EFFECTS OF ROAD MARKING LUMINANCE CONTRAST ON DRIVING SAFETY

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16. Abstract

This report presents a study on the effects of road marking luminance contrast on driving safety. Through laboratory driving simulation experiments, road marking color, configuration, luminance contrast, driving speed, subjects' age and gender, and their interactions, were investigated. Thirty-six subjects balanced by age and gender participated in the experiments. Each subject was presented with a series of digitally edited video clips showing different levels of marking luminance contrasts. The subject was required to make responses to the video stimuli based on marking color and configuration the video presented. It found that subjects' responses dropped with the increment of road marking luminance contrast values, but at different rates during different contrast segments. White markings are more visible than yellow markings. Driving at higher speed got faster responses but longer response distances. Older subjects took the longest responses while younger subjects took the least. Female subjects responded a little bit slower and needed longer response distances than males. To warrant proper responses and assure safe driving, the minimum contrast values for white and yellow road marking are estimated to be 1.1 and 3.3~3.5 respectively. When road markings' contrast values are below these thresholds, a repair or repaint on road markings might be needed.

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1. INTRODUCTION

Being one of three major groups of traffic control devices, pavement markings guide and regulate vehicle control, separate opposing lanes of traffic, prohibit passing maneuvers, delineate roadway edges, and provide information for drivers. Drivers rely more on retroreflective pavement markings to provide guidance information during nighttime than daytime. In Section 3A.02 (Standardization of Application) of the Manual on Uniform Traffic Control Devices (MUTCD) for Streets and Highways, it states that "…Markings that must be visible at night shall be retroreflective unless ambient illumination assures that the markings are adequately visible. All markings on Interstate highways shall be retroreflective" (FHWA, 2003). In order to be most useful, pavement markings must be standardized in use, colors, placement and maintenance.

Road marking luminance contrast is an important factor that could affect drivers' responses at various driving conditions. It tells how clearly a road marking stands out from its background, therefore, is more appropriate to be used in describing marking's visibility. Some researches investigated the effects of luminance contrast on traffic signs, but its influences on road markings were rarely studied. This report presents a human factors study on the effects of nighttime road marking luminance contrast on drivers' responses. It investigated the influences of several factors and their impacts on driving safety. It also studied the impacts of drivers' age and gender to different combinations of these factors. The findings might help determining the timing and luminance contrast condition to warrant a repair or repaint on road markings to assure safe driving.

2. NOMENCLATURE

2.1 Pavement Marking

Pavement marking is defined by American Association of State Highway and Transportation Officials (AASHTO) as “All lines, patterns, words, colors, or other devices, except signs, set into the surface of, applied upon, or attached to the pavement or curbing or to the objects within or adjacent to the roadway, officially placed for the purpose of regulating, warning, or guiding traffic” (AASHTO, 1983).

Pavement markings include two types, longitudinal markings (centerline, lane line, edge line, and pavement marker) and transverse markings (shoulder, word and symbol, stop, yield, crosswalk, speed measurement, and parking space). This study investigated the centerline and lane line. Thereafter, pavement marking in this paper means the longitudinal markings.

The common marking colors are white and yellow, and the common configurations are single skip, single solid, skip and solid, and double solid, which are shown in Figure 1.

2.2 Pavement Marking Retroreflectivity

Retroreflectivity is the portion of incident light from a vehicle’s headlights reflected back toward the eye of the driver of the vehicle (Figure 2). The retroreflectivity of pavement marking is provided by glass or ceramic beads that are partially embedded in the surface of pavement marking (Figure 3). The most commonly used measure of pavement marking retroreflectivity is the coefficient of retroreflected luminance R_L, expressed in millicandelas per square meter per lux ($mcd/m^2/lux$.) R_L is an absolute value and is unaffected by night and day.

The initial retroreflectivity values for newly installed white markings range from 175 to 700 mcd/m^2/lx, and for yellow markings range from 100 to 350 mcd/m^2/lx, depending on the region, the type of marking material, and the time frame in which the retroreflectivity is measured (Hawkins and Womack, 2002).

2.3 Retroreflectometer

Retroreflectometers measure the pavement marking retroreflectivity. The measurement is made at a particular fixed geometry which is intended to represent the actual field geometry as light rays travel from the vehicle headlights to the pavement marking and reflect back towards a driver's field of vision. In the United States, the standard geometry for pavement marking retroreflectivity measurement is 30 meters (see Figure 4), which was adopted by ASTM (Migletz and Graham, 2002).

2.4 Pavement Marking Luminance

Luminance is the luminous intensity or brightness of any surface in a given direction, per unit of projected area of the surface as viewed from that direction, independent of viewing distance. The SI unit is candela/m^2. Pavement marking luminance is directly proportional to the amount of the light energy that is retroreflected by the marking toward a driver's eyes.

2.5 Pavement Marking Luminance Contrast

Luminance contrast is defined as the ratio of the difference between the luminance of a target area and a surrounding background area to the background luminance alone. Therefore, pavement marking luminance contrast can be expressed as pavement marking luminance minus pavement surface luminance, divided by pavement surface luminance.

$$\text{pavement marking luminance contrast} = \frac{L_m - L_p}{L_p} \tag{1}$$

where:

L_m - pavement marking luminance;

L_p - pavement surface luminance.

Luminance contrast is much more important for overall visibility than luminance, because contrast tells how clearly a pavement marking stands out from its background. Therefore, contrast is more appropriate in measuring a marking's visibility.

2.6 Pavement Marking Detection Distance

Detection distance is often measured in terms of the point at which the beginning or end of a marking section first becomes visible to an observer from a moving vehicle. The nighttime detection distance of pavement markings is commonly used to evaluate the effects of pavement marking visibility on driving performance.

