where:

Bl = Back Light Luminance (0-122 cd/m^2)
Ca = Character Subtense Angle (0.025-1.34 degrees)
Va = Viewing Angle (0-60 degrees)
Ea = Ambient Light Illumination (20-1500 lux)

Notice that the effect of ambient illumination is linear for the range explored (essentially daytime conditions).

But the most important studies are recent UMTRI efforts to predict the time required for drivers to read numeric speedometers (Boreczky, Green, Bos, and Kerst, 1988). Drivers were shown slides of instrument panels while seated in a mockup and indicated by pressing a button if the speed shown was over 55 mph. Concurrently, they also responded to slides where the road scene normally would appear, thus occupying their attention as when they drive.

The time required to read digital speedometers can be predicted as follows:

$$\text{Response Time (ms)} = 1054 - 320A + 1050(1/H) + 202L + 89.6(1/\ln C) - 9.58(\ln I) + 4538(1/H^2)$$

where:

A = Age Group (1 for old, 2 for young)
H = Digit Height (5-19 mm)
L = Location (1=center, 2=sides)
C = Contrast Ratio (1.5:1-20:1)
I = Illumination (1-900 lux)

Notice that the time to read a display is proportional to the logarithm of illumination, with added illumination decreasing the time. It is quite likely that preferred levels are also proportional to the logarithm of illumination.

Summary

The literature provides a solid basis for this research. Typical interior illumination levels and methods of glare measurement have been reported. There also is some evidence of the effects of wearing sunglasses on reading displays, but not the electronic displays found in contemporary vehicles. Finally, there is a vast literature identifying the relationship between lighting and character variables and the time to read text on displays. What is lacking is the connection between preferences (to maximize reading performance, minimize glare) and what is described in the literature to lead to good performance.

TRANSMISSION CHARACTERISTICS OF SUNGLASSES

In this part of the study, light transmission levels of sunglasses used in the driver preferences experiment were examined. Because resources did not permit a wide range of sunglasses to be investigated, only a few popular options were considered. Following is a description of how their optical properties were measured.

Test Plan

Test Equipment and Materials

The sunglasses used in the study were Bolle® Irex 100 cateye and clip-on styles as well as Bolle® Acrylex aviator sunglasses. All of them had an amber tint and were in the middle of the range in transmission characteristics. In the U.S., Bolle® is one of several popular brands, and L.L. Bean, where the sunglasses were purchased, is one of the largest outdoor clothing and camping mail order firms. (Sales figures and market share data were not obtained.)

Spectral transmission levels for the sunglasses were obtained using a Beckman spectrophotometer (model ACTA-2). A Photo Research digital spot photometer (model PR-1980A-CD) and a Minolta Illumination meter (model T-1) were utilized to measure overall transmission levels.

Test Activities and Their Sequence

Light transmission levels as a function of wavelength were collected by placing the lens of the sunglasses in an enclosed chamber of the spectrophotometer. After selecting a wavelength to measure, the transmission level was automatically measured and presented on a display. The transmission level was obtained by a comparison of the intensities of two beams of light sent through the chamber; one through the lens and one through air.

Visible light was measured in the 400 nanometer (nm) to 780 nm wavelength range, while invisible ultraviolet light and infrared light were measured in the 370 nm to 400 nm range and the 780 nm to 800 nm range, respectively. The data were collected in 10 nm increments.

Overall light transmission levels were obtained using the photometer. A standard white reflectance source was placed on an outside platform where it was exposed to sunlight and its luminance was measured (using the photopic filter). Subsequently, the lens was interposed between the sun and the white reflectance source and the luminance level was recorded. Thus, the amount of light transmitted was the luminance level of the lens in front of the white source divided by that of the white source alone.

As a cross check, overall light transmission levels were measured outside with the illumination meter. A black tube, approximately six inches in length with a two-inch diameter, was held around the sensor to shield off scattered light. Light readings were taken with and without the lens of the sunglasses covering the opening of the black tube. Three pairs of measurements (with and without the lens over the black tube) were collected for each pair of sunglasses.

Results

As Figure 7 illustrates, the three sunglasses transmit different percentages of light as a function of wavelength. While the Irex 100 and clip-on glasses exhibit similar curves, steadily increasing and decreasing trends, the clip-ons transmit more light at each wavelength. The peak transmission level of the clip-ons is 24% whereas for the Irex 100 it is only 15%. The transmission level of the Acrylex increases as wavelength increases, with a sharp increase from 660 nm to 730 nm, and reaches its peak of 33% transmission at 800 nm.

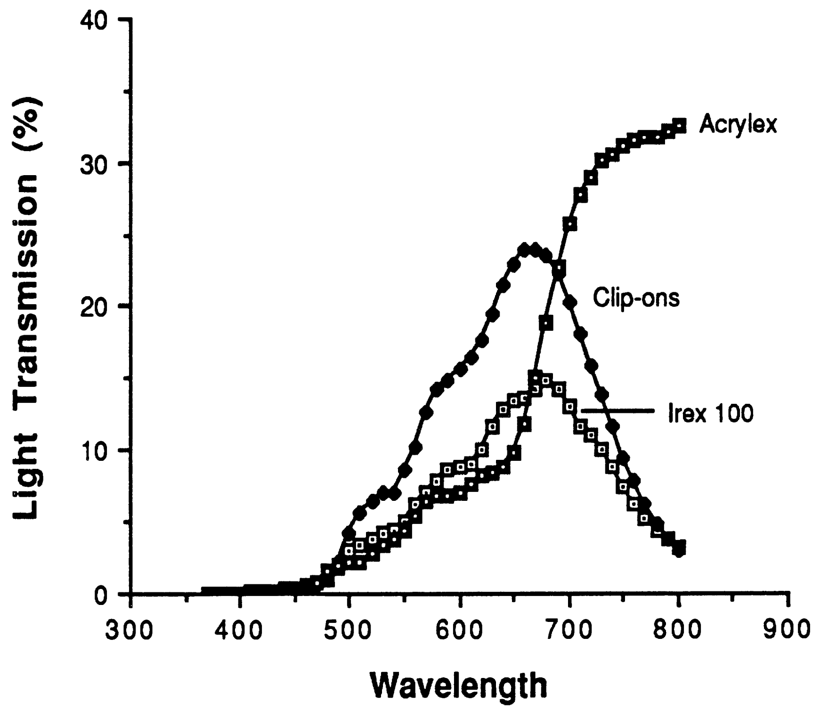


Figure 7. Light Transmission for Sunglasses as a Function of Wavelength

In the visible light range, the Acrylex curve peaks at 800 nm while the clip-ons and Irex 100 peak at 660 nm and 680 nm, respectively. Thus, the three glasses transmit more red light (650-780 nm), while absorbing blue (400-500 nm) and green (500-575 nm) light, the color of the electronic (VF) panel.

While no ultraviolet (UV) light was transmitted with any of the glasses (0.1%), some infrared light (IR) was transmitted. With the Irex 100 and clip-ons, low levels of IR light (4.0%) were measured whereas with the Acrylex lens 32% IR transmission was obtained.

Thus, while the clip-ons and Irex 100 exhibit similar transmission characteristics (the curves are parallel but transmission levels vary in the visible range), the Acrylex behaves differently.

The overall light transmission levels of the sunglasses presented in Table 5 differ depending on whether they were taken using the illumination meter or the photometer. With the photometer, the Irex 100 and the clip-ons have approximately the same levels, 13-14%, while the Acrylex transmit approximately 2.5-3.5% less light. For the light levels obtained with the illumination meter, the Irex 100 and Acrylex have similar transmission levels (7.27% and 6.18%, respectively) while the level for the clip-ons is higher (10.70%). These levels are all less than those taken with the photometer.

Table 5. Overall Transmission Levels of the Sunglasses

	Transmission Level (%)	
Sunglasses	Illumination Meter	Photometer
Irex 100	7.27	13.05
Acrylex	6.18	10.59
Clip-ons	10.70	13.93

The transmission levels obtained using the illumination meter are more accurate than those measured with the photometer. One can see by looking through the glasses that the clip-ons transmit more light than the Irex 100 and Acrylex, and that there is virtually no noticeable difference between the latter two. While the reason for the discrepancy between the instruments is unclear, it should be noted that the advertised light transmission level for the Irex 100 (the only one obtainable) is 9.93%. This level is slightly higher (2.66%) than that obtained with the illumination meter.

Thus, the overall transmission levels of the Irex 100 and Acrylex are similar whereas the clip-ons transmit more light.

INSTRUMENT CLUSTER PHOTOMETRY

In this part of the study, photometric measurements were taken of the instrument clusters. Measurements were made for two sets of clusters: production models and clusters with extended luminance ranges.

Test Plan

Test Equipment and Materials

All outdoor measurements were taken in the test vehicle, a 1989 4-door silver green Nissan Maxima sedan with a black interior. The vehicle had an automatic transmission, air conditioning, a sophisticated Bose radio with a tape deck, a power sunroof, adjustable suspension, and an adjustable transmission. The sunroof shade remained closed for all test conditions. A picture of the car is shown in Figure 8.

Figure 8. 1989 Nissan Maxima

Three types of instrument clusters for a 1989 Nissan Maxima were examined: an electronic cluster, a standard analog cluster, and a modified analog cluster. Two versions of the analog clusters were measured. One version was the production model, while the other consisted of clusters with extended luminance ranges (the maximum luminance level was increased over the production models).

The electronic cluster based upon vacuum fluorescent technology is offered as an option in the 1989 Maxima. The characters are blue-green on black. Since a key feature of the cluster is a numeric speedometer, the electronic cluster will sometimes be referred to as the digital cluster.

For the standard analog cluster, the characters are black on white. This is the opposite of common practice. At night, when the cluster lighting is on, the contrast direction is reversed and the characters are white on black.

The layout of the modified analog cluster was identical to that of the standard analog cluster. However, light characters were always shown on a black background. At night, the characters were green (on black).

Figures 9 and 10 show the electronic and analog clusters. Figure 11 shows the contrast reversal that occurs when the standard analog cluster changes from the day to night mode.

For measuring cluster luminance, a Photo Research (model 1980A-CD) digital spot photometer was used as before. In addition, a Spectra Disability Glare Integrator was utilized for veiling luminance measurements. The clusters were connected to an Eico (model 1064) adjustable power supply to take luminance measurements in the laboratory.

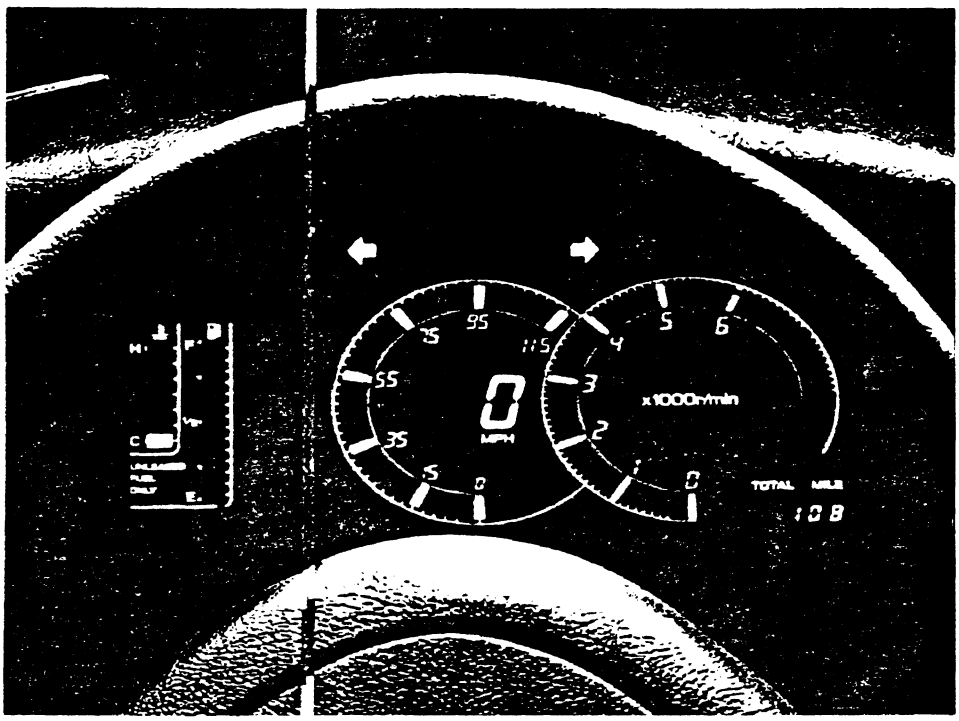


Figure 9. 1989 Nissan Maxima Electronic Cluster

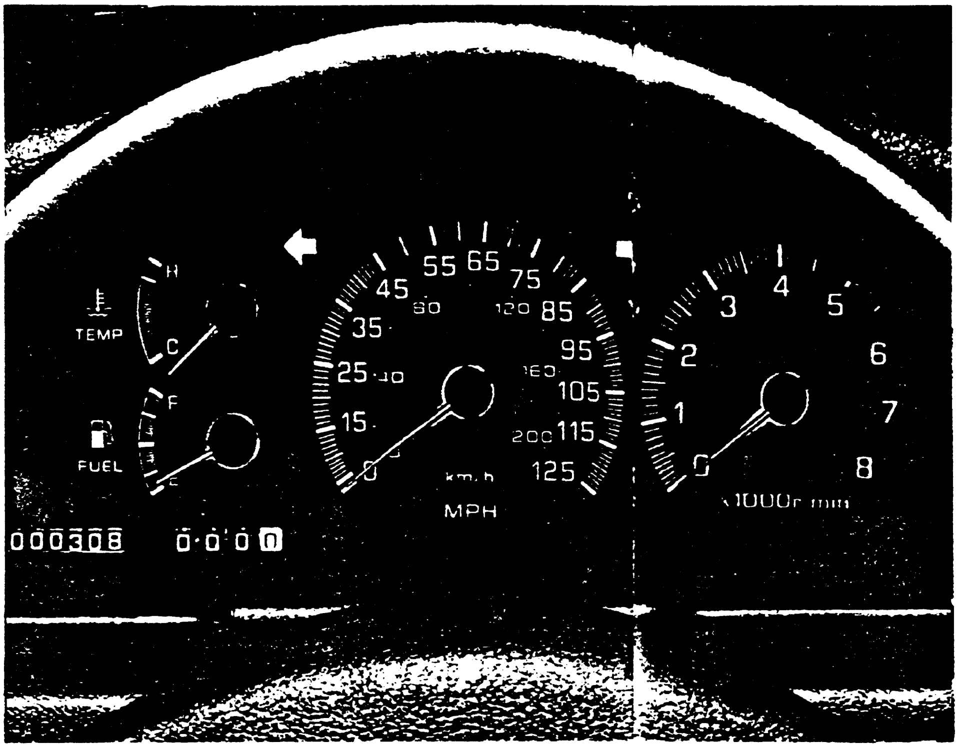


Figure 10. Standard 1989 Nissan Maxima Analog Cluster

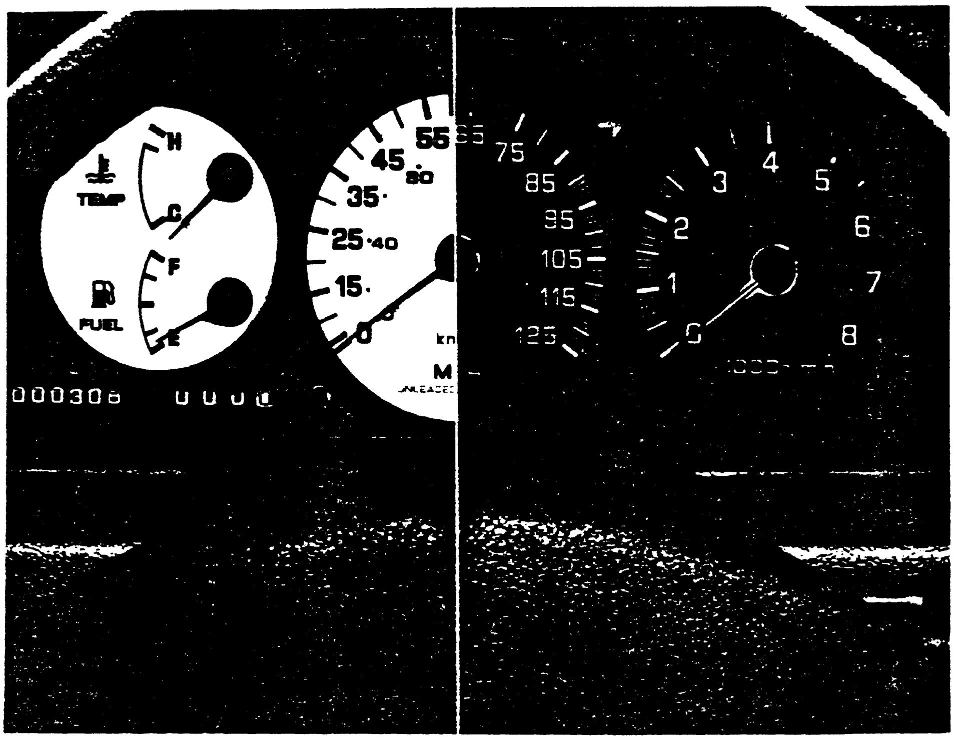


Figure 11. Day/Night Comparison of Standard Analog Cluster

Test Activities and Their Sequence

First, luminance levels were recorded for two analog instrument clusters which lacked extended luminance ranges, but which were measured in Japan. These readings were taken to verify that the UMTRI photometer was consistent with the photometers of Nissan and Kanto Seiki, the display manufacturer. Comparisons of the data appear in the Results section.

The analog clusters were propped up on a box sitting on a table and the photometer was positioned about 2.5 feet (0.76 m) away. The laboratory was dark (0.01 lux), except for scattered illumination from the photometer display and the instrument clusters.

Luminance measurements were taken at 11 locations on each cluster, 2 on the temperature gauge, 3 on the fuel gauge, 3 on the speedometer, and 3 on the tachometer. (See Figure 12 for the exact locations.) At location A on the fuel gauge and location K on the tachometer (see Figure 12), measurements were taken at 6 voltage levels (8.0, 10.0, 12.0, 13.5, 15.0, and 16.0 volts). At the other locations luminance levels were recorded at one voltage level,13.5 volts.

In addition, another set of measurements was taken on the three clusters (electronic, standard analog, and modified analog) used in the on-the-road study. Those clusters were modified so the maximum display luminance would be greater than that of the production cluster. Two sets of measurements were taken: in-the-lab and in-the-vehicle (out-of-doors). In the laboratory, measurements were made to determine the relationship between luminance and voltage (since it was not possible to measure cluster luminance while the car was driven, but cluster voltage could be measured). In the test vehicle, measurements were taken in order to assess cluster reflectance as well as veiling luminance.

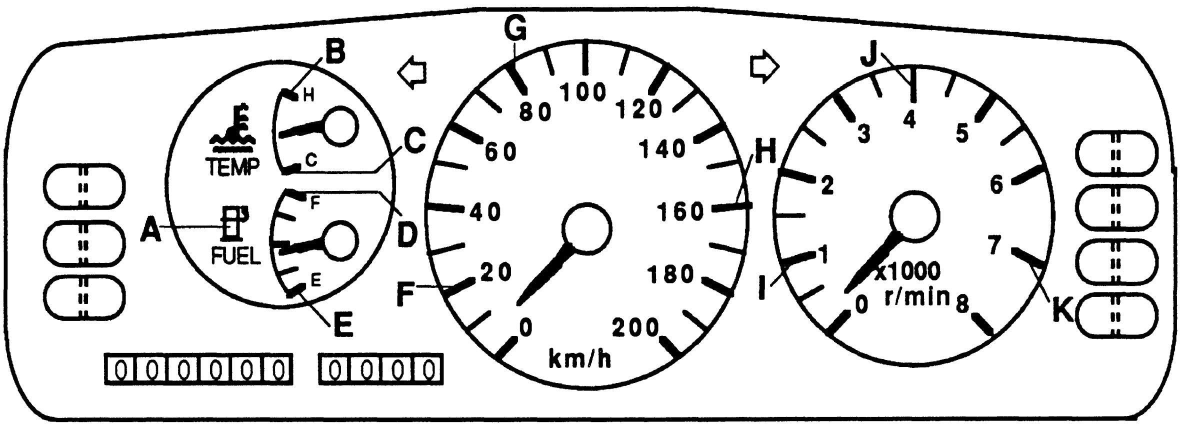


Figure 12. Luminance Measurement Locations for Analog Displays

Using the same setup as with the production clusters, luminance measurements were taken for the extended range analog clusters at location F (see Figure 12). The power supply connected to the cluster was set at 10 different voltage levels (0.0, 2.0, 4.0, 6.0, 8.0, 10.0, 12.0, 13.5, 15.0, and 16.0 volts) for the measurements.

Because the digital cluster could not be illuminated with the power supply, the car was placed in a dark garage (0.01 lux) and the cluster was measured while installed in the vehicle, again with the photometer 2.5 feet (0.76 m) away from the cluster. Readings at 17 voltage levels (0.0, 3.0, 3.4, 3.8, 4.2, 4.6, 5.0, 5.8, 6.6, 7.4, 8.2, 9.0, 9.8, 10.6, 11.4, 12.2, and 12.7 volts) were taken of the digit representing the speed (in this case, 0). These levels correspond to the steps of illuminance control in the vehicle.

In order to assess reflectance, extended range cluster luminance was measured outside both at night and during the day with each cluster installed in the vehicle. Again, measurements were taken at location F and the digit "0" for the analog and electronic displays, respectively, with the photometer 2.5 feet (0.76 m) away from the cluster. Only levels at low voltage settings (0.0, 2.9, 4.6, 5.4, 6.8, 8.3 volts) were recorded. Care was taken to assure that only ambient light was falling on the display and no chromatic light was reflected from the hood.

For all of the cluster measurements thus far, the measuring field setting on the photometer was 2 minutes of arc.

The Spectra Disability Glare Integrator was fitted onto the lens of the photometer in order to measure the equivalent veiling luminance arising from the light sources on the extended range clusters. For these readings the measuring field setting on the photometer was 1°. Again, the clusters were installed in the vehicle and the car was in a dark garage (0.01 lux). The lens, 2.5 feet (0.76 m) away from the cluster, was directed straight ahead at the windshield which is where the driver would be looking when driving. Readings at 16 voltage levels (the same as those for the in-the-vehicle luminance versus voltage measurements, except 0.0 volts) were recorded.

Results

Luminance levels of the production model green and white analog clusters were comparable to those of Nissan and Kanto Seiki at locations A (fuel symbol) and K (red tachometer tickmark). (See Figures 13 and 14.) While the values were virtually indistinguishable for the three at location A (an average difference of 0.2 cd/m^2), those at location K were slightly more spread out (an average difference of 0.8 cd/m^2) though still within the range of normal between-meter variability.