3. LITERATURE REVIEW

Using different performance criteria and factors, many investigators investigated the relationship between pavement marking and driving performance with respect to pavement marking detection distance, retroreflectivity levels, marking color, luminance contrast, and life cycle. Some of these studies are summarized below.

3.1 Pavement Marking Detection Distance and Driving Performance

Zwahlen and Schnell investigated the nighttime detection distances of yellow and white-painted and taped pavement markings of various widths under low-beam illumination (Zwahlen and Schnell, 1995). Different centerline and edge line configurations were tested. The results indicated no statistically significant differences ($\alpha = 0.05$) for the average begin or end detection distances using a line width between 0.1 and 0.2 meter. There was a statistically significant difference in the average detection distance ($\alpha = 0.05$) between a 0.1 and a 0.2 meter wide right edge line for a left curve, and the end detection distances were significantly ($\alpha = 0.05$) longer than the begin detection distances. Through a field experiment to study the visibility of new yellow center stripes as a function of the degree of pavement marking obliteration (Zwahlen, Hagiwara, and Schnell, 1995), they found that severe obliteration reduced the begin and end detection distance to a considerable degree, and if the non-obliterated center-line pavement marking treatment provides barely adequate visibility performance, it might not be possible to tolerate much obliteration at all before the visibility performance of the driver-vehicle-center stripe system fall below the acceptable minimum safety level. Aiming at providing nighttime pavement marking visibility data obtained under automobile low-beam illumination conditions in the field for further calibration of the Ohio University pavement marking visibility model CARVE (Computer Aided Road Marking Visibility Evaluator), Zwahlen and Schnell studied the effects of marking configuration (number of lines, dashed versus solid and line width) on end detection distance through field experiments (Zwahlen and Schnell, 1997). They found that increasing overall line luminance through use of wider lines, two rather than one line and solid rather than dashed lines increased end detection distances. Zwahlen and Senthilnathan (Zwahlen and Senthilnathan, 2002) used CARVE and a geometric curve data pre-processor computer program to predict the visibility distances of retroreflective pavement markings in horizontal curves under low beam illumination. The results of the study indicated that there was reduction in pavement marking visibility distance for level horizontal left curves. In order to provide a driver with an adequate minimum preview time or distance when driving through a horizontal left curve with low beams at night, consideration should be given to either increase the general minimum in-service levels of pavement marking retroreflectivity, or to use brighter and/or wider pavement markings in left curves in geographical regions characterized by a high frequency of horizontal curves. On the basis of a field experiment, the effects of lateral separation between double center-stripe pavement markings on visibility under nighttime driving conditions was studied (Zwahlen, Schnell, and Hagiwara, 1995). The research concluded that an increase in the lateral separation (from 0.05 to 0.2 meter) between the double center stripes was not a useful method to increase driver visibility in a practically significant manner. It was generally agreed that the visibility of road markings was primarily governed by the available luminance contrast. Based on the analysis of driver eye scanning behavior data collected from a series of field experiments, Schnell and Zwahlen studied driver preview distances as a function of pavement marking retroreflectivities (Schnell and Zwahlen, 1997). They found that an increase in the retroreflectivity of road markings resulted in a significant and desirable increase in visibility, and brighter markings were better and provide longer preview distance, which was desirable from an information acquisition, information processing, and safety point of view. Similar conclusions were drawn from the study conducted by Jacobs et al. on detection distance of pavement markings under stationary and dynamic conditions as a function of retroreflective brightness (Jacobs, et al., 1995).

3.2 Pavement Marking Retroreflectivity Levels and Driving Performance

Nighttime visibility of pavement markings is mainly based on the distribution of illumination from the vehicle headlights, the retroreflectivity of the marking, the contrast with the pavement surface, and the presence or absence of roadway lighting. The retroreflectivity level of the marking is the most significant factor for most pavement surfaces (Ethen and Woltman, 1986).

Many studies focused on the influence of road marking retroreflective brightness on driving performance. Currently, no specific minimum pavement marking retroreflectivity values are stated by either the MUTCD for Streets and Highways or the ASTM, i.e., there is no widely accepted minimum pavement marking retroreflectivity value in the United States. As early as in 1984, the Center for Auto Safety petitioned the Federal Highway Administration (FHWA) to establish standards for retroreflectivity. In 1993 Congress required FHWA to develop and implement minimum levels of retroreflectivity for pavement markings and signs mainly based on driving performance and safety. Consequently, a lot of efforts have been put to figure out the values.

Some studies were conducted to try to obtain accident-based marking retroreflectivity threshold values. Using the 3-year accident data along with corresponding retroreflectivity measurements of the longitudinal pavement markings in four areas of Michigan, Lee et al. tested the relationship between night time accidents and the level of pavement marking retroreflectivity (Lee, Maleck and Taylor, 1997). With the limited data, no correlation was found between the two, thus no accident-based minimum pavement marking retroreflectivity values could be obtained. In a similar study conducted by Abboud and Bowman, a crash-based retroreflectivity threshold of 140 to 156 mcd/m^2/lx was established using Mirolux 12, a 15-meter geometry retroflectometer. They recommended using 150 mcd/m^2/lx as the retroreflectivity threshold for white paint and the thermoplastic striping when traffic safety is the major concern (Abboud and Bowman, 2002A).

On the basis of field and laboratory evaluations and measurements, Graham and King reported that marking retroreflectance of 93 mcd/m^2/lx on dry road and 180 mcd/m^2/lx on wet road as adequate or more than adequate respectively for night conditions (King and Graham, 1989; Graham and King 1991). Andrady recommended 100 mcd/m^2/lx as the minimum retroreflectivity value under nighttime dry driving conditions (Andrady, 1997). Serres developed a correlation between subjective rating and line specific luminance from an experiment, and concluded that the minimum retroreflectance to median viewer was 150 mcd/m^2/lx, and marking replacement should be made at 100 mcd/m^2/lx (Serres, 1981). A Minnesota Department of Transportation (MnDOT) study through field evaluation and measurement using the Laserlux retroreflectometer revealed that, the threshold value of acceptable marking retroreflectivity was between 80 and 120 mcd/m^2/lx when driving at night under low beam headlight condition, and MnDOT recommended the use of 120 mcd/m^2/lx as the threshold retroreflectivity to develop its new pavement marking management program (Loetterle, Beck and Carlson, 1999). From a similar study, New Jersey Department of Transportation (NJDOT) reported the threshold values as between 80 and 130 mcd/m^2/lx for less than 55 years old New Jersey drivers, and between 120-165 mcd/m^2/lx for greater than 55 years old drivers (Parker and Meja, 2003). Using a Mirolux 12 retroreflectometer, the New York State Department of Transportation (NYDOT) measured retroreflectivity of epoxy, tape, and waterborne paint pavement markings in rural test sections of South Dakota. 120 mcd/m^2/lx and 100 mcd/m^2/lx were determined as the lowest acceptable retroreflectivity values for white and yellow marking respectively (Becker and Marks, 1993). Ethen and Woltman found a marking retroreflectance of 100 mcd/m^2/lx was the minimum acceptable value under dark conditions, providing that the contrast ratio was at least 3 (Ethen and Woltman, 1986). However, they recommended the desirable levels of retroreflectivity to be 400 mcd/m^2/lx under dark conditions and 300 mcd/m^2/lx for illuminated conditions. In the fall of 1994 and the spring of 1995, thirty-two state and local highway agencies participated in a field survey and measurements of retroreflectivity of both white and yellow pavement markings of six different marking materials, all using Retrolux Model 1500 Retroreflectometers. The study found that the acceptable minimum marking retroreflectivity ranged from 90 to 127 mcd/m^2/lx for nighttime dry pavement conditions, a minimum retroreflectivity value of 150 mcd/m^2/lx was recommended for over 80 km/h (50 mph) speed driving on highways, and a minimum retroreflectivity value of 180 mcd/m^2/lx was recommended for nighttime wet pavement conditions (Migletz et al., 1999). Migletz, Harwood and Bauer evaluated the service life of pavement markings using the retroreflectivity measurements at six-month intervals during a four-year period (Migletz, Harwood and Bauer, 2001). The threshold retroreflectivity values used to define the end of pavement marking service life were determined (see Table 1). These values were adopted by FHWA as candidate MUTCD criteria for pavement marking retroreflectivity, but they have not been approved and implemented as policy. In the fall of 1999, in the workshops sponsored by FHWA in an effort to establish minimum levels of retroreflectivity for pavement markings, representatives of 67 state, county, and city agencies reviewed FHWA guidelines, state and local agencies developed values, and made workshop recommendations seen as in Table 2 (Migletz and Graham, 2002).

From the above literature reviews, it can be seen that, a wide variety of factors affect what is subjectively considered by the average motorists as the minimum/threshold pavement marking retroreflectivity. These factors include marking material, type, color, process and location, road class and maintenance activity, traffic condition, roadway lighting condition, weather, driving speed, drivers' age and visual acuity, etc. Therefore it is a complicated issue. FHWA has been reviewing these various candidate levels of minimum retroreflectivity, and will make final selection(s) based on the review result and other factors. The new standard will be included in the next version of the MUTCD in the near future. Currently, the RIDOT minimum retroreflectivity values (when markings are applied) are 350 $mcd/m^2/lx$ for white markings and 225 $mcd/m^2/lx$ for yellow markings.

3.3 Pavement Marking Colors and Driving Performance

Currently there are two color specifications for pavement markings. The ASTM published a standard specification for the color of pavement materials in 2001 (ASTM, 2001). The specification establishes both daytime and nighttime color requirements for markings and applies through the life of the markings. It is viewed by some rather as an industry accepted standard than strictly followed by agencies. In August and December 2002, the FHWA published the final rule on daytime and nighttime color specifications for pavement markings and the corresponding amendment to the rule respectively (FHWA, 2002 A & B). These color specifications were intended to define the end-of-service life for pavement markings in the field. The values in the FHWA rule are almost the same as those in the ASTM specification.

Pavement marking colors affect the detection distance. Zwahlen and Schnell found that the average detection distance of white taped longitudinal lines to be 35-38 meters longer than that of yellow taped lines (Zwahlen and Schnell, 1995). They also found that supplementing a yellow centerline with white edge lines doubled the detection distance (Zwahlen and Schnell, 1997).

It is commonly believe that, when all other factors being equal (binder, beads, thickness, applications, etc.), in most cases white markings have higher retroreflectivity and luminance contrast ratio than yellow markings (except that white markings have poor contrast on light-colored concrete pavements), i.e., white markings are more visible than yellow markings, although both have the same decay rate (Migletz, et al., 1999; Scheuer, Maleck, and Lighthizer, 1997). It is reported that the retroreflectivity of a yellow marking is typically about 65 percent of a white marking under all other equal factors, and yellow markings begin to appear white as the distance to the marking is increased. Besides, yellow markings have less durable color performance than white. Therefore there are needs to increase retroreflectivity and improve color of yellow markings (Hawkins and Womack, 2002).