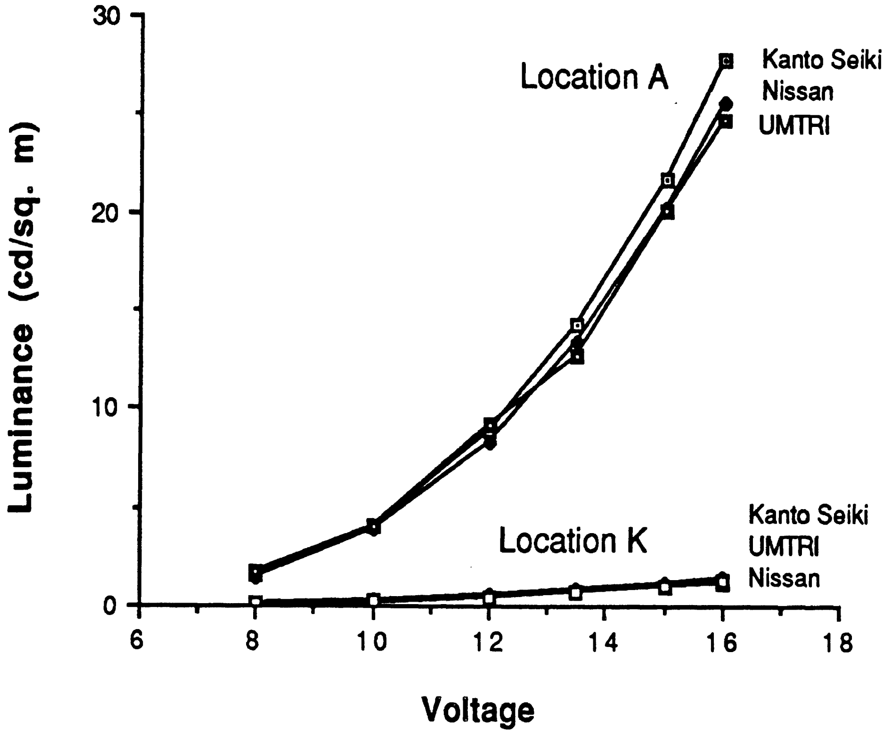


Figure 13. Luminance Level Comparisons for the Green Cluster

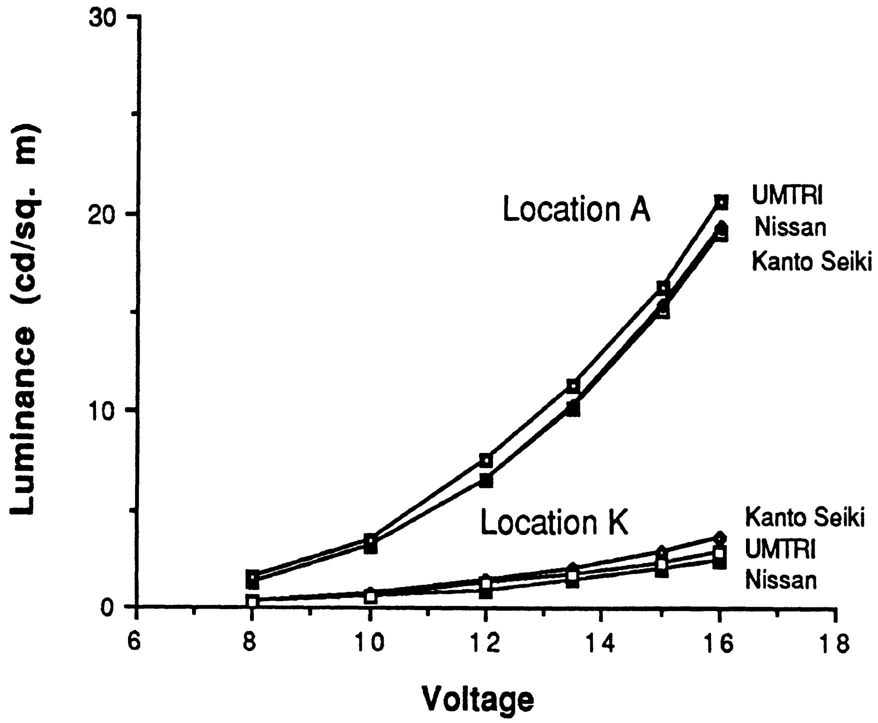


Figure 14. Luminance Level Comparisons for the White Cluster

Figures 15 and 16 show the luminance level obtained at locations B-J with a voltage level of 13.5 for the green and white clusters, respectively. The luminance levels measured by the three organizations differ by an average of 19%, with those of UMTRI in agreement with Nissan for the green cluster (11% difference) and with Kanto Seiki for the white cluster (8% difference). These differences are clearly within the limits of normal between-meter variability.

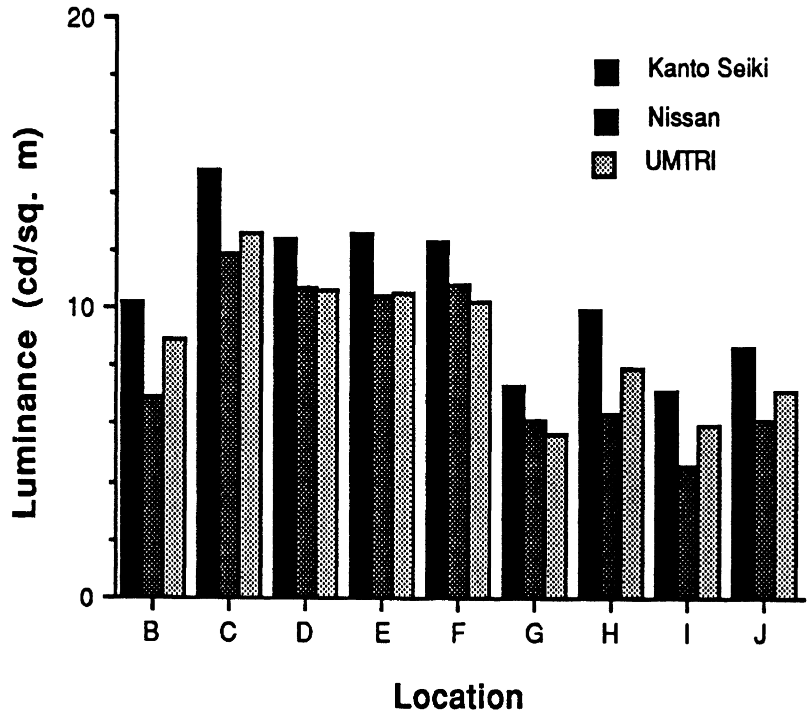


Figure 15. Luminance Level Comparisons for the Green Cluster at Locations B-J

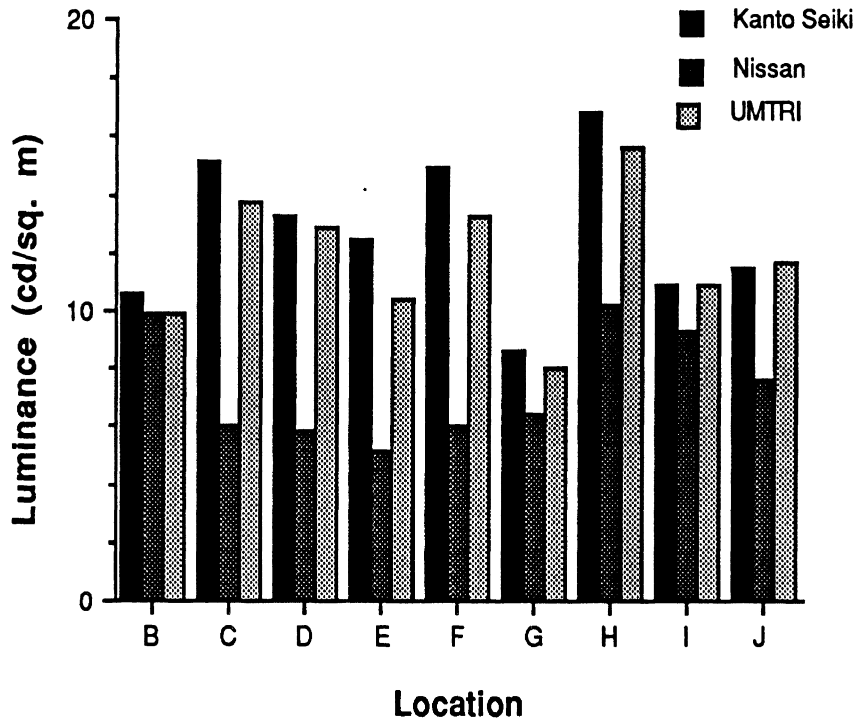


Figure 16. Luminance Level Comparisons for the White Cluster at Locations B-J

For the extended range clusters, as voltage level increased an increase in luminance level was observed. In Figure 17 it can be seen that the clusters exhibited similar character luminance levels below 10 volts. However, the green cluster had greater luminance than the white cluster at voltages above 10, with a maximum luminance for the green cluster of 80.0 cd/m^2 as compared to a maximum luminance of 53 cd/m^2 for the white cluster. The luminance levels of the electronic (digital) cluster are comparable to those of the white cluster below 12 volts but greater than the green cluster at 12.7 volts (the highest voltage level which could be measured).

Background levels as a function of voltage were found to exhibit similar trends as those of character levels, with small luminance levels (ranges from 0 to 0.57 cd/m^2) due to light scatter and reflectance. (See Figure 18.) In general, the luminance levels for the three clusters were approximately the same below 6 volts. The digital cluster luminance was lower than the others from 7 to 12 volts and then approximated the others at its highest measurable voltage level.

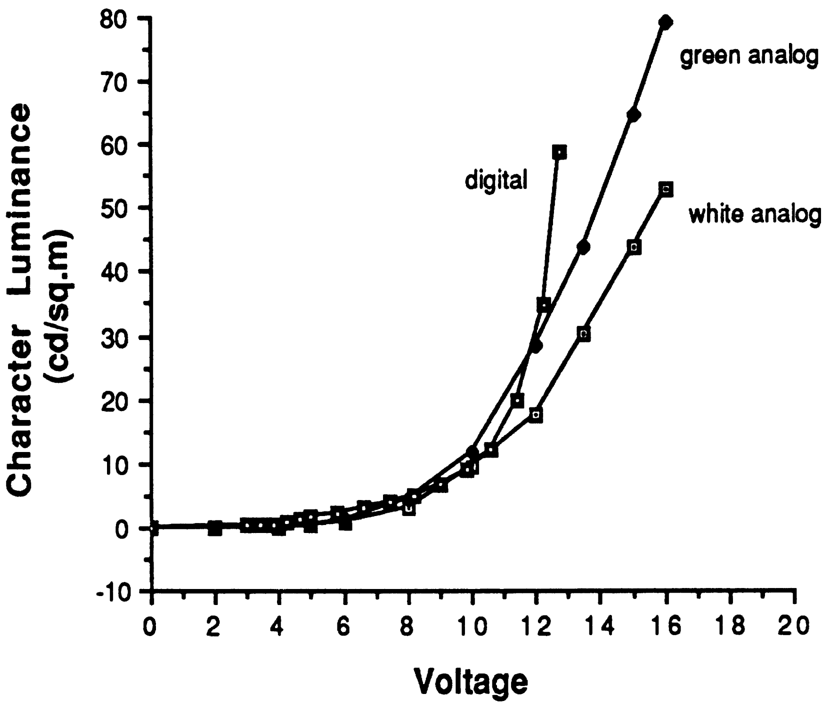


Figure 17. Character Luminance versus Voltage for Extended Range Clusters

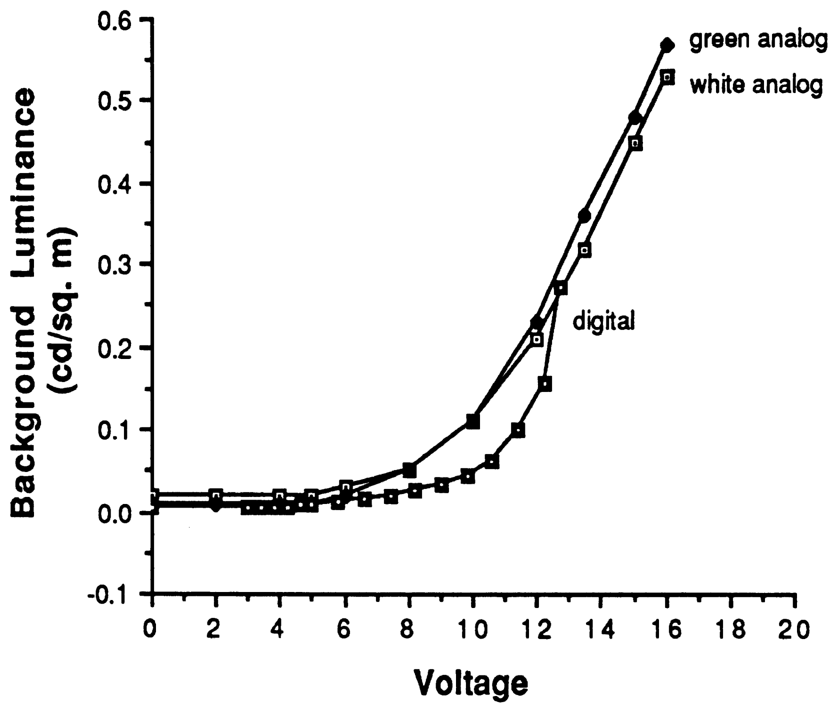


Figure 18. Background Luminance versus Voltage for Extended Range Clusters

Reflectance for each of the extended range clusters was calculated using the following formula:

$$\text{Reflectance (\%)} = \frac{L \times 3.14}{I} \times 100$$

where L = luminance (cd/m^2)
I = illuminance (lux)

Luminance was determined by averaging the values obtained in the lab and those taken under daytime (sunny) conditions. Reflectances of the character/background pairs were 1.2/1.1%, 21.7/3.8%, and 5.1/38.2% for the digital, green, and white clusters, respectively.

The reflectances of the three clusters are quite different. While the reflectivity does not differ between the character and background for the digital cluster, it does for the green and white clusters. For the green cluster, the characters reflect more light than the background whereas for the white cluster it is the opposite--the background is more reflective than the characters. This is due to the reversal characteristic of the white cluster.

By knowing the luminance and reflectance of the clusters, contrast could be computed for the various voltage levels. The following formulas were used:

Contrast = C = L_c/L_b

where L_c = character luminance = $L_v + L_r$

where L_v = character luminance due to voltage

L_r = character luminance due to reflectance
= (illum x reflect) / 3.14

and

L_b = background luminance = $L_v + L_r$

where L_v = background luminance due to voltage
(mainly scatter from character luminance)

L_r = background luminance due to reflectance
= (illum x reflect) / 3.14

Contrast was defined as the ratio of character luminance divided by background luminance, where both character and background luminance were a function of the imposed voltage and reflectance.

The glare effect from the light sources on the clusters (the various gauges), or the equivalent veiling luminance, was determined using the following equation:

Equivalent veiling luminance = Bv = Bg x Gc x 0.2918

where

Bg = average luminance with Glare Integrator (attachment lens)
Gc = correction factor to correct for change in sensitivity of instrument with the Glare Integrator
0.2918 = correction factor for instrument calibrated in metric units

Figure 19 shows the results for the three clusters. The white analog cluster has the highest equivalent veiling luminance, the green the second highest, and the digital cluster the least. The relatively flat curves indicate that equivalent veiling luminance increases only slightly as voltage increases.

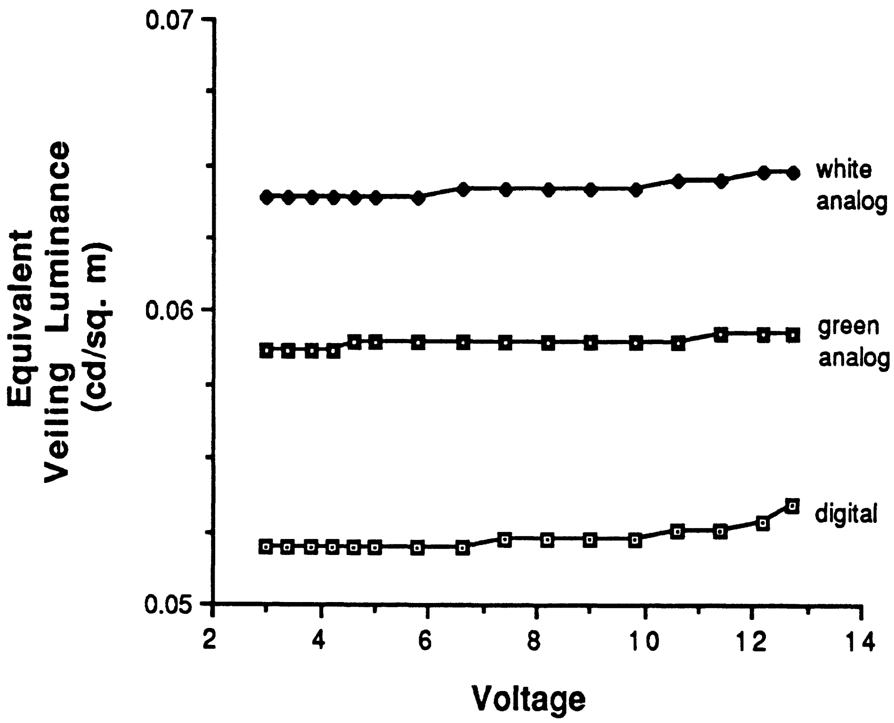


Figure 19. Equivalent Veiling Luminance Levels for the Three Clusters

DRIVER PREFERENCES EXPERIMENT

In the final part of the study, driver preferences for instrument panel luminance/contrast levels were obtained.

Test Plan

Test Participants

A total of 30 licensed drivers participated in this experiment, 20 U.S. citizens and 10 Japanese citizens. The U.S. participants were divided into two age groups, young (10 people, ages 25-41, mean=33) and old (10 people, 66-78, mean=71), with an equal number of men and women in each group. They were either friends of the experimenters or people who had served in previous UMTRI studies.

The Japanese sample consisted of 7 men and 3 women, all of whom were young (ages 29-43, mean=34). Nine Japanese people were employees of Nissan (and were selected by them) and one was a research assistant at UMTRI. While one person was born in the United States, the others had been here for as little as 6 months or as long as 20 years. Their English ranged from very good (one woman was a translator for Nissan and another was born here) to moderate (some difficulty understanding and speaking). (Language problems did not interfere with the study, however, since data were never collected until each participant demonstrated an understanding of the instructions by explaining them in their own words and going through practice runs in the parking lot.) It should be noted that it was difficult to recruit Japanese men because testing occurred on the same day for three consecutive weeks and this conflicted with their travel plans.

The corrected near visual acuity of the young American and Japanese participants was 20/22 or better, while that of the older subjects ranged from 20/50 to 20/20, with 20/200 reported for one older woman. Color vision of the young Americans and Japanese was perfect for a majority of participants (15 of 20) whereas only 2 older participants were found to have perfect color vision.

All participants were volunteers and received $60 for their time.

Test Equipment and Materials

The test vehicle was the same as that used in the photometric analysis. To facilitate adjustment of the panel luminance, a hand-held box with two pushbuttons was wired in parallel with the existing panel brightness switch. The right button increased panel brightness and the one on the left decreased it. The cord was long enough so that it could be held in either hand and rested on the participant's lap when not in use.

Three instrument clusters with extended ranges were examined: an electronic cluster, a standard analog cluster, and a modified analog cluster. These are the same clusters that were measured in the laboratory and were described previously.

In one of the daytime runs, participants wore a pair of sunglasses provided by the experimenters. They were either the Bolle® cateye, aviator, or clip-on styles described earlier.

A Titmus orthorater (model OV-7M) was used to measure participants' corrected near visual acuity and color vision.

Light sensors were placed in three locations to measure illumination levels--the roof, the instrument panel (IP), and on the front of a baseball hat (covering the driver's forehead). In addition, the instrument cluster was connected to a volt meter. Displays for the three illumination measurements and the cluster voltage were mounted in the glove box. Figure 20 shows this arrangement.

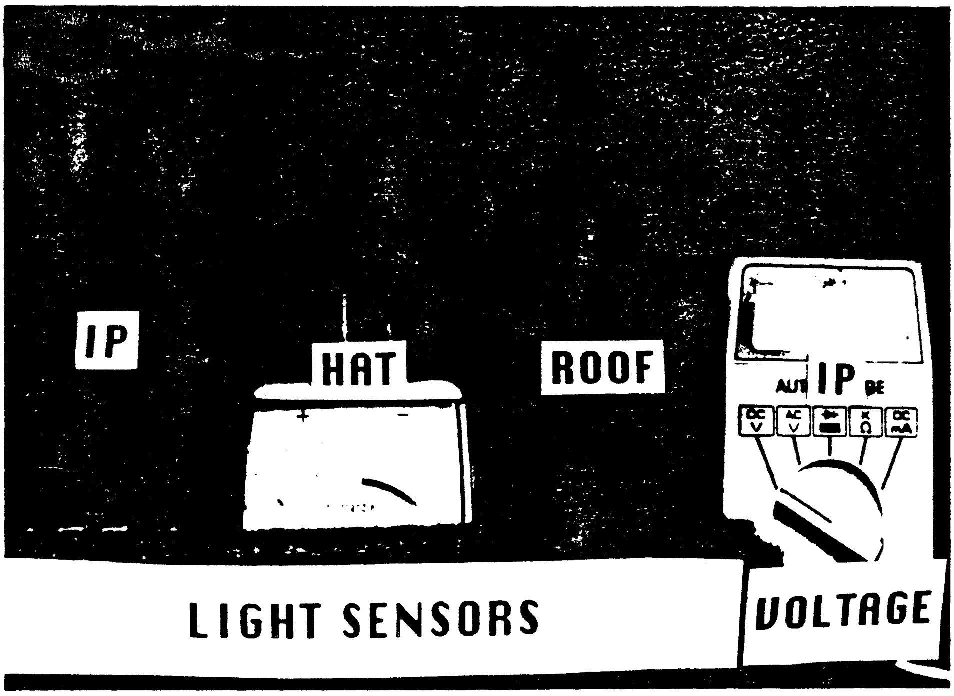


Figure 20. Displays Mounted in Glove Box

The roof sensor (for a Minolta T-1 illumination meter) was centered on the sunroof to measure ambient (exterior) illumination levels. It is shown in Figure 21.

The panel sensor (for a Minolta T-1 Illumination meter) was located about 4 inches to the right of the center of the panel (covering the tachometer). (See Figure 22.) This location was chosen to minimize the cable length required and to avoid blockage of the speedometer while at the same time providing a typical measure of panel illumination.

To measure the light level that the driver experienced, a sensor from a Gossen Panlux meter was mounted on a baseball cap (beak removed) and centered on the driver's forehead. This sensor is shown in Figure 23.