3.4 Pavement Marking Luminance Contrast and Driving Performance

There are relatively few marking contrast studies on driving performance. McKnights and Tippetts used a driving simulator to investigate the combined effect of marking width and marking-pavement contrast upon lanekeeping. The results presented that lanekeeping performance deteriorated as the contrast between marking and pavement surface declined to very low contrast ratio. Deterioration in lanekeeping performance also occurred with decreasing marking width, but only within the very low contrast range (McKnights and Tippetts, 1998). Analytical studies indicated that under ideal conditions, a contrast of 0.5 is necessary for the average drivers (Migletz, Fish, and Graham, 1994). However, this is only a theoretical value. Conditions are seldom ideal in the real world. Freedman et al. reported that, in order for drivers to obtain adequate visual guidance in the presence of glare on dry pavement surfaces, pavement marking should provide a minimum luminance contrast of 1.0 (Freedman et al., 1988). Employing an interactive driving simulator and using field evaluations, Blackwell and Taylor concluded that when the perceived luminance contrast between road markings and roadway was 2.0, the optimal driver performance, which was measured by the probability of exceeding lane limits, was obtained (Blackwell and Taylor, 1969). A similar study employing an interactive driving simulator and field evaluations obtained the same contrast value result (Allen et al., 1977).

3.5 The Lifecycle of Pavement Markings

The typical pavement marking life can range anywhere from three months to several years, while the typical pavement life may be 12 to 20 years (Thomas and Schloz, 2001). The most popular method to estimate the lifecycle of pavement markings is to develop models to predict the change of marking retroreflectance over time.

Andrady used data from earlier studies to develop a logarithmic model to evaluate the effective lifetime of pavement markings. A generalized model was generated based on the assumption of 100 mcd/lux/m^2 as the minimum acceptable retroreflectivity level (Andrady, 1997):

$$T_{100} = 10^{(R_0 - 100)/b} \quad (2)$$

where:

T_{100} - duration in months for retroreflectivity to reach a value of 100 units;

R_0 - estimate of the initial retroreflectivity value, mcd/lux/m^2;

b - gradient of the semi-logarithmic plot of retroreflectivity.

The T_{100} values depend on the geographic location (the type, condition, usage level of the pavement, and local weather conditions), application, and traffic conditions under which the data were generated.

In a similar study, Lee, Maleck, and Taylor examined the lifecycle of different pavement marking materials (Lee, Maleck, and Taylor, 1999). They developed models for different marking materials and showed the percentage loss in retroreflectivity per day as 0.14% for all materials. The linear models resulted in R^2 values ranging from 0.14 to 0.18. The linear regression model they developed for thermoplastic markings is:

$$Y = - 0.3622X + 254.82, R^2 = 0.14 \quad (3)$$

where:

Y - retroreflectivity of pavement markings, mcd/lux/m^2;

X - age of markings, days.

Based on crash and retroreflectivity data collected on Alabama roads and used a safety-based retroreflectivity threshold of 150 mcd/m^2/lx, Abboud and Bowman developed a logarithmic model to relate marking retroreflectivity with traffic volume (Abboud and Bowman, 2002B):

$$\text{Paints: } R_L = -19.457\ln(ADT \times A \times 0.0304) + 267,\ R^2 = 0.3139 \quad (4)$$

$$\text{Thermoplastic: } R_L = -70.806\ln(ADT \times A \times 0.0304) + 640,\ R^2 = 0.5847 \quad (5)$$

where:

R_L - pavement marking retroreflectivity, mcd/lux/m^2;

ADT - average daily traffic, in vehicles/day/lane;

A - pavement marking age, months.

However, due to the small R^2 values concluded in these studies, the applications of these aforementioned linear models might be of question.

3.6 The Role of Age and Gender in Driving Performance

Older drivers show declines in sensory, perceptual, cognitive, and psychomotor ability (Pietrucha et al., 1996). Consequently older drivers experience difficulty in seeing pavement markings and getting information from them when driving at night.

Older drivers' visual acuity, particularly under low-luminance conditions, declines apparently (Staplin, Lococo, and Sim, 1990). This poses one of the primary concerns and considerations in traffic control device design and implementation, especially when older drivers' performance is an issue. Pietrucha et al. reported that increases in size of delineation devices that include a legibility component could be important in providing earlier perception of road geometry, e.g., curve direction for older drivers (Pietrucha et al., 1996).

Mace found that drivers' preview time and perception-reaction time continually increase with age. This is because the cognitive abilities and psychomotor skills decrease with age (Mace, 1988). Jacobs et al. studied detection distance of markings from a vehicle under stationary and dynamic conditions as a function of marking retroreflective brightness. They found that subjects' age and gender, and the use of corrective lenses had no distinguishably consistent effect within the 23 subjects in the study (Jacobs, et al., 1995). Benekohal et al. found that drivers' nighttime visibility of pavement markings decreases with drivers' age (Benekohal et al., 1992). Zwahlen and Schnell also reported that drivers' age had a highly significant effect on pavement marking visibility. Visibility of pavement markings for older drivers was affected more by the visual angle of the pavement markings than by their brightness. The average nighttime end detection distance for older drivers was only about half of that for younger drivers (Zwahlen, and Schnell, 1999).

Molino et al. used a driving simulator to study the visibility of pavement markings. They used curve recognition distance as primary driver performance measure. Strong and significant age effect was found, i.e., younger subjects had greater curve recognition distances than older and middle-age subjects (Molino et al., 2003). Another study revealed that older drivers adopt a less flexible searching strategy, which means they look at fewer items on the road than younger drivers do in a same give time, therefore it is important to provide older drivers with more redundant and brighter pavement markings (Migletz, Fish, and Graham, 1994). Through field subjective evaluation and quantitative measurements, Graham et al. recommended 121 mcd/m^2/lx as minimum retroreflectivity value for drivers aged 60 years or older (Graham, Harrold, and King, 1996). They also found that whereas the average subjective ratings were similarly distributed relative to the retroreflectivity of pavement markings, there was a significant difference in the subjective ratings made by older and younger drivers. Older drivers consistently rated the retroreflectivity of markings lower than younger drivers did.

It is reported that contrast sensitivity declines with age, i.e., contrast threshold value increases with ages. From Figure 5 it can be seen that the contrast value for a 65-year old is almost twice the value for a less than 23-year old (Adrian, 1989). Staplin et al. investigated the effect of marking contrast on the detection of road curves on photographic slides, found that older drivers required a significantly higher (20-30 percent) contrast than young/middle-aged drivers (Staplin, Lococo, and Sim, 1990). Using an interactive driving simulator and field evaluations, Freedman et al. investigated the noticeability requirements for delineation on nonilluminated highway. The study concluded that to achieve 3 seconds of preview distance for older drivers on wet roadways, a contrast level of 2.0 to 3.0 was appropriate (Freedman et al., 1988). Migletz et al. reported that a marking luminance contrast ratio of at least 2.0 was required for older drivers (Migletz et al., 1999). Staplin et al. recommended a contrast level of 5.0 or higher for edgelines on horizontal curves for highways without median separation of opposing direction of traffic, and a contrast level of 3.75 or higher for edgelines on horizontal curves for highways where median barriers effectively block the drivers' view of oncoming headlights or where median width exceeds 15 m (Staplin et al., 2001).

In all, the above shown that older drivers require brighter and higher contrast pavement markings.

4. METHODOLOGY

This study focused on investigating the effects of road marking luminance contrast on driving safety. Laboratory driving simulation experiments were designed and conducted to explore the effects. The primary driver performance measure was drivers' response time and response distance, although accuracy of responses was also recorded and considered as a subsidiary and complementary measure. From the findings, it intends to predict the timing and a threshold for road marking luminance contrast level that requires a repair or repaint on road markings so as to assure safe driving.

4.1 Experiment Design and Setup

The experiment involved two groups of factors, main factors and blocking factors (Table 3). Main factors included road marking contrast (five levels), color (white and yellow), configuration (four configurations, e.g., white single skip, white single solid, yellow skip and solid, and yellow double solid), and driving speed (45 mph and 60 mph). Blocking factors were drivers' age (20-40, 41-60, and over 60 years old) and gender (female and male).

In order to investigate the effects of the main factors, blocking factors, and their interactions, for each road marking color, a two-factor blocked factorial design was employed. The statistical model is shown below:

$$T = \mu + L + S + L \times S + A + G + A \times G + \varepsilon \qquad (6)$$

where:

T – subjects' response time, in second;

μ – overall mean, in second;

L – road marking luminance contrast level;

S – driving speed, in mph;

A – subjects' age;

G – subjects' gender;

ε – error.

The statistical model based on response time for each pavement marking configuration is shown below:

$$T = \mu + V + S + V\times S + A + G + A\times G + \varepsilon \quad (7)$$

where:

T – subjects' response time, in second;

μ – overall mean, in second;

V – road marking luminance contrast value;

S – driving speed, in mph;

A – subjects' age;

G – subjects' gender;

ε – error.

The experiments were conducted in the Driver Performance Laboratory at the University of Rhode Island. Figure 6 depicts the experiment setup. The digitized nighttime driving video was sent from a Dell Dimension 4500 desktop computer to an InFocus LP™ 350 digital projector (1024 × 768 pixel resolution, 1300 Lumens), and projected onto a screen in front of a stationary 1998 Ford Taurus SHO sedan. The steering wheel was taken apart and replaced with a mounted Sidewinder force feedback wheel which was connected to the computer with a USB cable. A test subject sat in the driver's seat of the test vehicle located 10 feet from the screen, was required to press one of the four pre-defined keys in the wheel to signify her/his comprehension of the road marking stimuli in the video.

4.2 Experiment Preparation

4.2.1 Video Stimuli

Driving videos were recorded at a midnight of June 2003. The sky was dark, overcast, and moonless. The white marking video was shot on a straight and flat two-lane segment of Route 1 southbound between Route 110 and Route 2, Rhode Island (Figure 7). The yellow marking video was shot on a straight and flat one-lane segment of Route 2 northbound between Route 138 and Route 102, Rhode Island (Figure 8). According to the year 2001 data, the 24 hour average daily traffic for these two road segments are 18500 and 11400 vehicles/day/lane respectively (RIDOT, 2001). Both road segments were dry-asphalt pavements and in dark rural areas, and there were no obvious landmarks along roadsides. Leveled at drivers' eye height, a Canon XL1 digital video camcorder mounted on a tripod inside a 2001 Chrysler Voyager minivan was used to record these videos. Because drivers tend to use the left markings of the traveling lane as the major guidance and source of information, the left markings of the traveling lanes were chosen as the markings under investigation. During the video recording, the vehicle drove in the center of the traveling lane at the speed of 45 mph (the speed limit) by employing cruise control, the vehicle's low-beam headlamps were the only source of illumination to provide the luminance contrast between the pavement markings and the road surface, and other vehicles were absent from both directions of travel on the roadway.

The digital videos were downloaded onto a Dell Dimension 4500 desktop computer (Intel® Pentium® 4 2.53GHz Processor, 1GB dual channel DDR SDRAM memory, and

Advanced 128MB DDR 8X AGP ATI™ RADEON™ 9800 Pro graphics cards). Four 10-second video segments (one segment per road marking configuration), were selected mainly based on visual quality and accuracy of traveling speed (45 mph). These video segments were then digitally edited separately using Sonic Foundry VideoFactory™ and Jasc® Paint Shop Pro™ 7, and finally rendered as 4 10-second "original/base" videos clips (in NTSC DV avi format, 720 × 480 resolution, and 29.970 fps). The contrasts of the markings under investigation in the videos were correspondent to these of the markings under investigation in the real road segments. These "original/base" videos covered 660 ft. (200 m) road segment each, and had the visual effect as: in the beginning 4 seconds, the left marking of the traveling lane (the markings to be investigated) was obliterated and thus was not shown on the road. At the starting moment of the 5th second, the leading edge of the left marking began to appear at a distance of about 66 ft. (20 m). The vehicle approached the marking's leading edge in 1.5 seconds, and continued driving in the lane center for 4.5 seconds to the end of the 10-second running time video.