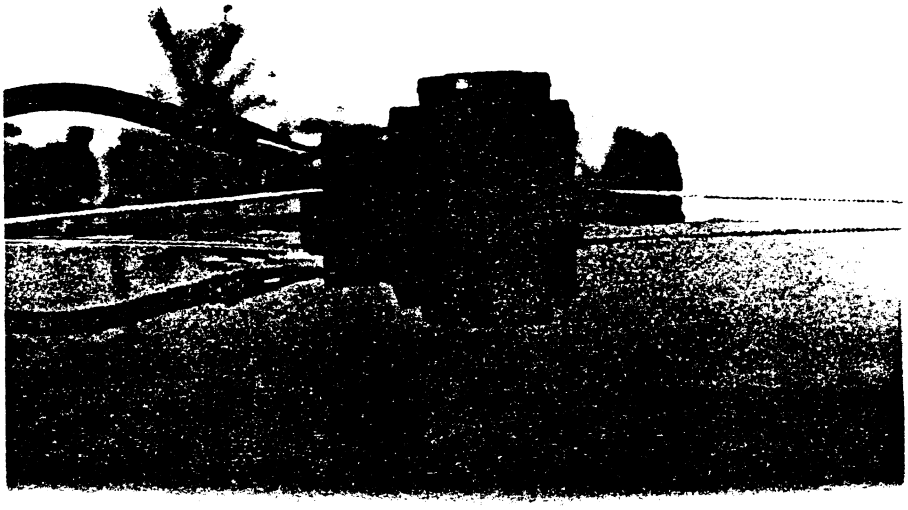


Figure 21. Roof Illumination Sensor

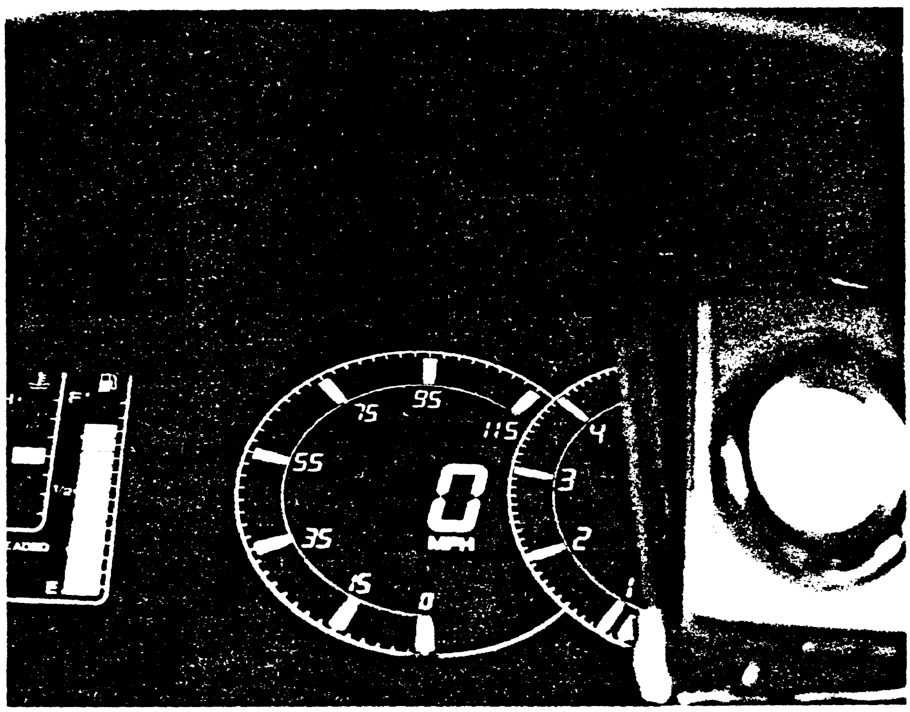


Figure 22. Panel-Mounted Sensor

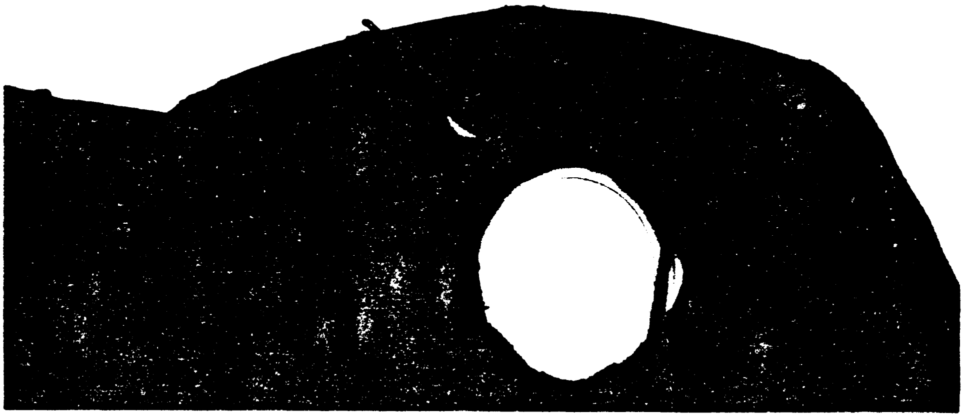


Figure 23. Sensor Mounted on Baseball Cap

Finally, to measure panel voltage, a Fluke (model 8020A 3-1/2) digital multimeter was used during the daytime sessions while a Radio Shack Micronta (model 22-188) digital voltmeter was used at night. Different meters were utilized because there was not enough light to read the Fluke meter at night.

The paperwork included a set of detailed instructions that identified exactly what the experimenter was to say and do (Appendix A), a consent form (Appendix B), a biographical form (Appendix C), and a data collection form used by the experimenter to record the lighting levels and test conditions (Appendix D).

Test Activities and Their Sequence

Prior to actual data collection several pilot subjects were tested in order to finalize the selection of sites. The location of the Washtenaw site was relocated from Arborland Mall to Ann Arbor Buick because of traffic congestion near the mall.

For the experiment, each person came to four test sessions. The first session (always during the day) lasted about an hour and a half and was used to collect biographical information and preference data for the electronic panel which was always tested first. Daytime viewing of the panel was done both with and without sunglasses, counterbalanced across participants.

At the remaining three sessions, which took approximately 45 minutes each and were always held at night, subjects viewed different instrument panels. In those sessions, the sequence of panels was partially counterbalanced across participants. (See Appendix E.) In most cases, the initial night session was run the same evening as the day session. The remaining two night sessions were usually run one and two weeks later, respectively. This was done to minimize the number of instrument panel changes, thus saving experimenter time, reducing vehicle wear, and reducing possible damage to the panels, connectors, and wiring harnesses. It was impossible to keep a rigid schedule due to problems with weather, people canceling sessions, and other procedural matters.

In the first session, the participant was given an overview of the experiment and signed the consent form. Subsequently, the experimenter obtained background information about the participant (age, occupation, education, type of vehicle driven, etc.), checked their corrected near visual acuity and color vision, and had them select a pair of sunglasses.

The participant was then taken to the car and shown a map of the route to drive, a 17-mile loop in Ann Arbor, Michigan. (See Figure 24.) This route, always driven in the same direction (clockwise), included a mixture of unlit rural roads (Earhart Rd. and Warren, a well-shaded road), lit suburban streets (Nixon Rd. and Geddes Ave., another well-shaded road), a lit city street (Washtenaw Ave. northwest from Stadium Blvd. to Geddes Ave.), a busy commercial strip well lit at night (Washtenaw Ave. from US-23 to Stadium Blvd.), a divided parkway (Huron Pkwy.), and a highway (US-23). These roads varied considerably in terms of their illumination, traffic density, sight distance, and speed limit. Daytime illumination levels were affected by tree coverage while nighttime levels were affected by lighting from nearby buildings and street lights.

Along the route, measurements were taken at nine sites as shown in the Figure. One of the preliminary steps in setting up this experiment was determining an appropriate route with a variety of light levels both during the day and at night. Two methods were involved in determining the route: (1) a survey of light levels on streets relatively close to UMTRI and (2) an analysis of the panel illumination levels collected by Kerst and Bos (1988) along an 8.9-mile route in Ann Arbor. These sites were selected to provide a variety of lighting conditions (since their ambient levels differed). They were also sites at which traffic flow would be fairly steady so that distractions from adjusting the panel brightness and interacting with the experimenter would not present an undue risk to the drivers.

At each site the driver was asked to set the panel brightness to four settings (judgments)--minimum, preferred, maximum, and dazzling. Minimum was the dimmest level that was acceptable to the driver so that the panel could be read at a glance while maximum was the brightest level that could be read at a glance. The preferred panel brightness was the light level the driver liked most. Finally, the dazzling level was reached when the panel was so bright that it interfered with looking ahead; that is, it was a disabling glare source. While setting the levels participants were encouraged to look back and forth between the panel and road to verify that the display could be read quickly.

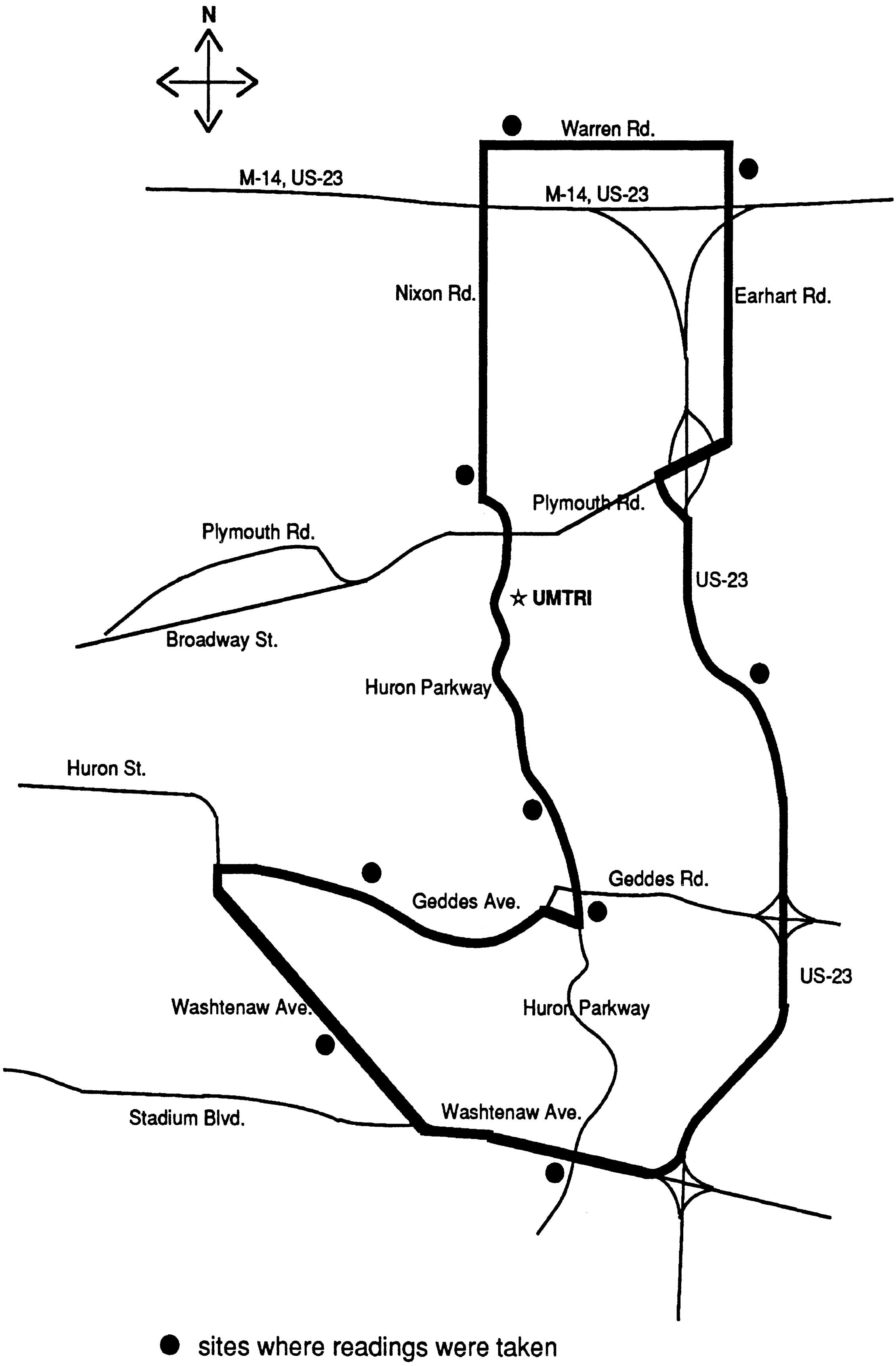


Figure 24. Route Used in Experiment

During the development of this experiment considerable discussion was given to the definition of the levels. Defining the minimum and maximum in terms of what the driver could "just" see (the threshold) was rejected because it is not desirable to present displays under conditions that sharply increase the time required for drivers to read them. The intent of the project was to discover what drivers wanted, not what they could sometimes tolerate. For dazzling, the emphasis was on disability levels rather than discomfort levels for consistency with the other measures. However, because the distinction between them was not emphasized, the two could have been confused by drivers.

Maximum and dazzling settings were always approached from lower levels, minimum from higher levels, and preferred from both higher and lower levels. Collection of the thresholds by approaching from both directions (doubling the number of data points) would be too time-consuming. Also, splitting the data collection procedure to collect half the measurements for every subject from each direction would be very error prone. And in many instances it was not possible because drivers wanted panel brightness greater than the cluster could provide for the maximum and dazzling levels.

Before leaving the UMTRI parking lot, the four judgments were explained and drivers were shown how to adjust the panel brightness. They then put on the hat, and if called for, sunglasses. Subsequently, they practiced adjusting the brightness levels.

Once on the road, all adjustments were made while the car was in motion. At each site drivers first set the panel brightness to the middle of the range. They then set it to the four levels in one of the following orders which was fixed for each driver: either maximum, preferred, minimum, and dazzling or dazzling, minimum, preferred, and maximum. Each sequence occurred five times within the three age-nationality groups. While the sequence was posted on the instrument panel, the experimenter prompted the driver to set each level.

When the desired setting was confirmed by the driver, the experimenter noted the levels of the meters on a clipboard in their lap. A small flashlight shielded from the driver was used to help the experimenter see at night. If drivers could not make the panel bright enough or dim enough, they were asked to say so.

When participants arrived for their night sessions, they got directly in the car. Before driving the route, they viewed the brightness range of the display and were reminded of the order to make the adjustments.

After all the measurements were taken, drivers were asked if the brightness range of the panel was wide enough and if the change of levels was smooth enough. At the end of the session drivers were thanked for their participation. For all but the last session, drivers were reminded of their next session.

Upon completion of the last session, drivers were asked a few additional questions about the instrumentation in their car (its color, type, etc.), how often they adjust it, and what colors they prefer. The last session ended with paying the participant.

Results

The main analysis is based on 5400 data points (30 drivers x 9 sites x 5 panels x 4 judgments). These data were collected to identify the relationship between ambient lighting levels and the luminance levels and contrast ratios desired by drivers. In order to check the reliability of the measurements, two participants repeated the test conditions. This confirmation is based on an additional 360 data points (2 drivers x 9 sites x 5 panels x 4 judgments) plus 360 from the main data set.

Since it was not possible to measure luminance in the field, a surrogate measure, panel voltage, was recorded. Appendix F shows voltage means for young and older Americans as well as the Japanese drivers. As was described in the previous section, panel luminance and contrast ratios were computed from the voltage data at location F on the analog clusters and at the digit "0" on the electronic cluster. Character and background luminance levels are given in Appendices G and H, respectively, for each panel, group, site, and judgment combination. In brief, the character luminance is a function of the luminance due to the imposed voltage plus the added luminance due to the reflectance of the panel. The background luminance also depends upon the background reflectance as well as the voltage of the panel (due to scatter from the character luminance). By knowing the luminance emitted from the panel as well as the reflectance given a certain voltage level, a contrast ratio was computed. (See the previous section for the specific formulas.) In the sections that follow, contrast ratios will be reported as whole numbers (e.g., 5) rather than ratios (e.g., 5:1).

Missing Data and Adjustments

Illumination levels were missing for 294 of the 17,280 values (1.7%) due to various complications. There were 3 occurrences where 1 or 2 of the 3 light levels were not recorded because the experimenter was distracted. There were also 3 instances where most or all of one light level was lost due to equipment malfunctions. However, the majority of the missing data (216 data points) were from the daytime-sunglasses condition for two participants. No data were collected for these sessions because the participants could not see that the digital cluster was on, no matter how high the luminance was set. (The voltage level recorded for these runs was the highest value possible.)

Missing data were estimated with one of two strategies. One strategy, used when the dash or hat light level was missing for a case (a panel-site-judgment combination), was to compute the mean for the three other light levels recorded at that site during the run. This was done because the dash and hat illumination levels within a site were observed to be consistent. The other strategy, adopted for the rest of the missing data, was to average levels obtained for similar runs (defined as runs which took place at comparable times, under the same weather conditions, and the week before or after the run with missing levels). Using this strategy, data from 2 to 7 runs were averaged to obtain a reliable estimate for each missing data point.

In addition, there were 12 roof illumination levels which were obtained but found to be inaccurate due to limitations of the voltmeter during daytime runs. These levels were estimated over 2 to 6 runs using the second strategy mentioned above. Finally, 24 light levels for two nighttime runs were estimated (from three other runs during the same week) for the first site on the route after it was determined that the levels recorded were taken slightly past the actual location. The voltages were not estimated because they were found to be comparable to others taken at the actual location.

Reliability of the Measurements

Two participants repeated the study. For these drivers, a young American woman and a Japanese man, the test conditions occurred in the same order for both runs. At least two weeks elapsed between comparable conditions to assure independence of their preferences.

The correlation of the contrast ratios from the first and second runs was extremely high ($r=0.94$, $p<0.001$). A t-test comparing the computed ratios from the two runs also indicated no significant difference ($\underline{t}$ [358] $=0.47$, $p>0.64$). The mean contrast ratios for both runs was 59. Thus the data were quite reliable.

Analysis of Variance Model

An Analysis of Variance (ANOVA) was performed on contrast ratio to determine differences between experimental conditions. In general, what people can see depends more on distinguishing an object from its background (its contrast), rather than the absolute luminance (except at very low luminance).

In the ANOVA that follows 4 factors were considered:

- Group (3 groups--young Americans, older Americans, and Japanese),
- Panel (5 combinations--2 daytime, digital with and without sunglasses and 3 nighttime, digital, green analog, and white analog),
- Judgment (4--minimum, preferred, maximum, and dazzling), and
- Site (9).

A full factorial model was used for the analysis. See Table 6 for the ANOVA summary. Because 82 estimated data points for panel illuminance were incorporated into the contrast formula, these degrees of freedom (df) were lost from the DPJS(G) interaction. Thus, the error term df's for the PJS and GPJS interactions were corrected from 2592 to 2510 (2592-82).

Due to confounding of effects with the variability of all of the factors in the error term, t-tests were performed on the daytime panel conditions (with and without sunglasses), Age (young versus older Americans), Sex (American men versus women), and Ethnic origin (American versus Japanese drivers).

Table 6. ANOVA Table for Contrast Ratio

Factor	**df(N)**	**df(E)**	**SS**	**MS**	**F**	**p**
Group [G]	2	27	30748.05	15374.0	1.58	.2236
Panel [P]	4	108	20153456.09	5038365.1	1535.55	.0000*
Judgment [J]	3	81	2912739.02	970913.0	315.57	.0000*
Site [S]	8	216	117764.21	14720.5	44.44	.0000*
Driver [D(G)]	27	---	262001.57	9703.8	---	---
GP	8	108	21113.56	2639.2	0.80	.6001
GJ	6	81	11411.00	1901.8	0.62	.7152
PJ	12	324	1497012.30	124751.0	94.16	.0000*
GS	16	216	7909.12	494.3	1.49	.1042
PS	32	864	55369.32	1730.3	6.97	.0000*
JS	24	648	7509.48	312.9	1.86	.0077*
DP(G)	108	---	354364.91	3281.2	---	---
DJ(G)	81	---	249213.25	3076.7	---	---
DS(G)	216	---	71543.28	331.2	---	---
GPJ	24	324	19383.64	807.7	0.61	.9267
GPS	64	864	14535.30	227.1	0.91	.6653
GJS	48	648	7445.95	155.1	0.92	.6215
PJS	96	2510	49556.68	516.2	3.16	.0000*
DPJ(G)	324	---	429241.66	1324.8	---	---
DPS(G)	864	---	214521.33	248.3	---	---
DJS(G)	648	---	108824.76	167.9	---	---
GPJS	192	2510	27517.28	143.3	0.88	.8139
DPJS(G)	2510	---	410165.91	163.4	---	---

* Effect is statistically significant at p<0.05 level

Key	df(N)	=	degrees of freedom (numerator)
	df(E)	=	degrees of freedom (error term)
	SS	=	Sum of Squares
	MS	=	Mean Square

Were There Differences Between Instrument Panels?

There were considerable and statistically significant differences between panels in the overall contrast ratios preferred by drivers ($p<0.0001$). For the nighttime conditions, the mean ratios were 178, 82, and 51 for the digital, green, and white panels respectively, which were all significantly different from each other (digital v. green: $F[1,108]=1517$, $p<0.001$, digital v. white: $F[1,108]=2696$, $p<0.001$, and green v. white: $F[1,108]=169$, $p<0.001$). As expected, the contrast ratios for the daytime (13) and night conditions (103) differed ($F[1,108]=3283$, $p<0.001$).

The preferred mean contrast ratios for each panel were 13, 186, 77, and 44 for the daytime conditions and digital, green, and white panels respectively. These levels are much greater than those typically reported in the literature as desirable (typically 3:1 is satisfactory). They may be an artifact of a luminance problem since the interior of the vehicle was dark and reflectance from the panels was low (character/background reflectance combinations--digital-0.012/0.011; green-0.217/0.038; white-0.051/0.382).

Did Wearing Sunglasses Alter Preferences?

While the ANOVA did not reveal a statistically significant difference between the digital panel conditions during the day (with sunglasses, 14, and without sunglasses, 12), a pairwise t-test, more appropriate here, indicated a significant difference (t [2158] =2.37, $p<0.02$). However, the data collected vastly underestimate the actual levels since the contrast ratios for the sunglasses condition were based on the data for those subjects that could see the digital cluster. Levels for the two people who could not see it would be considerably greater. Thus, wearing sunglasses significantly increased the contrast desired for the digital panel.

The preferred contrast ratios with and without sunglasses were basically the same as the overall ratios--14 and 11, respectively. Again, higher contrasts here than those in the literature can be explained by the luminance problem.

Were There Differences Between Judgment Types?

Differences between judgment types were statistically significant in the ANOVA ($p<0.0001$). The dazzling (88) and maximum (84) judgments did not differ from each other, however the preferred (67) and minimum (30) judgments were different from one other as well as from the high judgments (d_T (Tukey critical difference) [4,81]=8, $p<0.05$). The lack of a difference between the dazzling and maximum judgments may be an artifact of the limited range of the panels. As noted in Table 7, 67% of the time participants reported the highest luminance setting was not dazzling. (In those instances, the highest level achievable with the test hardware was recorded as dazzling.) In fact, even this figure may be an underestimate as participants sometimes forgot to mention when the highest setting was insufficient. It is also important to note that even the preferred and maximum judgments were not bright enough some of the time. In addition to the panel not being bright enough, there were also a few times (3%) when the lowest luminance level was not dim enough.

In order for the panels to have a sufficient maximum range for 99% of the population, the highest setting would have to be increased from 12.7 to 19.2 volts. This was determined by estimating a new mean and standard deviation for the voltage distribution from the maximum judgment given the skewed distribution (see Figure 25). It was found that 0.5% (3 standard deviations) and 16% (1 standard deviation) of the population set the panel to 5.8 and 10.6 volts, respectively. Using these figures, the maximum voltage of 19.2 for 99% of the population was obtained.

Table 7. How Often the Maximum Panel Luminance Was Reported Inadequate (%)

	Judgment				
Condition	Minimum	Preferred	Maximum	Dazzling	Total
Day					
Sunglasses	8.5	37.8	63.3	91.9	50.4
No Sunglasses	---	2.2	28.1	84.1	28.6
Night					
Digital	---	---	5.6	20.0	6.4
Green	---	0.8	33.3	72.6	26.7
White	---	3.7	18.1	64.4	21.6
Overall	1.7	8.9	29.7	66.6	

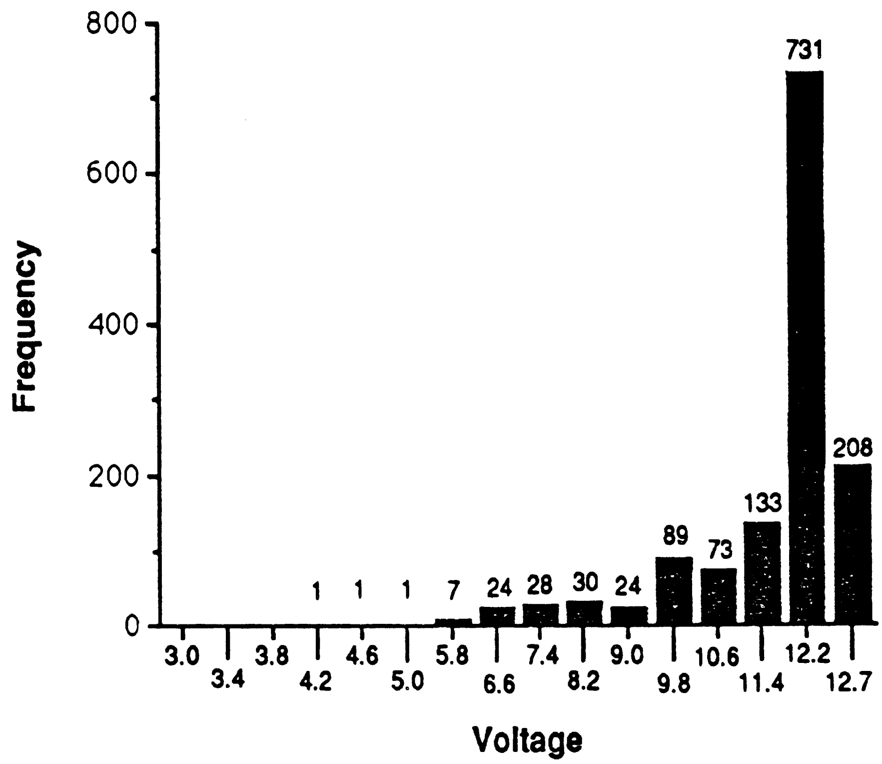


Figure 25. Frequency Distribution of Voltage for the Maximum Judgment

Knowing this new maximum voltage, luminance levels and contrast ratios were obtained for the digital panel (since this panel had the highest luminance at the previous maximum voltage of 12.7, it will have the highest luminance at 19.2 volts and thus will provide an estimate of required luminance and contrast ratios for the maximum setting). Extrapolating from the character and background luminance-voltage curves (Figures 17 and 18), the luminance for 19.2 volts is approximately 800 cd/m^2 and 3 cd/m^2 for the character and background, respectively. (See Figures 26 and 27.) (This extrapolation goes far beyond the data and could be off by a fair amount.) Thus, using a low illumination level at night of 0.02 lux, the highest contrast ratio would be approximately 267. (See the equation in the Calculation of Contrast Section.)

Does Site Matter?

Differences between sites were significant at the $p<0.0001$ level. Mean contrast ratios ranged from 58 (Washtenaw) to 75 (Geddes). Both of these sites were significantly different from all of the other sites (except that Geddes did not differ from Warren) ($d_T[9,216]=5$, $p<0.05$). In addition, Warren (71) and Earhart (70) were significantly different from Nixon (64) and the bridge on Huron Parkway (64) ($d_T[9,216]=4.7$, $p<0.05$). Thus, Geddes, Warren, and Earhart have high contrasts while low contrast sites include Nixon, Washtenaw, and the bridge on Huron Parkway. The other three sites, the highway, Washtenaw (NW), and Huron Parkway, fall into the middle of the range of contrast ratios. Since the data collection was intended to apply to a variety of illumination conditions, differences between sites were desired.

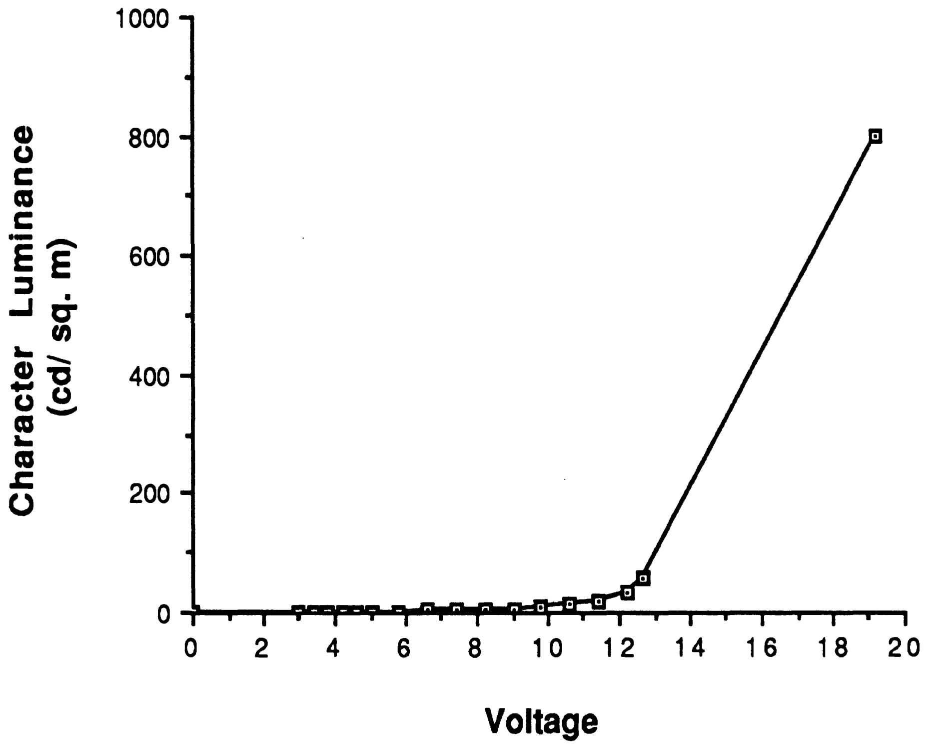


Figure 26. Character Luminance as a Function of Voltage for the Digital Panel

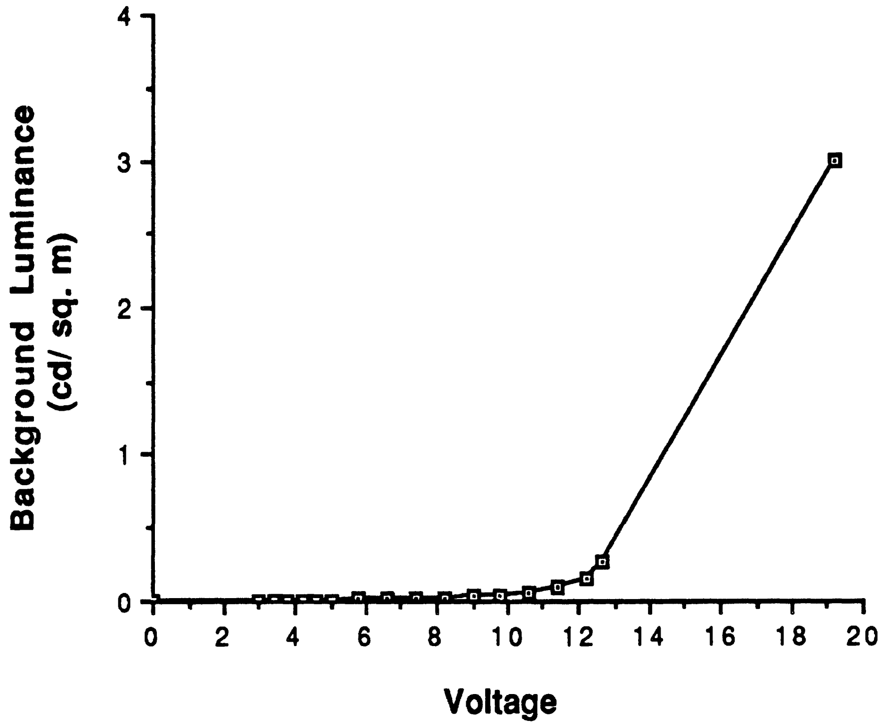


Figure 27. Background Luminance as a Function of Voltage for the Digital Panel

Were There Differences Due to Age, Sex, or Ethnicity?

There were no significant overall differences between the three groups of participants (US young, US old, Japanese young) in the ANOVA ($p>0.22$) though a simple t-test revealed a significant difference between young and older American drivers (t [3598] =2.40, $p<0.02$). The mean contrast ratios for young versus older American drivers were 64 versus 70, respectively. The preferred ratios were 61 for young and 72 for older Americans. Since vision deteriorates with age, this difference is not surprising. In addition, American men (65) and women (68) did not differ (t [3598] =-1.22, $p>0.22$).

No significant differences between Japanese drivers (who were young, mean age = 34 years) and young (t [3598] =-1.69, $p>0.09$) or older (t [3598] =0.75, $p>0.45$) Americans were found. The mean for Japanese drivers was 68, closer to the older Americans than the young ones.

Panel-Judgment Interaction

As shown in the ANOVA Table, there were three combinations of factors that significantly influenced desired contrast ratios--in particular, Panel and Judgment (PJ), Panel and Site (PS), and the combination of those three (PJS). There was also an interaction between Judgment and Site (JS). All were extremely significant

($p<0.0001$) except for the Judgment-Site interaction ($p<0.008$). These interactions are described in greater detail below.

Figure 28 shows this interaction for all five panel combinations. Further analysis shows that different contrast ratios were preferred for each judgment for the nighttime conditions ($d_T[4.324]=11$, $p<0.05$). Data from the maximum and dazzling judgments, however, did not contribute to the interaction.

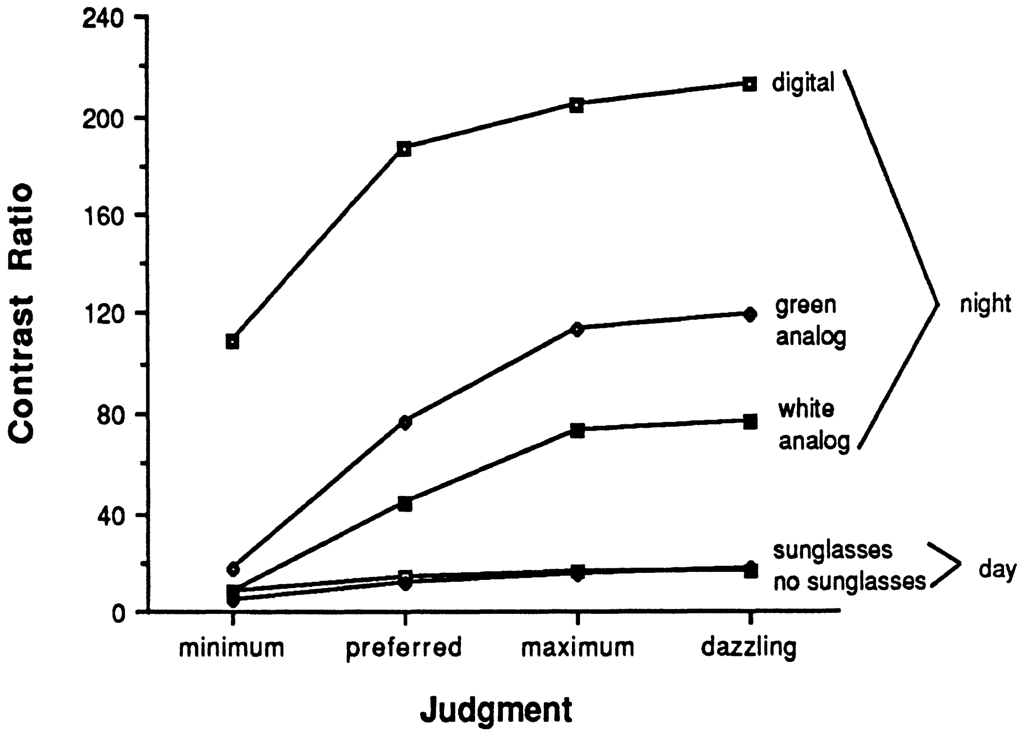


Figure 28. Contrast Ratio by Panel and Judgment

For the daytime conditions, the curves are relatively flat indicating that the judgments do not significantly differ from each other ($d_T[4.324]=11$, $p>0.05$). In the no sunglasses condition, however, the dazzling judgment is significantly different from the minimum ($d_T[4,324]=11$, $p<0.05$).

In the Figure one can also see that four of the five panels have similar contrast ratios for the minimum judgment. Comparisons for this judgment indicate that the white panel has the same contrast ratio as that found for both of the daytime conditions ($d_T[5,324]=12$, $p>0.05$) while the ratio for the green panel is the same as that of the sunglasses condition ($d_T[5,324]=12$, $p>0.05$). Further, the green and white panels do not significantly differ from each other ($d_T[5,324]=12$, $p>0.05$).

Table 8 presents the standard errors for the panel-judgment conditions. For the minimum and preferred judgments there was less variability during the day than there was at night while variability for the maximum and dazzling judgments was relatively consistent between day and night.

Table 8. Standard Errors for Panel-Judgment Conditions

	Judgment			
Panel	Minimum	Preferred	Maximum	Dazzling
Day				
Sunglasses	6	14	16	15
No Sunglasses	5	12	15	17
Night				
Digital	56	30	15	9
Green	23	33	15	10
White	14	27	18	14

Panel-Site Interaction

Figure 29 shows contrast ratio as a function of Panel and Site. This Figure clearly shows the day-night differences. The main reason for the interaction was high daytime levels at the Geddes site and nighttime panel variations at the Washtenaw site. Since Geddes is a shady site it was expected that the contrast would be lower than contrast at brighter sites since other light (such as glare from sun and street lamps) did not interfere with the luminance levels on the panel. The high contrast ratio at Geddes, however, can be attributed to a lower background luminance than at the other sites (due to less reflected light).

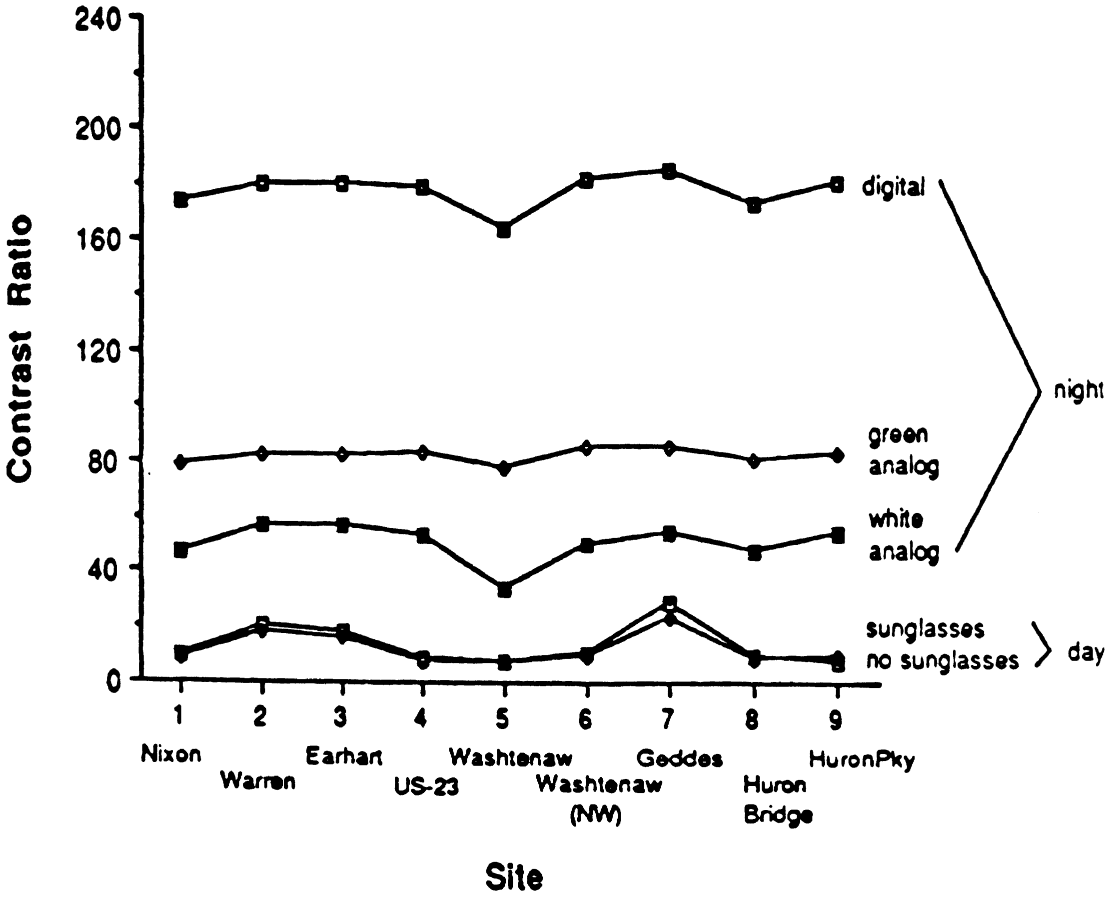


Figure 29. Contrast Ratio by Panel and Site

Panel-Judgment-Site Interaction

The interaction of panel and site for each judgment is shown in Figures 30-33. Notice that for the digital panel, contrast ratio does not differ as a function of site for the dazzling and maximum judgments, but there is significant variation for the preferred and especially the minimum judgments.