For each marking under investigation, 4 additional artificial luminance contrast level effects were created separately by adjusting (decrease/increase 15% and 30%) the "original/base" video clip contrast using Sonic Foundry VideoFactory™ and Jasc® Paint Shop Pro™ 7, and rendered as 4 10-second "artificial" videos. Therefore, totally 5 luminance contrast levels were used for each marking configuration, i.e., 70% (30% down, level 1), 85% (15% down, level 2), original/base contrast (level 3), 115% (15% up, level 4), and 130% (30% up, level 5) of the original/base contrast (Figures 9 to 12). Totally there were 20 10-second digital videos corresponding to the driving speed of 45 mph, which included 4 "original/base" videos and 16 "artificial" videos.

By using the “Time Compressing” tool in Sonic Foundry VideoFactory™, each of these 20 10-second digital videos was shorten in length to 7.5-second and sped up to reach the 60 mph driving effect. The overall visual effect became that, in the beginning 3 seconds, the left marking of the traveling lane (the markings to be investigated) was obliterated and thus was not shown on the road. At the starting moment of the 4th second, the leading edge of the left marking began to appear at a distance of about 66 feet (20 meters). The vehicle approached the marking’s leading edge in 1.125 seconds, and continued driving in the lane center for 2.375 seconds to the end of the 7.5-second running time video. Again, these 20 7.5-second digital videos included 4 “original/base” videos and 16 “artificial” videos.

In all, the combination of 2 driving speeds with 4 marking configurations and 5 levels of marking contrast per marking configuration yielded 40 combinations of the three factors, and consequently a total of 40 digital videos were obtained. All these video clip files were in NTSC DV avi format, 720 × 480 pixel resolution, and 29.970 fps.

4.2.2 Road Marking Luminance Contrast Measurements

Soon after the recording of the nighttime driving videos, field measurement of the road markings and their surrounding pavement retroreflectances was conducted in a partly cloudy day. A Retrolux 1500 pavement marking retroreflectometer was used. The working principle of the retroreflectometer granted the measurement of retroreflectances during daylight conditions. The pavement was dry. All the markings are epoxy resins and are reapplied every two years. Compared with the white markings in Route 1, the yellow markings in Route 2 looked relatively new and were reapplied recently.

For each marking configuration, measurements of the road markings and their surrounding pavement retroreflectances were taken on three randomly chosen locations over the 660 ft. (200 m) road segment covered in the digital videos (see Figure 13). Marking luminance contrast was calculated for each location, and then the average value was taken as the "original/base" luminance contrast of the under-investigation marking in the "original/base" digital video (Tables 4 to 7). For each marking configuration, consequently 4 artificial luminance contrast values corresponding to the markings in the artificial digital videos were calculated (Table 8).

4.2.3 Subjects

A total of 36 subjects were recruited from the community to participate in the study. Table 9 exhibits the subjects' demographic information. The subjects were recruited from three age groups with 12 in each: young (20-40 years old), middle-age (41-60 years old), and old (above 60 years old). Each age group was gender balanced, i.e., 6 subjects for each gender. Each subject was required to have a valid driver license, nighttime driving experience on interstate highways, and with normal or near-normal vision. Before starting the experiment, each subject read and signed a consent form (see Appendix A), and was oriented with the procedures of the experiment.

4.3 Experiment Approach and Procedure

Each subject started the experiment with entering her/his demographical information through an interactive screen (see Figure 14). Afterwards, a 5-minute practice session was performed to familiarize the subject. If the subject did not make a response properly, e.g., if a response was made too early or too late, an error/warning message would appear on the screen (see Figure 15) to remind the subject about the mistake she/he just made, and to help prevent it from reoccurring. All of these made sure that every subject understood the experiment and procedures involved before the actual run. With the subject's consent, the actual experiment started.

During the practice and experiment, all lights inside the laboratory were turned off with only the interior light in the vehicle left on. Digital video stimuli were played using Microsoft Windows Media Player version 8.00.00.4487 on full screen view. A subject was required to press one of the four pre-defined buttons in the wheel to signify her/his comprehension of the color and configuration of the marking-under investigation in each video stimulus. Subjects were required to press button "1" for white single skip line markings, button "2" for white single solid line markings, button "3" for yellow skip and solid line markings, and button "4" for yellow double solid line markings. The play of a video stimulus would terminate when a response button was pressed during the video presentation. The next video stimulus would be played after a random elapse time between 1 and 5 seconds. If a response was made too early, i.e., before the appearance of the leading edge of the left marking, or too late, i.e., after a video reached its maximum play duration and stopped automatically, an error/warning message would appear on the screen to alert the subject about the mistake and to help prevent it from reoccurring. The subject's response time (the time between the start of a stimulus and the moment of the subject's response) and accuracy (the numbers of correct responses divided by the total numbers of runs) along with information on the video stimuli were recorded into a Microsoft Access database.

In each experiment, the 40 digital videos were presented with 3 repetitions each. Therefore for each subject, there were a total of 120 video stimuli presentations in a random consequence. Normally each experiment took about 40 minutes.

Aiming at obtaining a better understanding of subjects' experience with the experiment and actual driving in Rhode Island, a ten-question survey (see Appendix B) was given to each subject after the completion of an experiment.