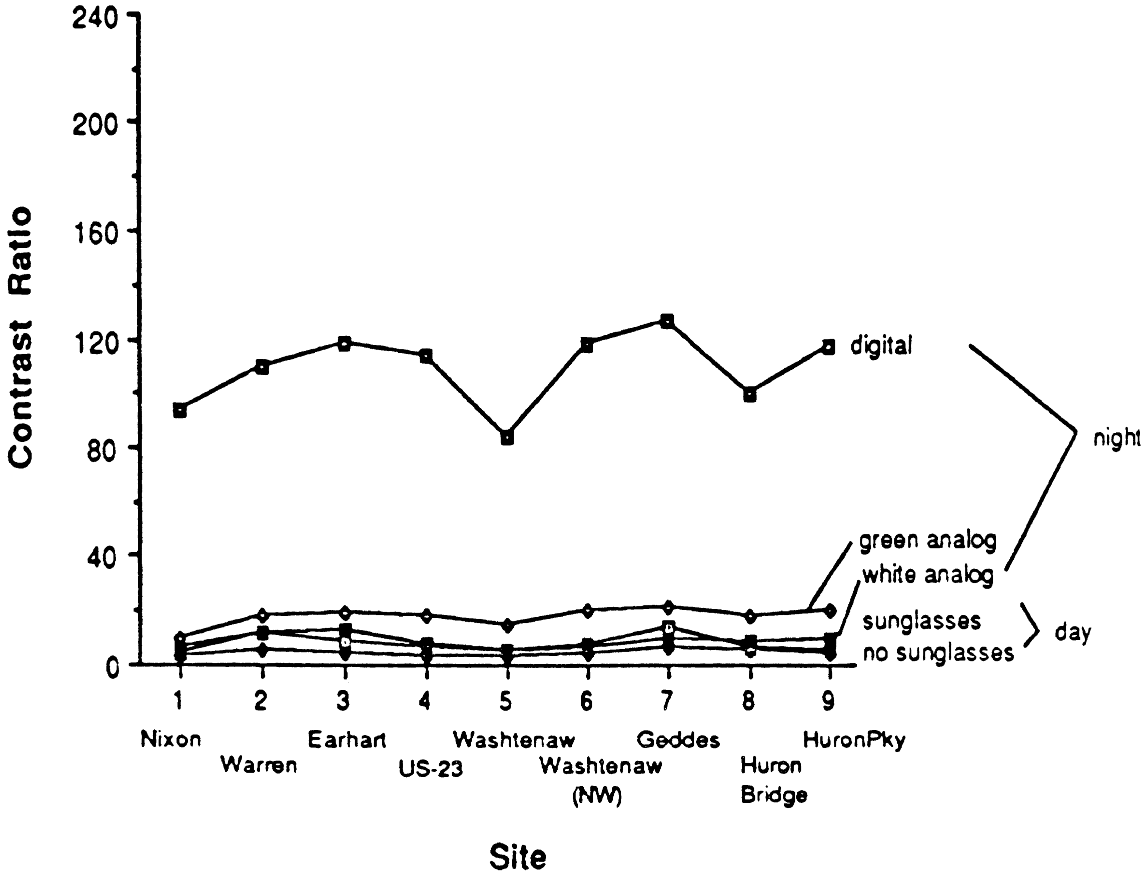


Figure 30. Contrast Ratio by Panel and Site for Minimum Judgment

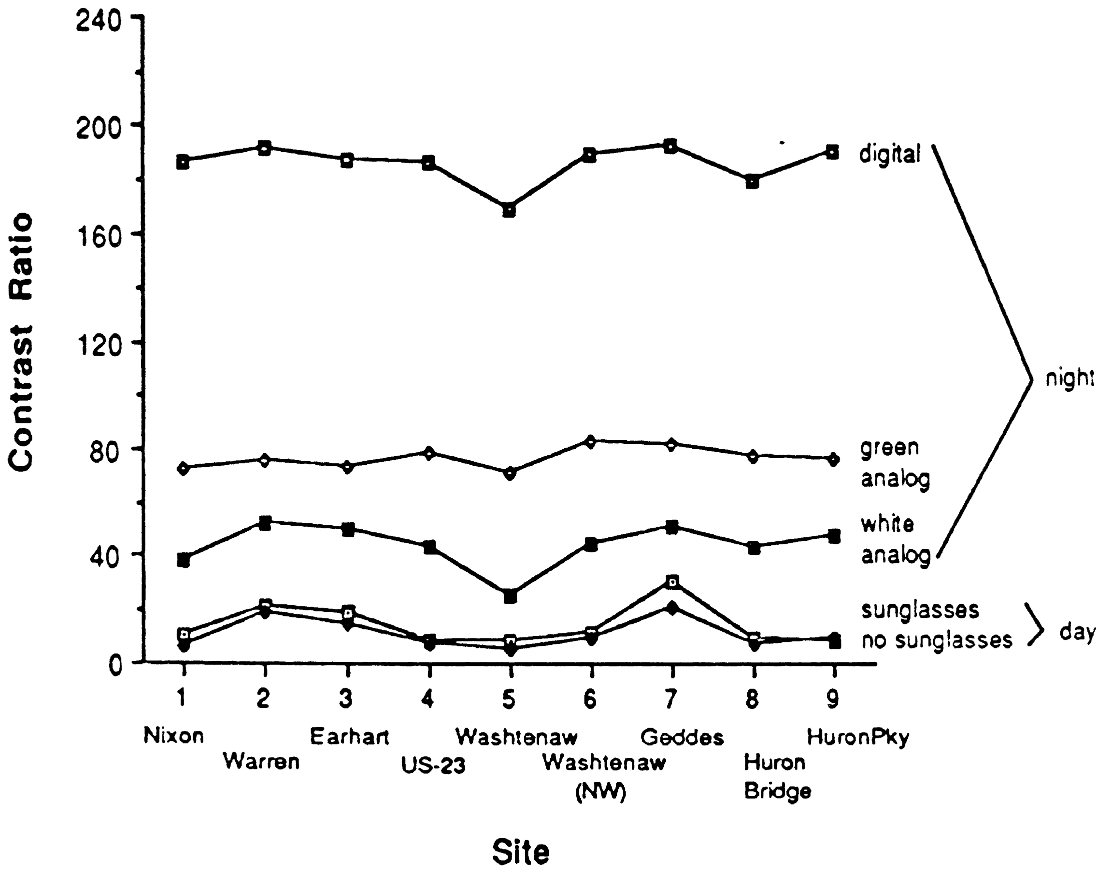


Figure 31. Contrast Ratio by Panel and Site for Preferred Judgment

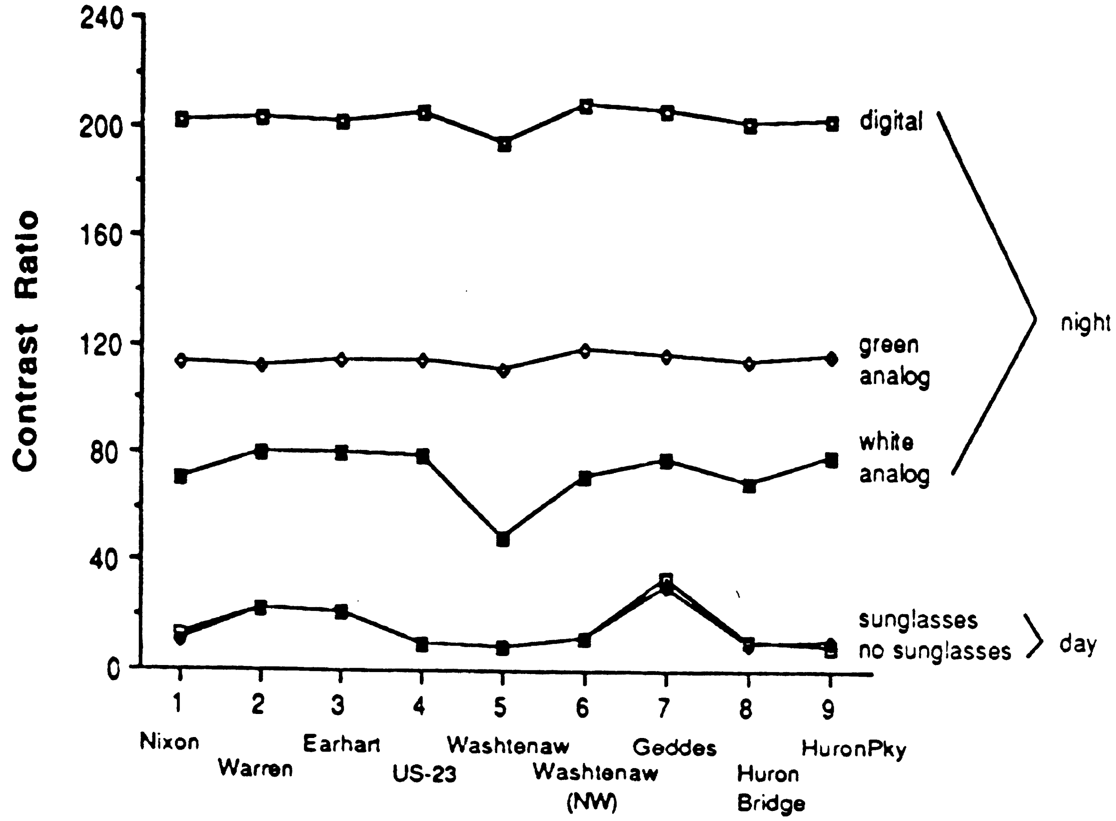


Figure 32. Contrast Ratio by Panel and Site for Maximum Judgment

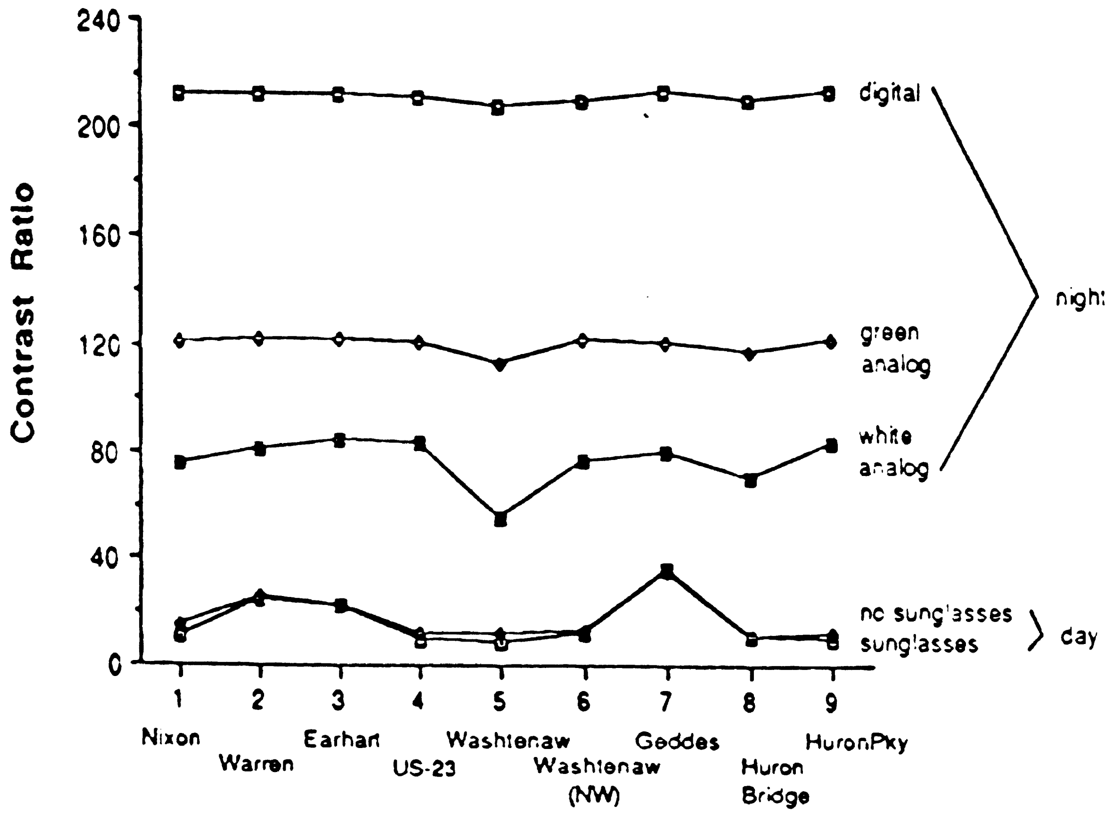


Figure 33. Contrast Ratio by Panel and Site for Dazzling Judgment

Judgment-Site Interaction

Figure 34 shows this interaction. For the most part, the practical impact of this interaction was small, and is only evident for the preferred setting for Earhart Road.

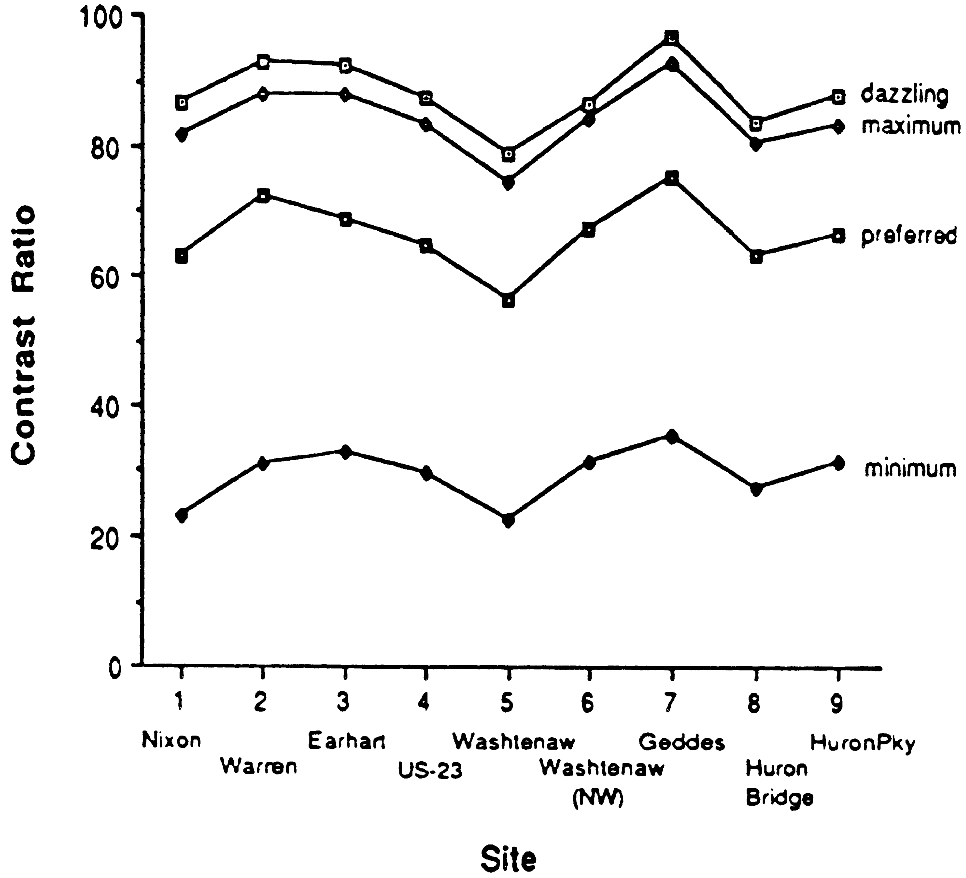


Figure 34. Contrast Ratio by Judgment and Site

Summary of Contrast Analysis

Differences between panels, judgments, and sites were found in the ANOVA. For panel, there were differences between both the conditions tested during the day (with and without sunglasses) and night (digital, green analog, and white analog). The simple effect of wearing sunglasses increased contrast for the preferred judgment by 20%. As expected, there were also differences between the judgment types (except for preferred/maximum without sunglasses and dazzling/maximum at night). Since maximum and dazzling judgments could not be achieved most of the time, the contrast ratios and luminances reported for these judgments could be considerably low. Sites varied as desired. Thus, the data cover a wide range of illumination levels both during the day and at night. In addition, there was an age difference as expected but no difference between American and Japanese drivers, contrary to the sponsor's expectations. There was also no difference between men and women. Finally, some statistically significant interactions complicated the analysis of the main effects.

Character Luminance

In addition, an ANOVA was also performed on luminance for the dazzling judgment. As noted in the introduction to this report, the perception of glare (what is dazzling to the driver) is a function of the total radiant flux reaching the driver's eyes (total luminance times area as a function of its deviation from the line of sight). Hence, in examining judgments of dazzling, luminance is the most appropriate dependent variable.

This ANOVA included the same factors as those in the ANOVA on contrast ratio (except the judgment factor). The ANOVA Table is shown in Table 9. The degrees of freedom for the DPS(G) interaction were corrected to account for the estimated data points. Roughly one-quarter of the estimated data (20 of 82 points) could be attributed to the dazzling judgment. Twenty df's were therefore subtracted from the original df's (864) for this term.

Table 9. ANOVA Table for Character Luminance (Dazzling Judgment)

Factor	**df(N)**	**df(E)**	**SS**	**MS**	**F**	**p**
Group [G]	2	27	1184.998	592.5	0.44	.6501
Panel [P]	4	108	415700.974	103925.2	206.59	.0000*
Site [S]	8	216	5098.082	637.3	5.15	.0000*
Driver [D(G)]	27	---	36559.573	1354.1	---	---
GP	8	108	3064.844	383.1	0.76	.6372
GS	16	216	2453.630	153.4	1.24	.2404
PS	32	844	6777.760	211.8	2.12	.0005*
DP(G)	108	---	54328.761	503.0	---	---
DS(G)	216	---	26742.317	123.8	---	---
GPS	64	844	7072.739	110.5	1.11	.2693
DPS(G)	844	---	84351.388	99.9	---	---

* Effect is statistically significant at $p<0.05$ level

Key	df(N)	=	degrees of freedom (numerator)
	df(E)	=	degrees of freedom (error term)
	SS	=	Sum of Squares
	MS	=	Mean Square

As with contrast ratio, the ANOVA revealed significant differences due to panel and site. (See Table 9.) For character luminance, however, no significant differences were found between the two daytime conditions--with (63 cd/m^2) and without sunglasses (60 cd/m^2) (t [2158] =1.95, $p>0.05$). Also, the Geddes site

(40 cd/m^2) only differed from two other sites (Washtenaw and Huron Parkway, both 46 cd/m^2) ($d_T[9,216]=6$, $p<0.05$).

Contrary to the analysis of contrast ratio, age was not a significant factor with respect to character luminance (t [3598] =-1.63, p>0.10). Again, neither sex (t [3598] =0.25, p>0.80) nor ethnicity (Japanese v. young Americans (t [3598] =-0.43, p>0.67) and older Americans (t [3598] =1.06, p>0.29)) were significant.

Figure 35 shows the panel and site interaction. The main contribution to this interaction are daytime variations from the nighttime panels at the Geddes and Huron Parkway sites.

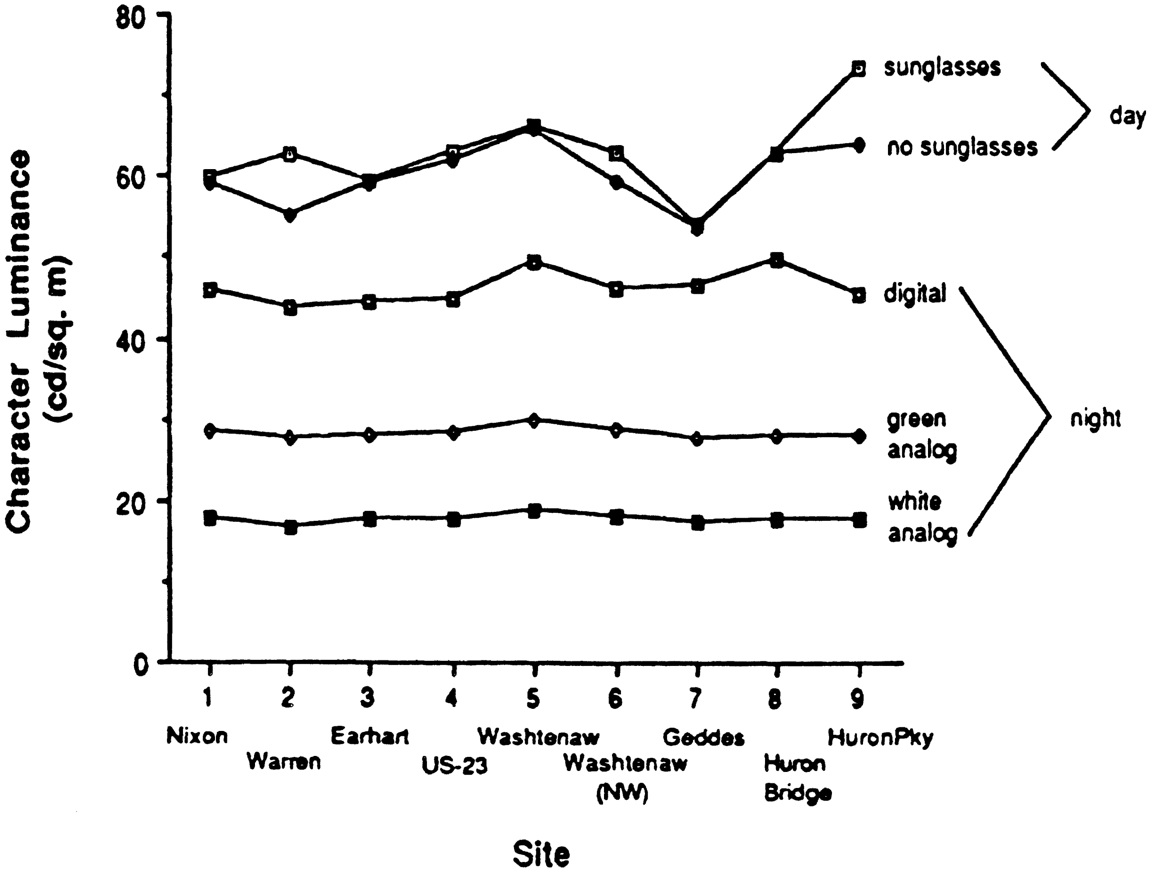


Figure 35. Character Luminance for Dazzling Judgment by Panel and Site

Summary of Character Luminance Analysis

The results of the character luminance data (dazzling judgment) were similar to that of contrast for panel and site, with the exception that wearing sunglasses did not alter desired levels. This is not surprising considering that drivers set the panel to its maximum voltage for the daytime conditions (which was not high enough for a majority of the cases).

Illumination Levels

Illumination levels of the roof (ambient), instrument panel, and hat (driver's face) are given in Table 10. Average ambient illumination during the day was 50,469 lux (4,689 fc), while that for the instrument panel was only 2,361 lux (219 fc) and the hat level even less. Thus the panel illumination was 5% of the ambient illumination level during the day. (This figure agrees with Allen (1963) who found that daytime panel illumination levels were 4% of ambient levels.) In contrast to the the daytime levels, the nighttime level for the hat was slightly higher than that for the instrument panel.

Table 10. Illumination Levels for Day and Nighttime Conditions

	Illumination Level (lux)					
	Day			Night		
Location	mean	min	max	mean	min	max
Roof	50,469	100	197,400	5.08	0.01	95.5
Instrument Panel	2,361	63	49,400	0.40	0.01	12.5
Hat	1,843	0	53,800	0.97	0.00	17.2

Correlations of the three illumination levels--instrument panel, roof, and hat--with each other are shown in Table 11. These correlations were performed separately for the day and nighttime conditions. While there were extremely high correlations between all of the levels at night, those during the day were somewhat lower. Note that the correlation of facial illumination (hat) with panel illumination during the day is not significant.

Table 11. Correlations between the Three Illumination Levels

	Correlation (r)	
Illumination Levels	Day	Night
Dash v. Roof	0.80**	0.98***
Hat v. Roof	0.69*	0.99***
Hat v. Instrument Panel	0.25	0.98***

*p<0.05
**p<0.01
***p<0.001

Contrast Ratio and Character Luminance versus Illumination Levels

Table 12 shows the correlations for contrast ratio and character luminance with the three illumination levels--instrument panel, roof (ambient), and hat (driver's face). Day and night correlations were similar except for the hat (driver's face) illumination level. Since there was a low correlation between instrument panel and facial (hat) illumination levels, it follows that contrast ratio and character luminance (which are partially determined by illumination on the instrument panel) would also have a lower correlation than the other light levels.

Table 12. Correlations of Preferred Contrast Ratio and Character Luminance with Illumination Levels

	Correlation (r)	
Preferred Contrast Ratio v.	Day	Night
Instrument Panel	-0.81	-0.92
Hat	-0.54	-0.87
Roof	-0.97	-0.87
Preferred Character Luminance v.		
Instrument Panel	0.89	0.89
Hat	0.65	0.94
Roof	0.94	0.94

It should be noted that the desired contrast ratio decreased as illumination increased, since at low levels the problem is to provide adequate luminance to make the characters visible, not just to distinguish them from the background.

Prediction of Desired Contrast Ratios

Regression analysis was used to develop predictions of the contrast ratios that drivers want. Potential predictors included illumination levels on the roof (R) (ambient), the instrument panel (IP), and the driver's face (Hat-H), as well as the driver's age. Because all of the variables have linear relationships with contrast as discussed previously, this is how they were incorporated into the model. Although age was not highly correlated with contrast ($r=0.20$), it was included in the model because it is known to be a predictor of human performance.

Separate equations were developed for each panel-judgment combination, except when no differences in preferences were found in the ANOVA. These exceptions were preferred/maximum for without sunglasses, all four judgments for sunglasses, and dazzling/maximum for the three nighttime conditions (digital, green, and white). Since there is no simple way to quantify the differences between panels, predictions were computed independently for each panel. A stepwise regression was performed in which factors with a significance level of $p<0.05$ entered into the equation and those with $p>0.10$ were excluded. The results are presented in Table 13.

High R^2 statistics (0.84-0.98) were found for most of the judgments (except minimum). Thus, at least 84% of the variability in contrast is explained by the factors specified in the models given in the Table. The equations for the minimum judgment, with substantially lower R^2 statistics, still explain approximately 50% of the variability in the data. These equations are therefore adequate predictors of contrast since they explain at least half of the variability in the data. For the green analog panel, the minimum and preferred contrast judgments could not be predicted. It is not clear why none of the potential predictors were significant. For these equations, then, the predicted contrast is simply the mean contrast ratio for these conditions.

The three illumination levels do not consistently contribute to any of the predictions--they are included in some equations and not in others. Age, however, is not included in any prediction equations and thus does not contribute to the prediction of contrast. Why age is not a factor is unclear since it was significant in the t-test.

Table 13. Contrast Prediction Equations for Each Panel-Judgment Combination

Condition	Predicted Contrast Equation	R^2
Minimum		
Without Sunglasses	6.51 - 0.00004 R	0.47
Digital	117.2 - 1.52 R	0.59
Green Analog	18	0.00
White Analog	9.67 - 1.28 H	0.47
Preferred		
Digital	190.97 - 12.01 IP	0.90
Green Analog	77	0.00
White Analog	49.44 - 5.47 H	0.84
Preferred/Maximum		
Without Sunglasses	30.35 - 0.0004 R	0.90
Dazzling/Maximum		
Digital	208.56 -11.05 IP + 0.85 R	0.90
Green Analog	117.87 - 8.51 IP + 2.41 H	0.95
White Analog	81.12 - 1.35 R	0.98
Dazzling		
Without Sunglasses	36.8 - 0.0004 R	0.92
All		
Sunglasses	31.15 - 0.002 H - 0.0004 R	0.95

where R = roof illumination (ambient) (lux)
H = hat illumination (driver's face) (lux)
IP = instrument panel illumination (lux)

How Frequently do Drivers Adjust Panel Brightness?

Upon completion of the study, participants were asked how often (on the average) they adjust the panel brightness in their car each time they use it. The responses are presented in Table 14. A majority of the drivers never (or almost never) adjust panel brightness, while only two do it at least once and one person more than once per car trip. Drivers frequently gave one of two responses for when they adjust the brightness level--on long trips (31%) or when ambient illumination levels change (54%).

Table 14. How Often Drivers Adjust the Panel Brightness During One Car Trip

	American (n=20)		Japanese (n=10)	
Response	Young	Old	Young	Total
Never	7	5	5	17
Almost Never	2	5	3	10
Once	--	--	2	2
More than Once	1	--	--	1

CONCLUSIONS

This section summarizes answers to the eight questions posed in the introduction, and are based on driver performance data and driver comments.

Answers to Questions

1. What panel luminance/contrast levels do American drivers identify as minimally acceptable, preferred, maximally acceptable, and dazzling?

Mean contrast levels were 29 for minimum, 67 for preferred, 85 for maximum, and 88 for dazzling across all conditions. As expected, the minimum judgment had the lowest contrast ratio and maximum and dazzling had the highest ratios. Contrary to expectation, dazzling did not differ from maximum, but this was probably because the panel could not be made bright enough due to limitations of the hardware.

The preferred mean contrast ratios varied from 186 for the digital panel at night (mean ambient illumination at night = 5 lux) to 11 for the digital panel without sunglasses (mean ambient illumination during the day = 50,469 lux). With sunglasses, the preferred contrast for the digital panel was significantly higher at 14. Preferred contrast ratios for the green and white analog panels (at night) were 77 and 44, respectively. However, these ratios were slightly underestimated since the maximum voltage of the panels was inadequate approximately 10% of the time.

The panels were not dazzling approximately two-thirds of the time, which is good from a design perspective since a dazzling panel is not desirable. (It would act as a glare source for the driver.) For the maximum judgment, the highest setting was inadequate 30% of the time (with a majority of this being for the daytime sessions). Drivers' comments confirmed this--68% said that the range did not go high enough. Thus, the maximum range of the panels needs to be increased. It was estimated that a maximum voltage of 19.2 volts would be necessary to accommodate the preferences of 99% of the population.

2. Do Japanese drivers prefer the same luminance/contrast levels as Americans?

There were no differences in desired contrast levels for young or older American and Japanese drivers. Thus, the voltage range of the panel can be designed without compensating for differences in American and Japanese markets.

3. **How do these luminance/contrast level preferences vary as a function of ambient illumination?**

As ambient illumination level increased, preferred character luminance increased. The correlation between ambient illumination and preferred character luminance was 0.94. On the other hand the preferred contrast ratio decreased as ambient illumination level increased (r=0.92). At low illumination levels character legibility is more a function of absolute luminance rather than contrast with the background. Prediction equations for contrast ratios appear in the Driver Preferences Results Section.

4. **For American drivers, how do these preferences vary as a function of age (young vs. old) and sex?**

Older drivers preferred higher contrast levels than did younger drivers. The preferred levels were 61 for young and 72 for older American drivers. No difference was found between male and female drivers.

5. **Do these preferences vary as a function of the type of instrumentation or its color?**

The contrast ratio desired depended upon the instrument panel of interest (digital or analog) and its color (blue-green, green, or white), and the differences between panels were statistically significant. The preferred contrast ratio for the digital panel (blue-green) at night was 186 versus 61 for the analog panels. The green and white panels had preferred contrasts of 77 and 44, respectively. It should be noted that the reflectances of the panels were all quite low. The character/background reflectance combinations were: digital, 0.012/0.011; green, 0.217/0.038; and white, 0.051/0.382.

6. **How do sunglasses alter preferences for daytime levels?**

Wearing sunglasses significantly increased the estimated overall contrast level from 12 (without sunglasses) to 14 (an increase of about 17%). Further, with sunglasses the maximum voltage setting was inadequate 38% of the time for the preferred contrast. Thus, since American drivers tend to wear sunglasses for daytime driving, the maximum voltage at which the panel can be driven should be increased to provide the desired contrast. It should be recalled that the digital panel tested had an extended luminance range, greater than that found in the 1989 Maxima.

7. **What is the relationship between ambient and interior illumination levels and the illumination levels drivers experience?**

   The light levels are linearly related to each other. The correlation (r) between the panel and ambient illumination levels was 0.80 during the day and 0.98 at night. The correlation of the ambient level with what drivers experienced (the hat level) was 0.69 for the daytime and 0.99 for the night. Correlations of the interior and hat levels were lower (r=0.25 during the day and r=0.98 at night). All correlations were significant except for the hat-interior combination during the day.

8. **How often and for what reason do American drivers adjust the panel brightness level?**

   A majority of the American drivers (12 of 20) never adjust the brightness level and 7 responded that they do occasionally. (None of these respondents had digital panels which are adjusted more often than analog panels.) Those who adjust the level do so when on a long car trip or when ambient illumination levels change.

Prediction Equations

The equations which were developed predict a sufficient amount of the variability in contrast (47%-98%) and thus, can be used to determine adequate contrasts for panel-judgment combinations based on ambient, instrument panel and driver-experienced illumination levels. Specifically, the preferred contrast levels predict at least 84% of the variability in contrast (except for the green analog panel which could not be predicted with any of the variables, thus, the mean provides an adequate prediction).

The prediction equations for the preferred contrasts are:

Condition	Equation
Day	
with sunglasses	31.15 - 0.002 H - 0.0004 R
without sunglasses	30.35 - 0.004 R
Night	
Digital	190.97 - 12.01 IP
Green Analog	77
White Analog	49.44 - 5.47 H

where R = roof illumination (ambient) (lux)
H = hat illumination (driver's face) (lux)
IP = instrument panel illumination (lux)

Drivers' Comments

Upon completion of the study, drivers commented on illumination color and types of brightness switches. With regard to color illumination, 53% said that they liked green or blue-green light while 20% wanted white. With regard to brightness switches, 50% of the drivers had a knob in their car while the others either had a thumbwheel (27% of the drivers) or pushbutton (23% of the drivers). When given a choice of the three controls (knob, thumbwheel, and pushbutton), the thumbwheel was thought to be the easiest to adjust (73% of the drivers preferred it). Finally, drivers were asked which of the three instrument panels they preferred. The green analog panel was favored slightly (37% of the drivers) over the digital panel (30% of the drivers) with the rest of the drivers having no preference.

Summary and Recommendations

Lighting levels on instrument panels need to be designed with the driver in mind. Desired contrast ratios for instrument panels were affected by the age of the driver. Older drivers preferred higher contrasts (72) than did younger drivers (61). Also, contrasts varied depending upon whether drivers wore sunglasses. The preferred contrast ratio when wearing sunglasses, 14, was significantly higher than that without sunglasses, 11. Thus, the results indicate that greater contrast should be provided for older drivers and those wearing sunglasses, about 20-25% more, than for young drivers or those without sunglasses. In addition, the maximum luminance level of the Nissan digital panel tested may have to be increased to accommodate the use of sunglasses, since 38% of the drivers could not set the panel luminance high enough for the preferred judgment when wearing sunglasses. Because desired contrasts did not differ between American and Japanese drivers, the lighting range of the panels can be designed in the same manner for both markets.

Preferred contrast ratios also depended upon the panel type (digital, green analog, or white analog). Thus, when determining panel lighting levels, the type of panel and its color illumination should be considered. According to the results of this study, a digital (VF) panel with blue-green characters would need to have a high contrast (186), an analog panel with green characters (black background) would need an intermediate contrast (77), and an analog panel with white characters (black background) would require a lower contrast (44).

In addition to these other factors, ambient illumination had an effect on preferred character luminance levels and contrast ratios. As ambient illumination increased, character luminance decreased and contrast ratio increased.

Finally, ambient, instrument panel, and driver-experienced illumination levels can be used to predict adequate contrasts for specific panel-judgment combinations.

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APPENDIX A
EXPERIMENTAL PROCEDURE

This appendix contains the experimental procedure for collection of the driver preference data. Instructions to the experimenter are shown in *italics* and suggested dialogue is shown in **UPPERCASE BOLD**.

EXPERIMENTAL PROCEDURE

Instructions for Day Sessions (Sessions 1 and 2):

Session 1...

One hour before the participant arrives...

1. Fill out as much of the biographical information sheet about the participant as possible and have the consent form ready.

2. Get the data collection form and fill out the information about the participant and session.

3. Review the pre-trip checklist and respond accordingly.

When the participant arrives...

ARE YOU ________? *(Use their name.)* **HELLO, MY NAME IS ____ AND I AM ONE OF THE EXPERIMENTERS WORKING ON THE PANEL ILLUMINATION STUDY.** *(Don't say test.)* **BEFORE WE GET STARTED, I WOULD LIKE TO TELL YOU A LITTLE BIT ABOUT THIS STUDY.**

THE PURPOSE OF THIS STUDY IS TO DETERMINE WHAT DASHBOARD BRIGHTNESS LEVELS PEOPLE PREFER. YOU WILL DRIVE A NEW CAR OVER A 17-MILE COURSE IN ANN ARBOR, TWICE DURING THE DAY AND THREE TIMES AT NIGHT. PERIODICALLY, I WILL ASK YOU TO ADJUST THE PANEL BRIGHTNESS TO YOUR LIKING. THE TWO DAYTIME SESSIONS TAKE APPROXIMATELY TWO HOURS ALL TOGETHER AND CAN BE COMPLETED IN ONE VISIT. THE THREE NIGHTTIME SESSIONS TAKE APPROXIMATELY ONE HOUR EACH AND MUST BE COMPLETED ON SEPARATE VISITS. THERE WILL BE APPROXIMATELY ONE WEEK BETWEEN NIGHT SESSIONS. THE RESULTS OF THIS STUDY WILL BE USED TO HELP DESIGN FUTURE VEHICLES. SINCE YOU WILL BE DRIVING THOSE VEHICLES, YOUR INPUT IS VERY IMPORTANT.

YOU WILL BE PAID $60 AT THE END OF THE FIFTH AND FINAL SESSION. THIS INCLUDES $8 PER HOUR FOR 5.5 HOURS, PLUS A $16 BONUS FOR COMPLETING THE STUDY. IF YOU CAN NOT COMPLETE THE STUDY, YOU WILL BE PAID AT A RATE OF $8 PER HOUR FOR THE SESSIONS THAT YOU DID COMPLETE. I SHOULD REMIND YOU THAT YOU CAN WITHDRAW FROM THIS STUDY AT ANY TIME.

IF YOU WOULD LIKE TO VISIT THE REST ROOM, NOW WOULD BE A GOOD TIME TO DO SO. I SHOULD ALSO NOTE THAT SMOKING IS PROHIBITED IN THIS BUILDING AS WELL AS IN THE CAR WE WILL BE USING, SO PLEASE REFRAIN FROM DOING SO.

BEFORE WE GET TO THE ACTUAL EXPERIMENT, THERE IS SOME PAPERWORK TO COMPLETE.

Filling out the consent form, support voucher, and biographical form...

Get a consent form from the clipboard. **FIRST, YOU NEED TO READ AND SIGN THIS OFFICIAL CONSENT FORM THE UNIVERSITY REQUIRES US TO GIVE YOU, WHICH BASICALLY REPEATS IN WRITING WHAT I JUST SAID.** *Have the participant sign the consent form. (Make sure they circle either "yes" or "no" as proof to whether or not they agreed to be videotaped.)*

Get the appropriate support voucher from the clipboard depending on whether or not the participant is a UM employee. **PLEASE PRINT YOUR NAME, MAILING ADDRESS, AND SOCIAL SECURITY NUMBER AND THEN SIGN YOUR NAME OVER HERE.** *Point to where they should sign their name.*

NEXT, I NEED TO KNOW A LITTLE MORE ABOUT YOU. *Get a biographical form from the folder. The experimenter should fill out the biographical form so the information is legible. The participant's name, the experimenter's name, along with the date and time of the session, should already have been recorded.* **WHAT IS YOUR HOME ADDRESS?** *Be sure to get their zip code. If the participant is a student, just get their local address, not their permanent address.*

You should already have their home phone. Also record their sex.

HOW OLD ARE YOU? *Some people, especially women, may be reluctant to give you their age. Tell them the information is used for statistical purposes only and you will not tell anyone their age. If they are still reluctant, start out by asking for their age decade* **(ARE YOU BETWEEN 31 AND 40?)** *and then go from there. If it takes some effort to pry it out, offer a positive comment to put them at ease if it seems reasonable.* **(GEE, YOU CERTAINLY DON'T LOOK ...).**

WHAT DO YOU DO FOR A LIVING? *Focus on how they spend most of their time. If the person is retired, note that along with their former occupation. If the person is a student, also list their major and level (junior, Ph.D candidate, etc.) as well. If the person is a student with a part-time job, ignore the job.*

HOW MUCH SCHOOL HAVE YOU COMPLETED? *Ask them if they have a high school degree and proceed from there.*

ARE YOU RIGHT-HANDED, LEFT-HANDED, OR AMBIDEXTROUS?

WHAT IS THE COLOR OF YOUR EYES?

WE ARE DOING THIS STUDY FOR NISSAN AND ONE OF NISSAN'S PREMISES IS THAT PREFERENCES FOR ILLUMINATION LEVELS VARY WITH ETHNIC ORIGIN. THEREFORE, NISSAN HAS ASKED US TO PROVIDE SUCH INFORMATION TO THEM. WHAT IS YOUR ETHNIC ORIGIN? *If they hesitate, read them the choices and have them choose one.*

WHAT KIND OF VEHICLE DO YOU DRIVE MOST OFTEN? *If they are employed as a driver (e.g., truck driver), then ask about their "personal vehicle" as well. In any case, make sure you get the make, model, and year. If they are unsure, you might want to look at their vehicle after the experiment is over, if they drove it to UMTRI. If you still can't tell, take a look at the owner's manual, if they have one.*

ABOUT HOW MANY MILES DO YOU DRIVE IN A YEAR? *If they don't know, then ask them for a weekly average and multiply by 52. Tell them what it would work out to be.*

HOW MUCH OF THAT IS AT NIGHT? *Have them give you a percentage. For example, a quarter of their driving is at night. If they don't know, then ask them for a weekly average and multiply by 52. Tell them what it would work out to be.*

WHAT TYPE OF ROADS DO YOU DRIVE ON AT NIGHT? MOSTLY HIGHWAY, CITY, SUBURBAN AND RURAL, OR A MIX?

DO YOU NORMALLY WEAR GLASSES WHEN DRIVING? CONTACTS? BIFOCALS? TRIFOCALS?

Testing the participant's visual acuity...

NEXT I'M GOING TO CHECK YOUR VISUAL ACUITY WITH THIS INSTRUMENT. *Point to the orthorater.* **IF YOU WEAR GLASSES OR CONTACTS WHEN DRIVING, PLEASE WEAR THEM WHILE I INVESTIGATE YOUR NEAR VISUAL ACUITY.** *Set up the orthorater with the dial set at number 9 next to the amber light (make sure it comes on) and the lever on the right side set up for near vision. Make sure the switches on the back are set to left eye and right eye.* **WHEN YOU LOOK IN THE VISION TESTER, YOU WILL SEE 14 DIAMONDS. EACH DIAMOND CONTAINS 4 CIRCLES, ONE IN EACH CORNER. THREE CIRCLES ARE INCOMPLETE CIRCLES AND ONLY ONE IS COMPLETE, OR CLOSED. PLEASE INDICATE THE LOCATION OF THE COMPLETE CIRCLE (I.E., TOP, BOTTOM, LEFT, RIGHT).** *Give the participant feedback on how well they are doing. GOOD!, etc. Have the participant continue until they have missed two locations in a row, then stop the test. The participant's near visual acuity corresponds to the last correct response. Record their near visual acuity on the biographical form.*

NEXT, I NEED TO CHECK YOUR COLOR VISION. *Flip the lever on the side to the "far" setting and turn the dial so the number 5 appears next to the green light and it comes on.* **WHEN YOU LOOK INTO THE ORTHORATER YOU WILL**

SEE 6 CIRCLES AND IN EACH CIRCLE YOU SHOULD BE ABLE TO MAKE OUT A NUMBER. PLEASE TELL ME THE NUMBER THAT YOU SEE IN EACH CIRCLE. *Record the number(s) which they are unable to see on the biographical form. Give the subjects feedback on how well they are doing,* **GOOD,** *etc.*

Sunglass Selection...

NOW THAT I'VE FINISHED CHECKING YOUR VISION, WE'RE READY TO GET STARTED WITH THE STUDY. BECAUSE TWO SESSIONS INVOLVE DRIVING DURING THE DAY, YOU WILL NEED TO WEAR SUNGLASSES. *Ask the participant if he/she wears glasses for driving. If they do then show them the clip-on lenses. Otherwise,* **WE HAVE TWO PAIRS OF SUNGLASSES FROM WHICH YOU CAN CHOOSE.** *Tell them to select a pair of sunglasses which they will feel comfortable wearing during the study.*

NOW THAT WE'RE FINISHED HERE, IT'S TIME TO GO DOWN TO THE CAR. *Take the sunglasses and bio sheet when you go down to the parking lot.*

Introduction to the car...

Have the participant sit in the driver's seat of the car and show them how to operate the controls to adjust the seat and the steering wheel, as well as the side and rearview mirrors; make sure they are in a comfortable driving position. When they are settled in and your instruments are set up, go over the instructions.

FIRST I WILL GO OVER THE ROUTE WITH YOU. YOU ARE NOT EXPECTED TO REMEMBER THIS, IT IS JUST TO GIVE YOU AN IDEA OF WHERE WE WILL BE DRIVING. *Show the participant the route and point out the location of UMTRI. Explain the route to the participant, tracing it with your finger. Point out the designated measurement locations.*

NOW WE'RE READY TO START THE CAR. WHEN THE CAR IS STARTED, THE SHOULDER BELT WILL AUTOMATICALLY LOCK INTO PLACE. HOWEVER, YOU MUST BUCKLE YOUR LAP BELT. *Have the participant start the car. Buckle your lap belt and make sure the participant does the same. If not, please remind them. If they have objections to buckling the belt, remind them that it is a Michigan state law.* **ARE YOU COMFORTABLE?**

IN ORDER TO ADJUST THE PANEL BRIGHTNESS THE CAR LIGHTS HAVE TO BE ON. ADJUST THE LIGHT SWITCH ON THE STALK TO THE LEFT OF THE STEERING WHEEL TO THE SECOND NOTCH. *Help the participant if they have trouble. Make sure the low beams are on.*

IN ORDER TO ADJUST THE LIGHT LEVEL, YOU WILL USE THESE SWITCHES. *Point out the switches and have the participant press the buttons a few times to get the feel of them.* **PRESS THE RIGHT BUTTON TO INCREASE**

THE PANEL BRIGHTNESS, OR TO MAKE THE PANEL BRIGHTER, AND THE LEFT BUTTON TO DECREASE THE BRIGHTNESS, OR TO MAKE THE PANEL DIMMER. TRY IT NOW TO SEE WHAT IT IS LIKE.

WHILE WE'RE DRIVING I WILL ASK YOU TO ADJUST THE DISPLAY LIGHT TO FOUR DIFFERENT LEVELS; A MAXIMUM LEVEL, A PREFERRED LEVEL, MINIMUM LEVEL, A DAZZLING LEVEL. *Mention the levels in the order in which the participant will adjust them and point to the sign with the levels as you explain them.* **THE MAXIMUM LEVEL IS THE BRIGHTEST LEVEL THAT'S ACCEPTABLE TO YOU SO THAT YOU CAN READ THE DISPLAY AT A GLANCE. THE PREFERRED LEVEL IS THE LIGHT LEVEL THAT YOU LIKE. IT CAN BE ONE OF THE OTHER THREE LIGHT LEVELS OR SOMETHING ELSE. THE MINIMUM LEVEL IS THE DIMMEST LIGHT LEVEL THAT'S ACCEPTABLE TO YOU SO THAT YOU CAN READ THE DISPLAY AT A GLANCE. THE DAZZLING LEVEL IS THE LIGHT LEVEL WHICH INTERFERES WITH WHAT YOU'RE LOOKING AT DOWN THE ROAD. IT SHOULD BE SO BRIGHT THAT IT BOTHERS YOU. DO YOU HAVE ANY QUESTIONS?**

WHEN YOU ARE SETTING THE BRIGHTNESS TO ONE OF THE LEVELS, IF YOU CAN NOT SET IT EXACTLY WHERE YOU WANT IT, LET ME KNOW. FOR INSTANCE, IF THE MINIMUM LEVEL IS NOT DIM ENOUGH, IF YOU THINK THE DISPLAY COULD BE DIMMER AND YOU COULD STILL READ IT, LET ME KNOW THIS. IF DAZZLING ISN'T DAZZLING, LET ME KNOW. ALSO, IF THE MAXIMUM LEVEL ISN'T BRIGHT ENOUGH, IF YOU WANT THE DISPLAY BRIGHTER, LET ME KNOW.

WE'LL DO A PRACTICE RUN IN THE PARKING LOT SO YOU HAVE AN IDEA OF WHAT IT WILL BE LIKE ON THE ROAD.

NOW WE'LL GO OVER WHAT A TYPICAL RUN WILL BE LIKE ON THE ROAD. BEFORE WE REACH A DESIGNATED POINT, I WILL TELL YOU TO ADJUST THE LIGHT LEVEL TO A LEVEL IN THE MIDDLE OF THE RANGE. THEN I'LL SAY, *the first level.* **YOU'LL SET IT TO THIS LEVEL, THEN SAY OKAY. NEXT, I'LL SAY,** *the second level* **AND YOU'LL SET IT TO THIS LEVEL AND THEN SAY OKAY. WE WILL CONTINUE IN THIS MANNER FOR THE REMAINING TWO LEVELS. THEN WE WILL DRIVE FOR AWHILE AND I WILL ASK YOU TO ADJUST THE LIGHT LEVELS AGAIN. IN ALL, YOU WILL ADJUST THE LIGHT LEVEL AT NINE DIFFERENT POINTS ALONG THE ROUTE. REMEMBER, YOU WILL BE DRIVING WHILE YOU ADJUST THE PANEL BRIGHTNESS. DO YOU HAVE ANY QUESTIONS?**

IN ORDER TO MEASURE THE LIGHT LEVEL AT YOUR EYES, WE ARE ASKING YOU TO WEAR A HAT WHICH HAS A LIGHT SENSOR ATTACHED TO IT. *Show the participant the hat.* **WEAR THE HAT LIKE THIS** *(put it on to demonstrate how it should be worn)* **SO THAT THE SENSOR IS IN THE FRONT.** *Hand it to the participant and have them put it on.* **ARE YOU**

COMFORTABLE? *If the hat does not fit comfortably, show the participant how to adjust it.*

NOW WE'LL TRY A PRACTICE RUN. *Let the participant get comfortable, then begin.* **SET IT TO THE MIDDLE OF THE RANGE.** *Mention the levels in the appropriate order.* **MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Watch the participant to make sure they are setting the levels appropriately. If the participant does not respond in the appropriate manner, then correct them. If the participant responds too slowly, remind them that they should respond as accurately, but as quickly as possible.*

DO YOU HAVE ANY QUESTIONS? *Give the participant a little verbal prod to make sure they understand the procedure. If they have a question, put them at ease and address each question they have no matter how insignificant.*

DURING THE STUDY, CONCENTRATE ON DRIVING WHILE TRYING TO GIVE AS MUCH ATTENTION AS YOU CAN TO THE LIGHT LEVEL ON THE DISPLAY WHEN YOU ARE ASKED TO ADJUST IT. BECAUSE WE WILL BE DRIVING ON SOME HIGHLY TRAVELED ROADS, PLEASE BE CAUTIOUS WHEN YOU ARE DRIVING AND DO NOT GO FASTER THAN THE SPEED LIMIT. ALSO TRY TO STAY IN THE RIGHT-HAND LANE SINCE WE WILL BE MAKING A LOT OF RIGHT-HAND TURNS.