4.4 The Follow-up Field Experiment

In addition to the aforementioned driving-simulation based laboratory experiment, a follow-up field experiment was performed aiming at capturing drivers' subjective evaluations of road marking quality at selected routes. All the selected routes were two-lane (one lane in one direction) rural roads (Figure 16).

Before the field experiments, following the aforementioned measuring strategy and procedures, field measurement of center road markings (double solid yellow) and their surrounding pavement retroreflectances was conducted on the selected routes in a partly cloudy day of November 2003. The same Retrolux 1500 pavement marking retroreflectometer was used. The pavement was dry. Marking luminance contrast was calculated for each route. These roads are listed in an increasing order of their contrast levels (Table 10).

The field experiments were conducted at nighttimes (ranged from 6:00 pm to 9:00 pm) of November 2003. 12 subjects (4 from each age group) participated in the field experiment. Each subject drove her/his own car. Each experiment started at the North Road northbound. Prior to the experiment, a project assistant, who sit on the passenger's seat, informed the subject that the contrast levels of the road markings were ranked in an increasing order, i.e., the higher the marking contrast value was, the higher the ranking of marking contrast level was. The contrast ranking of North Road, which was 3, was informed to each subject as a reference value in the marking quality evaluation. During the experiment, the subject drove in the center of a traveling lane at the speed of 25~30 mph (the speed limit). The vehicle's low-beam headlamps were the only source of illumination to provide the luminance contrast between the pavement markings and the road surface, and other vehicles were mostly absent from both directions of travel on the roadway. The subject was responsible for driving and marking quality evaluation, and the project assistant was in charge of recording the subject's responses (the rankings of marking contrast levels).

5. RESULTS AND ANALYSIS

5.1 Laboratory Driving Simulation Experiment Results and Analysis

Analysis of variance (ANOVA) based on response time and response distance (distance traveled in the response time at a given speed) were conducted for the white marking and the yellow marking. The results are shown in Tables 11 to 14. For the white marking, it found that marking luminance contrast level, driving speed, age, gender, and the interaction between age and gender were all significant at a 0.05 significance level. For the yellow marking, marking luminance contrast level, driving speed, age, gender, and their interaction were significant at a 0.05 significance level. For both the white and yellow marking, the main effect plots (Figures 17 to 20) show that, the marking with the highest contrast level took the least response time or distance. Driving at 60 mph responded faster than driving at 45 mph, but driving at higher speed took longer response distance. Older subjects took the longest response time or distance while younger subjects took the least. Females exhibited longer response time or distance than males did.

For each pavement marking configuration, ANOVA based on response time and response distance were conducted with the results shown in Tables 15 to 22. Table 23 summarizes the p values for the factors for each marking configuration. For the white single skip road marking, it found that marking luminance contrast, driving speed, subjects' age, and subjects' gender were significant at a 0.05 significance level. The interaction between age and gender was significant, while the interaction between luminance contrast and driving speed were not; for the white single solid road marking, it found that marking luminance contrast, driving speed, subjects' age, and subjects' gender were significant at a 0.05 significance level.

The interaction between age and gender was significant, while the interaction between luminance contrast and driving speed were not; for the yellow skip and solid road marking, it found that marking luminance contrast, driving speed, subjects' age, and subjects' gender were significant at a 0.05 significance level. The age-gender and luminance contrast-driving speed interactions were not significant; and for the yellow double solid road marking, it found that subjects' age, subjects' gender, the age-gender and luminance contrast-driving speed interactions were significant at a 0.05 significance level. The marking luminance contrast and driving speed were not significant.

Main effect plots using subjects' response time and response distance as the responses were shown in Figures 21 to 28.

All these main effect plots show similar patterns, i.e., generally speaking, subjects' responses (either response time or response distance) dropped with the increment of marking luminance contrast values, but at different rates during different contrast segments. The marking with the highest contrast level took the least response time or distance. It can be seen that, to get similar responses, subjects need much less contrast values from white markings than from yellow markings, i.e., white markings are more visible than yellow markings. Driving at 60 mph responded faster but with longer response distance than driving at 45 mph. As to the effects of age on responses, older subjects took the longest response time and response distance while younger subjects took the least. The effect of gender found that female subjects responded a little bit slower and needed longer response distance than male subjects.

Correlation analysis was conducted for each marking configuration to reveal the relationship between response distances and marking luminance contrast values, but found no meaningful correlations (Table 24).

For the white single skip marking, Figures 21 and 22 show that the largest changes in subjects' response occurred in the 0.939~1.271 segment, i.e., they dropped at the highest rate when the marking luminance contrast increased from 0.939 to 1.271, then the drop rate slowed down obviously. For the white single solid marking, Figures 23 and 24 show that subjects' responses did not always drop with the increment of marking luminance contrast values. The major reason for this is that, white single solid markings are often used as right edge line, they are seldom used as lane markings except on ramps or traffic intersections. For the major purpose of balancing, white single solid markings had to be digitally created in the videos. It was noticed that, during laboratory experiments, when the marking under investigation (the left markings of the traveling lane) was the white single solid line, some subjects still tended to look at the right marking (white single break line) and made responses. Therefore, the responses to white single solid markings were of little value, and the corresponding data were discarded and not considered for further analysis. Consequently, the responses-marking contrast relations for white single skip markings only was used to determine the minimum contrast value for white marking to warrant proper responses and assure safe driving.