If this is a sunglass session, get the sunglasses out and have the participant put them on.

NOW WE'RE READY TO BEGIN.

Collecting data...

PULL OUT OF THE PARKING LOT AND TAKE A RIGHT AT THE CORNER.

TURN RIGHT AT THE STOP SIGN AND MAKE ANOTHER RIGHT ONTO HURON PARKWAY.

Immediately after they turn the corner at Baxter and Huron Parkway say, **WE'LL DRIVE TO THE END OF HURON PARKWAY AND THEN TAKE A RIGHT TURN ONTO NIXON ROAD. THAT'S IN A HALF MILE.**

OUR FIRST READINGS WILL BE ON NIXON ROAD. YOU CAN SET IT TO THE MIDDLE OF THE RANGE NOW SO THAT YOU'LL BE READY. *Watch the volt meter to make sure that the participant sets the panel brightness to the middle of the range. If it is too high or too low, let them know so that they can adjust it appropriately. Acknowledge that it is set correctly.*

Immediately after you turn right onto Nixon Road, **WE'LL DRIVE 2 MILES ON NIXON, THEN WE'LL TURN RIGHT ONTO WARREN ROAD. IN APPROXIMATELY HALF A MILE, NIXON WILL TURN INTO A DIRT ROAD.**

When you are approaching the Parkway Meadows apartment entrance, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay. PREF. Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

When you approach the bridge, **AFTER THE BRIDGE, YOU'LL SEE A YELLOW SIGN DISPLAYING AN INTERSECTION. THIS INDICATES THAT WARREN ROAD IS COMING UP AND THAT WE SHOULD TAKE A RIGHT.**

RIGHT AFTER WE TURN ONTO WARREN ROAD WE'RE GOING TO TAKE READINGS. YOU CAN SET IT TO THE MIDDLE OF THE RANGE NOW SO THAT YOU'RE READY.

Immediately after you turn the corner at Nixon Road and Warren Road, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

THIS IS WARREN ROAD. WE'LL DRIVE FOR ABOUT 1 MILE AND THEN MAKE A RIGHT AT THE FIRST INTERSECTING ROAD, EARHART ROAD, WHICH HAS A STOP SIGN AT THE CORNER.

WE'LL TAKE READINGS RIGHT AFTER WE TURN ON TO EARHART ROAD. YOU CAN SET IT TO THE MIDDLE OF THE RANGE NOW SO THAT YOU'RE READY.

Immediately after you turn the corner at Warren Road and Earhart Road, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

WE'LL STAY ON EARHART ROAD UNTIL IT ENDS AT PLYMOUTH ROAD IN A MILE AND A HALF, THEN WE'LL TAKE A RIGHT. THIS ROAD WILL TURN INTO A PAVED ROAD AND WE'LL PASS DOMINO'S FARMS.

OUR NEXT READINGS WILL BE ON U.S. 23.

When the white fence is in sight, **THIS IS PLYMOUTH. TAKE A RIGHT TURN AT THE STOP SIGN.**

NOW, WE'LL GET ON U.S. 23 SOUTH. THE ENTRANCE IS ON THE LEFT, JUST AFTER THE THIRD TRAFFIC LIGHT.

YOU CAN SET IT TO THE MIDDLE OF THE RANGE, SO THAT YOU'LL BE READY FOR READINGS.

As soon as you are on the highway, **WE'LL GET OFF 23 AT THE WASHTENAW ROAD WEST EXIT, NUMBER 37B. THAT'S IN ABOUT 3.5 MILES.**

Immediately after the overpass for Earhart Road, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

WE HAVE TWO MILES UNTIL OUR EXIT. OUR NEXT READINGS WILL BE ON WASHTENAW AFTER WE PASS HURON PARKWAY.

As you approach the exit, **THE EXIT IS COMING UP. WE GET OFF HERE.**

At the end of the ramp, **YOU'LL TAKE A RIGHT ONTO WASHTENAW.**

Immediately after you turn right onto Washtenaw, **WE'LL STAY ON WASHTENAW FOR ABOUT 4 MILES UNTIL WE TURN RIGHT AT GEDDES ROAD.**

YOU CAN SET IT TO THE MIDDLE OF THE RANGE SO THAT YOU'LL BE READY.

Immediately after you pass Huron Parkway, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

When you approach where Washtenaw curves, **WE HAVE TO GET INTO THE RIGHT LANE HERE SO THAT WE STAY ON WASHTENAW. OUR NEXT READINGS WILL BE IN A MILE. YOU CAN SET IT TO THE MIDDLE OF THE RANGE SO THAT YOU'LL BE READY.**

Immediately after the curve, **WE'LL CONTINUE ON WASHTENAW FOR ABOUT 2 MILES UNTIL WE TURN RIGHT AT GEDDES ROAD.**

Immediately after you pass Devonshire, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

OUR NEXT READINGS WILL BE ON GEDDES ROAD. YOU CAN SET IT TO THE MIDDLE OF THE RANGE SO THAT YOU'LL BE READY.

As you approach Observatory, **GEDDES ROAD IS AT THE SECOND LIGHT. WE'LL BE TURNING RIGHT THERE.**

Immediately after you turn, **WE'LL STAY ON GEDDES UNTIL IT ENDS AND MERGES INTO HURON PARKWAY. THAT'S IN ABOUT 2 MILES.**

Immediately after you pass Onondaga, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

OUR NEXT READINGS WILL BE RIGHT AFTER WE TURN ONTO HURON PARKWAY, ON THE BRIDGE. YOU CAN SET IT TO THE MIDDLE OF THE RANGE NOW SO THAT YOU'LL BE READY.

As you approach the Huron overpass, **GO STRAIGHT HERE. WE'LL BE GETTING ON HURON WHICH WILL TAKE US BACK TO UMTRI.**

As soon as you have turned onto Huron Parkway and are approaching the bridge, **IT'S TIME TO TAKE READINGS. MAX.** *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

OUR NEXT READINGS WILL BE IN HALF A MILE. YOU CAN SET IT TO THE MIDDLE OF THE RANGE NOW SO THAT YOU'LL BE READY.

As soon as you approach the Geddes Lake Townhouses complex,
IT'S TIME TO TAKE READINGS. MAX. *Wait for the participant to say okay.* **PREF.** *Wait for the participant to say okay.* **MIN.** *Wait for the participant to say okay.* **DAZ.** *Wait for the participant to say okay.* **GOOD.**

Upon completion of the readings...

WE ARE FINISHED WITH THE READINGS. DO YOU WANT TO STOP TO TAKE A BREAK BEFORE DRIVING AROUND THE ROUTE AGAIN?
Respond accordingly.

NOW I AM GOING TO ASK YOU A FEW QUESTIONS.

Get the participant's biographical sheet and turn to the appropriate section. **WHEN YOU SET THE PANEL BRIGHTNESS AT THE DAZZLING LEVEL, HOW OFTEN WAS IT ACTUALLY DAZZLING?** *Wait for the participant to respond and if they have a hard time, then prompt them.*

IS THE RANGE FOR PANEL BRIGHTNESS THAT IS IN THE CAR NOW SUITABLE? *Wait for the participant to respond and if they have a hard time, then prompt them. If they say no,* **WHY NOT?**

DO THE BRIGHTNESS LEVELS CHANGE SMOOTHLY ENOUGH? *Wait for the participant to respond and if they have a hard time, then prompt them. If they say no,* **WHY NOT?**

If this was a sunglass session, have the participant take off the sunglasses. If Session 2 is a sunglass session, have the participant put the sunglasses on.

Session 2...

Attach the data collection sheet for Session 2 to the clipboard. Drive around the route again, taking readings in the same locations as Session 1. Give the participant the same instructions as during the first session.

Upon completion of the readings...

WE ARE FINISHED WITH THE READINGS. NOW I AM GOING TO ASK YOU A FEW QUESTIONS.

Get the participant's biographical sheet and turn to the appropriate section. **WHEN YOU SET THE PANEL BRIGHTNESS AT THE DAZZLING LEVEL, HOW OFTEN WAS IT ACTUALLY DAZZLING?** *Wait for the participant to respond and if they have a hard time, then prompt them.*

IS THE RANGE FOR PANEL BRIGHTNESS THAT IS IN THE CAR NOW SUITABLE? *Wait for the participant to respond and if they have a hard time, then prompt them. If they say no,* **WHY NOT?**

DO THE BRIGHTNESS LEVELS CHANGE SMOOTHLY ENOUGH? *Wait for the participant to respond and if they have a hard time, then prompt them. If they say no,* **WHY NOT?**

Thank the participant for his/her time and remind them of their next session. **THANK YOU FOR YOUR TIME! PLEASE DON'T FORGET YOUR SCHEDULED APPOINTMENT ON _______** *(mention day, date, and time)* **TO COMPLETE THE NEXT PART OF THIS STUDY.** *The participant is done for the day; thank him/her.*

If there are no more subjects for the day...

Try to park in a shady spot. Turn off all of the instruments. (Don't forget about the Minolta in the back seat.) Take the light sensor off the roof of the car and the sign off the back. Put up the sunscreen in the windshield.

Check the gas gauge. If it is less than half full, get money from Flora and go to the Total station to fill it up.

Leave the forms and the key on Colleen's desk.

Instructions for Night Sessions (Sessions 3-5):

One-half hour before the participant arrives...

1. Get the data collection forms and biographical sheets for the participants. Fill out the information about the participants and sessions.

2. Set up the instruments in the car. (Review the Pre-Session Checklist for the nighttime instrument settings.)

3. Set up the lighting.

4. Go over the Pre-Session Checklist. Respond accordingly.

5. Wait outside in front of UMTRI for the participant to arrive.

6. Turn on the instruments before the participant arrives.

When the participant arrives...

HI __________ . *(Use their name).* **ARE YOU ALL SET? YOU CAN GET IN THE CAR AND ADJUST THE SEAT AND MIRRORS SO THAT YOU ARE COMFORTABLE. REMEMBER, WE NEED YOU TO WEAR THE HAT.** *(Have the participant put the hat on.) Remind them to put on their lap belt.*

TONIGHT WE ARE USING A DIFFERENT INSTRUMENT PANEL. THIS IS ______ *(an analog or a digital display).* **WHY DON'T YOU LOOK AT THE ADJUSTMENT RANGE OF THIS DISPLAY.** *(Watch your voltmeter. When it is at the brightest and dimmest levels let the participant know.)*

BEFORE WE START, I'D LIKE TO REVIEW THE ORDER IN WHICH YOU ARE GOING TO MAKE THE ADJUSTMENTS. *(Turn the interior lights on. Go over the levels in the appropriate order. Point to the levels as you go over them.)* **FIRST YOU'LL SET IT TO MAX. THIS IS THE MAXIMUM LEVEL THAT'S ACCEPTABLE TO YOU SO THAT YOU CAN READ THE DISPLAY AT A GLANCE. THEN YOU'LL SET IT TO PREFERENCE. THIS IS THE LEVEL THAT YOU PREFER. NEXT YOU'LL SET IT TO MIN. THIS IS THE MINIMUM LEVEL THAT'S ACCEPTABLE TO YOU SO THAT YOU CAN READ THE DISPLAY AT A GLANCE. FINALLY, YOU'LL SET IT TO DAZZLING. THIS IS A LEVEL THAT'S SO BRIGHT THAT IT MIGHT INTERFERE WITH WHAT YOU'RE LOOKING AT DOWN THE ROAD. IT SHOULD BE SO BRIGHT THAT IT BOTHERS YOU. DO YOU HAVE ANY QUESTIONS?** *(If the participant has questions, respond accordingly.)*

REMEMBER, IF YOU CAN'T GET THE LIGHT LEVEL EXACTLY WHERE YOU WANT IT, LET ME KNOW. FOR INSTANCE, IF THE MINIMUM LEVEL IS NOT DIM ENOUGH, IF YOU THINK THE DISPLAY COULD BE DIMMER AND YOU COULD STILL READ IT, LET ME KNOW THIS. IF DAZZLING ISN'T DAZZLING, LET ME KNOW. ALSO, IF THE MAXIMUM LEVEL ISN'T BRIGHT ENOUGH, IF YOU WANT THE DISPLAY BRIGHTER, LET ME KNOW.

WE WILL BE TAKING READINGS AT THE SAME LOCATIONS ON THE ROUTE. DO YOU NEED TO GO OVER THE ROUTE? *(Usually the participant does not need to go over the route, but if so then show them the map again.)*

IT LOOKS LIKE WE'RE ALL SET. DO YOU HAVE ANY QUESTIONS BEFORE WE BEGIN?

Collecting data...

Give the participant the same instructions as during the day sessions.

Upon completion of the readings...

WE ARE FINISHED WITH THE READINGS. NOW I AM GOING TO ASK YOU A FEW QUESTIONS.

Get the participant's biographical sheet and turn to the appropriate section. **WHEN YOU SET THE PANEL BRIGHTNESS AT THE DAZZLING LEVEL, HOW OFTEN WAS IT ACTUALLY DAZZLING?** *Wait for the participant to respond and if they have a hard time, then prompt them.*

IS THE RANGE FOR PANEL BRIGHTNESS THAT IS IN THE CAR NOW SUITABLE? *Wait for the participant to respond and if they have a hard time, then prompt them. If they say no,* **WHY NOT?**

DO THE BRIGHTNESS LEVELS CHANGE SMOOTHLY ENOUGH? *Wait for the participant to respond and if they have a hard time, then prompt them. If they say no,* **WHY NOT?**

If this is not their last session, **THANK YOU FOR YOUR TIME! YOUR NEXT SESSION IS SCHEDULED FOR ___________ .** *Read the appointment slip and hand it to them.* **WE'LL CALL YOU AHEAD OF TIME TO CONFIRM THE APPOINTMENT.**

If this is their last session, continue with the questions...

Display information...

DOES THE VEHICLE YOU DRIVE MOST OFTEN HAVE A MOVING POINTER OR DIGITAL SPEEDOMETER? *If it does not have a digital speedometer,* **HAVE YOU EVER USED A DIGITAL SPEEDOMETER BEFORE THIS STUDY?**

DOES THIS VEHICLE HAVE A HEAD-UP DISPLAY? A HEAD-UP DISPLAY IS A DISPLAY ON THE WINDSHIELD WHICH ALLOWS THE DRIVER TO VIEW THE SPEEDOMETER WITHOUT TAKING HIS EYES OFF THE ROAD.

Color illumination information...

WHICH COLOR PANEL ILLUMINATION DOES THE CAR YOU DRIVE MOST OFTEN HAVE? *If they are not sure, prompt them.* **WHITE? RED? ORANGE? YELLOW? GREEN? BLUE/GREEN?**

HAVE YOU EVER DRIVEN CARS WITH OTHER PANEL ILLUMINATION COLORS? *If they say yes,* **WHAT COLORS?** *If they have a hard time remembering, prompt them.* **WHITE? RED? ORANGE? YELLOW? GREEN? BLUE/GREEN?**

WHICH COLOR PANEL ILLUMINATION DO YOU PREFER? *If they are not sure, prompt them.* **WHITE? RED? ORANGE? YELLOW? GREEN? BLUE/GREEN? WHY?**

Panel brightness information...

HOW FREQUENTLY DO YOU ADJUST THE PANEL BRIGHTNESS IN YOUR CAR? *If they have a hard time remembering, prompt them.* **ONCE PER CAR TRIP? MORE THAN ONCE PER CAR TRIP? NEVER?** *If they adjust the panel brightness,* **WHEN DO YOU ADJUST THE PANEL BRIGHTNESS?**

WHAT TYPE OF PANEL BRIGHTNESS SWITCH IS IN YOUR VEHICLE? *Show them the examples.* **WHAT TYPE OF BRIGHTNESS SWITCH IS EASIEST TO ADJUST?**

Final comments...

DO YOU HAVE ANY FINAL COMMENTS THAT YOU'D LIKE TO ADD? FOR INSTANCE, DO YOU HAVE A STRONG PREFERENCE FOR ONE DISPLAY OVER ANOTHER? DO YOU DISLIKE ONE DISPLAY MORE

THAN THE OTHERS? DO YOU HAVE ANY COMMENTS ABOUT INSTRUMENT PANEL BRIGHTNESS LEVELS IN GENERAL?

THIS IS YOUR LAST SESSION. THAT MEANS YOU GET PAID. *If they need to fill out a support voucher, use the appropriate one (UM or non-UM employee). If they are on the UM payroll,* **YOU SHOULD RECEIVE A CHECK THROUGH THE MAIL SHORTLY.** *If they get paid cash,* **HERE IS YOUR 60 DOLLARS. THANKS AGAIN FOR YOUR PARTICIPATION. YOU HELPED US OUT!**

Turn off all of the instruments. Take the light sensor off the roof and the sign off the back of the car. Cover the instruments with the black cloth in the trunk and put the sunscreen on the dash.

APPENDIX B
PARTICIPANT CONSENT FORM

This appendix contains the consent form which the participants signed giving their permission to participate in the study. It is normally printed on UMTRI letterhead paper.

PARTICIPANT CONSENT FORM

DRIVER PREFERENCES FOR INSTRUMENT PANEL LUMINANCE LEVELS

PARTICIPANT CONSENT FORM

This study concerns the panel brightness levels people want. By knowing that information, manufacturers will be able to design cars that are suited to people's needs.

In this study, you will drive a new car over a 17-mile course in Ann Arbor, twice during the day and three times at night. Periodically, we will ask you to adjust the panel brightness to your liking. The two daytime sessions will take approximately two and a half hours and can be completed in one visit. The three nighttime sessions will take one hour each and must be completed on separate visits. There will be approximately one week between night sessions. With your permission, we may videotape one or more of your sessions.

You will be paid $60 for your participation in the entire study ($8 per hour times 5.5 hours, plus $16 bonus for completing all of the sessions). If you cannot complete the study, you will be paid for the sessions you complete.

You can withdraw from this study at any time. There is a small chance you may have trouble with the task and will be asked not to complete the study.

There are no hazards that you will be exposed to in this study besides those encountered in everyday driving.

I have read and understand the information above.

____________________ print your name	____________________ date
____________________ sign your name	____________________ experimenter (witness)

You can videotape one or more of my sessions. Yes No (circle one)

Experimenter: Paul Green (313) 763-3795

APPENDIX C
PARTICIPANT BIOGRAPHICAL FORM

This appendix contains the participant biographical form that was used for the experiment. This form was started at the beginning of the first session and was completed at the end of the fifth session for a given participant.

- Appendix C-Participant Biographical Form -

BIOGRAPHICAL FORM

The University of Michigan
Transportation Research Institute
Human Factors Division
Dr. Paul Green, Project Director
Colleen P. Serafin, Project Leader

Participant # ________
Experimenter ________
Date/Time ________

1. Name:____

2. Address:____

3. Home Phone:______________ 4. Sex:______ 5. Age:______

6. Occupation:_______________________________________
   (If retired or student,note such & former occupation/major)

7. Education: (circle highest level completed)

high school	some	degree
trade/tech school	some	degree
college	some	degree
grad/prof school	some	degree

Physical Information***

8. Handedness: right   left   ambidextrous   (circle one)

9. Eye color: blue   green   brown   grey   hazel   other_____

10. We are doing this study for Nissan and one of Nissan's premises is that preferences for illumination levels may vary with ethnic origin. Therefore, Nissan has asked us to provide such information to them. (Circle One)

    Ethnic Origin: American Indian or Alaskan Native
    Asian or Pacific Islander
    Black, not of Hispanic origin
    Hispanic
    White, not of Hispanic origin
    Not sure

Driving Information***

11. Vehicle Driven Most Often:______________________________
    (include year, make, model)

12. Total Miles Driven/Year: ______________

13. What Fraction is at Night? ___________%

14. When you drive at night, what type of roads do you drive on? (circle one)

mostly highway   mostly city   mostly suburban/rural   mixed

Vision **

15. Eyewear when driving: (circle one)
nothing   glasses   contacts   bifocals   trifocals

16. Corrected Near Visual Acuity: 20/___

17. Color Vision (Ishihara): A___(12) B___(5) C___(26)
D___(6) E___(16) F___(none)

18. Sunglasses Selection: Cateye   Aviator   Clip-ons

Comments:____
____
____

Complete the following section after the FIRST DAYTIME session.

19. When you set the panel brightness at the dazzling level, how often was it actually dazzling? (circle one)
most of the time   some of the time   hardly ever   never

20. Is the adjustment range for panel brightness that is in the car now suitable?
yes   no   not sure   (circle one)

21. If not, why?____
____

22. Is the way in which brightness levels change smooth enough?
yes   no   not sure   (circle one)

23. If not, why?____
____

Comments:____
____

Complete the following section after the SECOND DAYTIME session.

24. When you set the panel brightness at the dazzling level, how often was it actually dazzling? (circle one)
    most of the time   some of the time   hardly ever   never

25. Is the adjustment range for panel brightness that is in the car now suitable?
    yes   no   not sure   (circle one)

    26. If not, why?____

    ____

27. Is the way in which brightness levels change smooth enough?
    yes   no   not sure   (circle one)

    28. If not, why?____

    ____

Comments:____

____

Complete the following section after the FIRST NIGHT session.

29. When you set the panel brightness at the dazzling level, how often was it actually dazzling? (circle one)
    most of the time   some of the time   hardly ever   never

30. Is the adjustment range for panel brightness that is in the car now suitable?
    yes   no   not sure   (circle one)

    31. If not, why?____

    ____

32. Is the way in which brightness levels change smooth enough?
    yes   no   not sure   (circle one)

    33. If not, why?____

    ____

Comments:____

____

Complete the following section after the SECOND NIGHT session.

34. When you set the panel brightness at the dazzling level, how often was it actually dazzling? (circle one)
    most of the time   some of the time   hardly ever   never

35. Is the adjustment range for panel brightness that is in the car now suitable?
    yes   no   not sure   (circle one)

    36. If not, why?____
    ____

37. Is the way in which brightness levels change smooth enough?
    yes   no   not sure   (circle one)

    38. If not, why?____
    ____

Comments:____
____

Complete the following section after the THIRD NIGHT SESSION.

39. When you set the panel brightness at the dazzling level, how often was it actually dazzling? (circle one)
    most of the time   some of the time   hardly ever   never

40. Is the adjustment range for panel brightness that is in the car now suitable?
    yes   no   not sure   (circle one)

    41. If not, why?____
    ____

42. Is the way in which brightness levels change smooth enough?
    yes   no   not sure   (circle one)

    43. If not, why?____
    ____

Display Information ***

44. Does the vehicle you drive most often have a moving pointer or digital speedometer? (circle one)
    moving pointer   digital   not sure

45. If it does not have a digital speedometer, have you ever used one before?
yes no not sure (circle one)

46. Does this vehicle have a Head-Up Display (HUD)? A Head-Up Display is a display on the windshield which allows the driver to view the speedometer without taking his eyes off the road.
yes no not sure (circle one)

Color Illumination Information **

47. Which color panel illumination does the car you drive most often have?
white red orange yellow green blue/green not sure (circle one)

48. Have you ever driven cars with other panel illumination colors?
yes no not sure (circle one)

49. If yes, what color(s) illumination? (circle all that apply)
white red orange yellow green blue/green not sure

50. Which color panel illumination do you prefer? (circle one)
white red orange yellow green blue/green not sure

51. Why?____
____

Panel Brightness Information **

52. How frequently do you adjust the panel brightness in your car? (circle one)
once per car trip more than once per car trip never

53. When do you adjust the panel brightness? ______________________________
____

54. What type of panel brightness switch is in your vehicle? (Show the examples)
thumbwheel knob slide switch not sure other________ (circle one)

55. What type of brightness switch is easiest to adjust?
thumbwheel knob slide switch not sure other________ (circle one)

Thank you for your participation!

Final Comments: ____
____
____

- Appendix C-Participant Biographical Form -

APPENDIX D
DATA COLLECTION FORM

This appendix contains the data collection form which the experimenter used to record light levels and test conditions for each session.

DATA COLLECTION FORM

Participant # _______
Experimenter ________________

Date: ________ Blower temp:
Start Time : ________ A.M. P.M. fans:
End Time: _________

Weather, day: sunny mostly sunny night: clear partly cloudy (circle one)

Session Type: Day Night (circle one) Session #: _____

Sunglass No Sunglass (circle one if day)

Digital Green White (circle one)

Gossen Scale: A B Mag: x100 x10 x1 Sensor Mag: x1 x20
Micronta over by _____
Minolta dash (d) range: ________
Minolta roof (r) range: ________

CODES: B not bright enough
\+ between this and above
\- between this and below

ORDER: MAX PREF MIN DAZ

LOCATION	MINOLTA-d	GOSSEN	MINOLTA-r	FLUKE	COMMENTS
Nixon Rd Parkway Meadows Apt entrance					

Warren Rd right after turn corner					

Earhart Rd right after turn corner					

Participant # ____________________
Session #____________________
ORDER: MAX PREF MIN DAZ

CODES: B not bright enough
+ between this and above
- between this and below

LOCATION	MINOLTA	GOSSEN	MINOLTA	FLUKE	COMMENTS
US 23 bridge over Earhart Rd					

Washtenaw Ann Arbor Buick					

Washtenaw Devonshire					

Geddes Rd Onondaga Rd					

Participant # ____________________

Session #____________________

ORDER: MAX PREF MIN DAZ

CODES: B not bright enough
+ between this and above
- between this and below

LOCATION	MINOLTA	GOSSEN	MINOLTA	FLUKE	COMMENTS
Huron Pkwy bridge					

Huron Pkwy Geddes Lake Townhouses complex					

	Micronta	-> Minolta
Minolta: lux		
Gossen: ft-c	0.318	31800
Minolta: lux	173.1	17310
Fluke: volts	65.1	6510

APPENDIX E
COUNTERBALANCING FOR NIGHT SESSIONS

This appendix contains the assignment of drivers to the four panel orders at night.

COUNTERBALANCING FOR NIGHT SESSIONS

Table E-1. Number of Drivers Assigned to the Four Panel Orders at Night

	American (n=20)				Japanese (n=10)	Total
	Males		Females			
	Young	Old	Young	Old		
Digital -> Analog						
D W G	2	2	3	1	2	10
D G W	0	1	0	1	3	5
Total	2	3	3	2	5	15
Analog -> Digital						
W G D	1	1	1	1	1	5
G W D	2	1	1	2	4	10
Total	3	2	2	3	5	15

Key D = digital
W = white analog
G = green analog

APPENDIX F
VOLTAGE PREFERENCES

This appendix contains mean voltage preferences for the three driver groups--young Americans, older Americans, and Japanese--as a function of judgment (minimum, preferred, maximum, and dazzling), panel (daytime--with and without sunglasses and nighttime--digital, green analog, and white analog), and site (9).

VOLTAGE PREFERENCES

Table F-1. Minimum Judgment

	Sunglasses*			No Sunglasses			Digital			Green			White		
Site	Y**	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1***	11.5	11.8	11.6	9.5	9.7	9.6	3.5	4.6	3.9	3.1	3.6	3.7	3.4	4.2	3.8
2	10.3	11.4	11.5	7.7	9.4	8.9	3.4	4.6	4.1	3.5	4.0	4.0	3.4	4.6	4.1
3	11.7	12.1	11.8	9.4	10.6	9.8	4.6	4.4	4.2	3.7	4.1	4.0	3.5	4.3	4.3
4	11.9	12.0	11.8	10.1	10.9	10.5	3.9	4.3	4.2	4.0	3.8	4.1	3.3	4.1	4.1
5	11.5	12.0	11.9	9.7	10.8	9.9	4.6	5.1	4.5	4.0	4.1	4.3	4.5	4.5	5.5
6	11.3	11.6	11.7	9.0	10.5	9.9	4.0	4.9	4.9	3.9	4.5	4.3	3.8	4.2	4.9
7	10.0	10.4	10.5	7.1	8.1	7.1	4.0	4.8	4.5	3.8	4.3	4.3	4.0	4.0	4.3
8	11.5	12.0	11.9	9.6	10.4	10.4	4.1	4.8	5.0	3.6	4.2	4.4	3.5	4.1	5.4
9	11.2	11.6	11.8	9.8	10.7	10.1	3.5	4.7	4.1	3.8	4.3	4.2	3.5	4.1	4.4

* Sunglasses and No Sunglasses = Daytime Conditions
Digital, Green, and White = Nighttime Conditions

** Y = Young Americans
O = Older Americans
J = Japanese

***Site 1 = Nixon Rd.
Site 2 = Warren Rd.
Site 3 = Earhart Rd.
Site 4 = US-23
Site 5 = Washtenaw Ave.
Site 6 = Washtenaw Ave. (NW)
Site 7 = Geddes Ave.
Site 8 = Huron Pkwy. Bridge
Site 9 = Huron Pkwy.

Table F-2. Preferred Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	12.5	12.5	12.5	11.7	11.9	11.9	7.5	9.6	7.6	6.7	8.7	7.3	7.2	8.4	8.1
2	12.0	12.4	12.6	11.5	12.2	11.6	7.2	9.7	7.3	6.4	8.3	7.3	6.9	8.7	7.4
3	12.5	12.6	12.5	11.9	12.5	11.9	7.0	9.4	7.3	6.5	7.8	7.3	6.8	8.4	7.3
4	12.5	12.6	12.6	12.1	12.4	12.2	7.1	8.7	7.4	7.2	8.3	7.0	7.0	8.3	7.1
5	12.4	12.5	12.6	12.0	12.3	11.8	8.5	10.2	8.7	7.3	9.1	8.5	8.1	9.7	8.8
6	12.3	12.4	12.4	11.8	12.4	11.7	7.6	9.8	8.5	7.5	9.1	7.5	7.5	8.8	8.4
7	12.1	12.1	12.1	11.1	11.7	11.0	7.9	9.2	8.2	6.9	8.4	8.2	7.9	8.7	7.6
8	12.5	12.5	12.5	12.1	12.3	12.0	8.2	9.7	8.4	6.4	8.5	7.8	7.7	7.8	8.5
9	12.5	12.5	12.5	12.0	12.3	12.0	7.4	9.3	8.0	6.4	8.8	6.9	7.2	8.2	7.5

Table F-3. Maximum Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	12.5	12.5	12.6	12.2	12.6	12.6	10.3	11.7	10.6	10.7	11.7	10.9	10.3	11.8	11.0
2	12.4	12.6	12.6	12.2	12.5	12.5	10.1	11.6	10.4	10.0	11.9	9.9	10.6	12.0	10.4
3	12.6	12.6	12.6	12.4	12.6	12.6	9.7	11.6	9.8	10.8	11.6	10.1	10.9	11.9	10.2
4	12.6	12.7	12.7	12.5	12.7	12.7	9.8	11.4	10.6	10.8	11.9	10.1	10.9	12.0	9.9
5	12.5	12.6	12.6	12.4	12.6	12.5	10.9	11.8	11.5	11.4	11.9	11.3	11.9	11.9	11.6
6	12.6	12.6	12.6	11.9	12.6	12.5	11.1	11.9	11.1	11.4	12.1	10.9	10.9	12.1	11.1
7	12.6	12.6	12.6	12.2	12.6	12.4	11.3	11.8	11.0	10.6	12.0	10.7	11.0	12.1	11.2
8	12.6	12.6	12.6	12.4	12.6	12.6	11.6	11.5	11.4	10.3	12.1	11.2	11.1	12.0	11.3
9	12.6	12.6	12.6	12.4	12.6	12.6	10.9	11.2	11.0	10.4	12.1	10.7	10.7	12.1	10.7

Table F-4. Dazzling Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	12.6	12.4	12.6	12.6	12.6	12.6	12.0	12.8	11.8	11.9	12.1	11.7	11.8	12.1	11.6
2	12.6	12.6	12.6	12.5	12.5	12.7	11.6	12.4	11.7	11.8	12.1	11.5	11.2	12.2	11.0
3	12.6	12.6	12.6	12.6	12.6	12.7	11.6	12.4	11.9	11.7	12.1	11.7	11.9	12.1	11.4
4	12.6	12.6	12.7	12.7	12.5	12.7	11.4	12.4	11.9	11.7	12.2	11.7	12.0	12.3	11.3
5	12.6	12.6	12.6	12.6	12.6	12.6	12.4	12.3	12.4	12.1	12.1	12.0	12.2	12.2	12.1
6	12.5	12.6	12.6	12.5	12.6	12.6	12.1	12.4	12.2	12.0	12.1	11.8	11.7	12.1	12.0
7	12.5	12.6	12.6	12.5	12.6	12.5	12.2	12.4	12.3	11.5	12.1	11.7	12.0	12.1	11.3
8	12.6	12.6	12.6	12.5	12.6	12.6	12.6	12.6	12.3	11.7	12.1	11.7	11.7	12.2	11.8
9	12.6	12.6	12.6	12.5	12.6	12.6	12.1	12.3	12.0	11.6	12.1	11.8	11.7	12.2	11.6

APPENDIX G
CHARACTER LUMINANCE PREFERENCES

This appendix contains mean character luminance preferences (cd/m^2) for the three driver groups--young Americans, older Americans, and Japanese--as a function of judgment (minimum, preferred, maximum, and dazzling), panel (daytime--with and without sunglasses and nighttime--digital, green analog, and white analog), and site (9).

CHARACTER LUMINANCE PREFERENCES

Table G-1. Minimum Judgment

	Sunglasses*			No Sunglasses			Digital			Green			White	
Site	Y**	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1***	35.82	39.81	37.62	16.93	17.14	24.26	0.61	1.72	0.93	0.08	0.19	0.12	0.13	0.30	0.31
2	19.34	29.36	26.06	8.28	13.30	10.34	0.54	1.39	1.11	0.20	0.29	0.35	0.12	0.84	0.45
3	38.66	46.68	40.68	16.84	24.22	18.49	6.04	1.53	1.07	0.26	0.42	0.57	0.21	1.00	0.66
4	40.59	42.29	38.00	21.03	28.83	25.84	0.81	1.24	1.07	0.47	0.27	0.42	0.11	0.44	0.33
5	49.94	44.60	42.61	20.82	30.99	36.28	1.44	1.96	1.36	0.57	0.64	0.61	0.49	0.35	1.66
6	39.60	38.17	33.73	17.57	27.98	22.24	0.90	1.75	1.76	0.40	0.90	0.42	0.18	0.62	0.78
7	14.24	22.28	15.43	7.02	9.05	5.44	0.95	1.64	1.49	0.41	1.11	0.60	0.40	0.31	0.38
8	35.48	47.81	41.83	22.07	28.10	26.32	0.99	1.69	1.83	0.26	0.91	0.76	0.09	0.48	0.37
9	35.42	55.27	49.51	18.42	35.62	23.36	0.53	1.51	0.95	0.52	0.68	0.52	0.11	0.48	0.43

* Sunglasses and No Sunglasses = Daytime Conditions
Digital, Green, and White = Nighttime Conditions

** Y = Young Americans
O = Older Americans
J = Japanese

*** Site 1 = Nixon Rd.
Site 2 = Warren Rd.
Site 3 = Earhart Rd.
Site 4 = US-23
Site 5 = Washtenaw Ave.
Site 6 = Washtenaw Ave. (NW)
Site 7 = Geddes Ave.
Site 8 = Huron Pkwy. Bridge
Site 9 = Huron Pkwy.

Table G-2. Preferred Judgment

	Sunglasses			No Sunglasses			Digital			Green			White	
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	56.14	57.38	62.88	41.98	41.46	46.90	4.83	15.67	5.14	3.45	10.43	5.20	4.01	5.96	4.73
2	44.33	52.04	55.08	31.96	41.12	32.19	4.32	20.04	4.71	2.80	8.81	4.98	2.45	7.55	3.52
3	58.43	56.23	53.32	39.36	55.24	40.08	4.74	14.59	4.55	3.76	7.33	5.76	2.23	7.18	3.41
4	58.91	60.21	59.79	46.16	54.03	49.11	5.46	12.47	4.91	4.63	9.31	4.52	4.13	6.32	2.69
5	67.35	59.49	65.98	46.93	54.18	65.03	8.03	20.05	7.30	5.97	12.63	9.94	5.88	10.54	7.76
6	54.49	53.55	51.87	42.50	52.12	36.07	4.92	18.67	7.11	5.77	11.48	4.86	4.86	8.75	5.56
7	43.47	48.37	39.83	26.93	37.61	21.99	6.41	13.95	6.46	4.19	10.50	7.31	5.92	7.86	3.80
8	60.78	61.58	62.00	49.53	54.15	49.08	6.49	18.16	7.08	3.46	11.46	5.41	5.39	6.01	6.19
9	58.92	75.97	61.34	44.48	72.67	40.75	4.69	17.21	5.50	3.01	10.92	4.02	4.14	7.26	4.05

Table G-3. Maximum Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	58.13	58.00	64.01	55.62	57.38	65.36	24.49	38.44	23.23	20.20	27.43	20.65	11.87	17.50	14.52
2	52.25	57.24	57.02	45.99	54.49	54.19	24.83	34.68	16.93	17.36	27.82	14.67	12.82	18.52	12.51
3	60.64	58.01	59.26	49.55	57.71	57.48	20.60	34.34	15.58	20.90	26.75	17.00	14.57	18.23	11.71
4	62.74	62.30	64.11	57.06	62.98	62.81	20.62	36.73	25.69	21.18	28.29	16.39	14.04	18.48	10.92
5	72.37	68.00	65.30	57.25	61.18	70.63	29.61	42.51	28.29	25.32	28.10	23.88	17.93	17.69	16.63
6	64.37	61.12	60.84	52.07	61.83	56.27	27.53	40.14	26.27	25.02	29.30	20.95	14.27	18.76	14.69
7	57.04	57.69	55.40	46.72	52.48	51.18	27.86	39.65	21.98	20.29	28.44	20.18	14.21	18.47	14.82
8	61.06	64.42	63.52	57.12	64.62	73.87	35.38	34.94	30.73	18.50	29.66	22.19	14.67	18.08	15.32
9	62.16	76.90	65.63	55.35	89.00	61.23	22.30	32.21	21.90	18.40	29.47	19.67	13.65	18.76	13.07

Table G-4. Dazzling Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	60.15	54.94	63.86	57.28	58.06	61.48	44.93	56.29	36.89	27.95	29.67	27.66	17.49	18.84	16.61
2	59.79	55.12	75.82	54.22	53.24	57.51	42.41	47.02	42.05	27.32	29.57	26.53	15.87	19.17	14.74
3	58.50	61.52	58.56	59.14	58.56	59.63	42.52	49.21	41.54	26.92	29.94	27.00	18.04	18.92	15.87
4	62.21	62.50	63.77	64.00	59.01	62.05	40.12	51.10	43.09	27.76	30.53	26.64	18.27	19.83	15.54
5	68.44	61.61	68.36	62.48	61.52	73.33	49.18	49.96	48.67	30.18	29.93	29.22	19.18	19.12	18.49
6	64.47	66.55	57.26	56.89	59.53	61.70	46.48	49.04	42.84	29.11	29.83	27.80	17.31	18.52	18.15
7	54.83	53.69	53.23	53.63	53.46	53.92	45.47	48.08	46.22	26.73	29.72	26.94	18.23	18.76	15.46
8	61.74	62.48	64.41	61.01	62.62	64.77	51.29	52.92	44.88	27.04	30.12	27.36	16.99	19.01	17.41
9	60.82	86.62	73.64	59.84	67.75	64.43	45.21	49.95	41.66	26.95	29.92	27.67	17.20	19.17	16.81

APPENDIX H
BACKGROUND LUMINANCE PREFERENCES

This appendix contains mean background luminance preferences (cd/m^2) for the three driver groups--young Americans, older Americans, and Japanese--as a function of judgment (minimum, preferred, maximum, and dazzling), panel (daytime--with and without sunglasses and nighttime--digital, green analog, and white analog), and site (9).

BACKGROUND LUMINANCE PREFERENCES

Table H-1. Minimum Judgment

	Sunglasses*			No Sunglasses			Digital			Green			White		
Site	Y**	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1***	9.14	7.33	10.14	7.41	5.83	12.56	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.05	0.14
2	3.84	2.19	2.01	3.04	2.45	2.86	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
3	6.09	6.09	5.02	4.86	5.11	5.71	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03
4	7.44	7.46	7.21	7.87	7.11	7.44	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.03
5	22.53	9.33	10.00	9.03	8.40	21.59	0.01	0.02	0.02	0.04	0.03	0.03	0.46	0.27	0.18
6	14.51	8.41	7.47	8.18	10.88	9.19	0.01	0.01	0.01	0.01	0.02	0.01	0.04	0.15	0.05
7	2.59	1.14	1.68	2.56	1.08	1.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03
8	9.39	10.99	11.12	9.84	9.48	11.24	0.01	0.01	0.02	0.01	0.03	0.03	0.12	0.04	0.11
9	10.39	25.48	19.34	7.01	15.45	9.65	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.03

* Sunglasses and No Sunglasses = Daytime Conditions
Digital, Green, and White = Nighttime Conditions

** Y = Young Americans
O = Older Americans
J = Japanese

*** Site 1 = Nixon Rd.
Site 2 = Warren Rd.
Site 3 = Earhart Rd.
Site 4 = US-23
Site 5 = Washtenaw Ave.
Site 6 = Washtenaw Ave. (NW)
Site 7 = Geddes Ave.
Site 8 = Huron Pkwy. Bridge
Site 9 = Huron Pkwy.

Table H-2. Preferred Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	7.21	6.98	11.03	8.88	6.08	12.34	0.03	0.08	0.03	0.05	0.10	0.06	0.09	0.13	0.15
2	3.88	5.06	2.56	3.80	2.03	2.63	0.02	0.09	0.02	0.03	0.08	0.05	0.05	0.10	0.06
3	8.56	4.60	4.08	4.81	7.54	4.38	0.02	0.07	0.02	0.04	0.07	0.06	0.04	0.09	0.06
4	8.11	7.10	7.45	7.68	6.92	7.94	0.03	0.06	0.02	0.05	0.09	0.05	0.07	0.09	0.06
5	18.81	9.68	11.78	12.39	8.45	27.79	0.05	0.10	0.04	0.08	0.14	0.10	0.30	0.45	0.36
6	9.99	6.29	4.34	10.05	6.56	5.49	0.03	0.09	0.04	0.06	0.11	0.05	0.11	0.14	0.12
7	4.32	6.73	1.77	4.78	1.61	1.70	0.03	0.07	0.03	0.05	0.09	0.07	0.09	0.11	0.07
8	9.65	10.82	9.51	10.41	10.52	11.77	0.04	0.09	0.04	0.04	0.10	0.06	0.19	0.14	0.16
9	9.15	26.55	12.58	7.85	26.78	5.18	0.02	0.08	0.03	0.04	0.10	0.04	0.07	0.10	0.06

Table H-3. Maximum Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	9.31	6.67	10.41	9.04	5.66	12.26	0.12	0.18	0.11	0.17	0.22	0.18	0.16	0.24	0.21
2	4.22	4.65	2.68	3.46	4.05	2.83	0.12	0.16	0.08	0.15	0.23	0.13	0.15	0.22	0.15
3	7.77	4.47	4.30	4.29	4.20	4.15	0.10	0.16	0.07	0.17	0.22	0.15	0.17	0.21	0.14
4	7.93	7.09	7.43	7.56	6.83	7.55	0.10	0.17	0.12	0.18	0.23	0.14	0.17	0.22	0.14
5	20.72	14.07	11.15	11.44	7.82	19.29	0.14	0.20	0.14	0.23	0.24	0.22	0.30	0.48	0.53
6	12.50	9.08	7.07	11.05	9.73	6.50	0.13	0.19	0.12	0.21	0.24	0.18	0.19	0.24	0.24
7	5.78	5.94	2.52	5.15	1.60	2.50	0.13	0.18	0.10	0.17	0.23	0.17	0.19	0.23	0.19
8	9.03	11.67	9.08	9.91	11.85	18.13	0.17	0.17	0.15	0.16	0.25	0.19	0.31	0.29	0.23
9	8.72	21.79	12.95	8.29	32.88	6.11	0.11	0.15	0.10	0.16	0.24	0.17	0.17	0.23	0.16

Table H-4. Dazzling Judgment

	Sunglasses			No Sunglasses			Digital			Green			White		
Site	Y	O	J	Y	O	J	Y	O	J	Y	O	J	Y	O	J
1	8.64	6.82	10.71	6.44	5.84	8.70	0.21	0.26	0.17	0.23	0.24	0.23	0.23	0.26	0.22
2	5.12	2.67	19.48	4.40	2.91	2.26	0.20	0.22	0.20	0.22	0.24	0.22	0.19	0.22	0.18
3	5.36	7.69	3.66	6.39	4.97	4.20	0.20	0.23	0.19	0.22	0.24	0.22	0.21	0.22	0.19
4	7.44	7.27	7.11	7.77	7.16	6.86	0.19	0.24	0.20	0.23	0.25	0.22	0.22	0.23	0.19
5	16.24	8.21	13.52	10.33	8.13	17.64	0.23	0.24	0.23	0.27	0.26	0.27	0.35	0.49	0.38
6	13.04	13.18	5.10	6.96	8.06	7.86	0.22	0.23	0.20	0.24	0.24	0.23	0.23	0.24	0.24
7	4.63	1.83	1.85	3.98	2.06	2.65	0.21	0.22	0.22	0.22	0.24	0.22	0.22	0.23	0.20
8	9.65	9.46	10.34	9.42	8.70	9.80	0.24	0.25	0.21	0.22	0.26	0.24	0.31	0.27	0.39
9	8.37	30.72	18.36	9.67	14.28	9.48	0.21	0.23	0.19	0.22	0.24	0.23	0.20	0.23	0.20