In order to better investigate the threshold value for white marking luminance contrast, smooth 3rd order polynomial trendlines were added to the discrete points in Figures 21 and 22 respectively (see Figures 29 and 30). It is believed that the threshold white marking luminance contrast value is reached at the inflection point (turning point) for each curve, i.e., the x value at the moment of $y'' = f''(x) = 0$ is the threshold white marking luminance contrast value, because it is at this point that a curve changes from concave up to concave down. Therefore the threshold white marking luminance contrast values were calculated from the plots in Figures 29 and 30 as 1.12 and 1.11 respectively, which were rounded off to 1.1. When white markings' luminance contrast value is below this threshold, a repair or repaint on white road markings is needed.

Similarly, from responses w.r.t. marking contrast plots for yellow skip and solid marking in Figures 31 and 32, the threshold yellow skip and solid marking luminance contrast values were obtained as 3.54 and 3.49 respectively; and from responses w.r.t. marking contrast plots for yellow double solid marking in Figures 33 and 34, the threshold yellow skip and solid marking luminance contrast values were obtained as 3.34 and 3.30 respectively. Therefore, the minimum contrast value for yellow marking to warrant proper responses and assure safe driving can be estimated in the range of 3.3~3.5. When yellow markings' luminance contrast value is below this range, a repair or repaint on yellow road markings is needed.

Comparing with the aforementioned threshold luminance contrast values in 3.4, here a minimum marking contrast value or range is proposed for each marking color. It is noticed that luminance contrast threshold for yellow markings is much higher than that for white markings.

5.2 Survey Results and Analysis

Responses to Questions 1 to 6 are shown in Tables 25 to 30. The responses showed that, during the laboratory experiments, most of the subjects noticed the differences in road marking luminance contrast (Table 25), and most of them thought yellow marking was easier to identify. However, the laboratory simulation results found no significant different between the white marking and the yellow marking (Table 26). In real driving, yellow marking was easier to identify at daytime (Table 27) but white marking was easier to identify at night (Table 28). Road marking was ranked in the order from the most important to the least important in assisting driving, and they were: wet roads at night, rain day, dry roads at night, cloudy day, and sunny day (Table 29). Subjects could better identify road marking configurations when drove at 45 mph (Table 30).

Responses to Questions 7 to 10 are shown in Tables 31 to 34. The survey results showed that most subjects picked the picture with the highest luminance contrast level as the easiest one to identify. This agrees with the lab simulation results which found that the stimulus with the highest contrast level requires the least amount of response time. However, it did not find significant difference in accuracies with respect to stimulus with different contrast levels. On the whole, for each marking configuration, the profile of response percentages in the survey was in accordance with that of average response time to different road marking luminance contrast in the lab simulation. For each marking configuration, ANOVA for the differences between the real rankings and subjects' responses was conducted (Table 35). Age and gender were found not significant factors.

5.3 The Follow-up Field Experiment Results and Analysis

The results of the follow-up field experiments are shown in Table 36. Paired t-test analysis results shown that subjects were able to identify the correct ranks of the road sections with the highest and the lowest road marking luminance contrast. The identification of those road sections with medium marking luminance contrast were found inconsistent. The inconsistent result might be due to the short term memory effect, because the assessment of marking ranks were done in sequence and the ranking of the previous section might have a carry-over effect in the assessment on the current road section.

6. SUMMARY

Through a series of laboratory driving simulation-based experiments and field experiments, the effects of road marking luminance contrast on driving safety were studied. The conclusions and recommendations are summarized below:

Subjects' responses dropped with the increment of road marking luminance contrast values, but at different rates during different contrast segments. The marking with the highest contrast level took the least response time or distance. However, no meaningful correlations between response distances and marking luminance contrast values were found.

To get similar responses, subjects need much less contrast values from white markings than from yellow markings, i.e., white markings are more visible than yellow markings.

Driving at higher speed got faster responses but longer response distances.

Older subjects took the longest response time and response distances while younger subjects took the least.

Female subjects responded a little bit slower and needed longer response distances than males.

To warrant proper responses and assure safe driving, the minimum contrast values for white road marking and yellow road marking are estimated to be 1.1 and 3.3~3.5 respectively. When road markings' contrast values are below these thresholds, a repair or repaint on road markings might be needed.

In the end, it should be noticed that the aforementioned findings, conclusions, and recommendations are based on the driving simulation experiments under lowbeam headlight at night on dry straight and flat road conditions. Many factors, such as pavement marking width, location, material, road alignment, and weather, were not considered in the study. To better understand the effects of road marking luminance contrast on driving safety under these factors, further studies that can better simulate real driving scenario will be required.

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Table 1 Threshold retroreflectivity values used to define the end of pavement marking service life (Migletz, Harwood and Bauer, 2001)

Marking Color	Threshold Retroreflectivity Values* ($mcd/m^2/lux$)		
	Non-Freeway (≤ 40 mph)	Non-Freeway (≥ 45 mph)	Freeway (≥ 55 mph)
White	85	100	150
White with RRPMs** and/or lighting	30	35	70
Yellow	55	65	100
Yellow with RRPMs** and/or lighting	30	35	70

* The retroreflectivity values were measured at 30-m (98.4-ft.) geometry.
** RRPM: raised retroreflective pavement markers.

Table 2 Minimum retroreflectivity guidelines for pavement marking materials recommended by state, country, and city Agencies (Migletz and Graham, 2002)

Marking Color	Threshold Retroreflectivity Values* ($mcd/m^2/lux$)		
	Local and Minor Collector (30 mph)	Major Collector and Arterial (35-50 mph)	Highways, Freeways, and All Roads (55 mph)
White	Presence**	80	100
Yellow	Presence**	65	80

* The retroreflectivity values were measured at 30-m (98.4-ft.) geometry.

** Presence is a pavement marking visible at night, but with no retroreflectivity value.

Table 3 The factors and their levels in the experiment

Main Factors	Level
Road marking color	White, yellow
Road marking configuration*	White single skip line White single solid line Yellow skip & solid lines Yellow double solid lines
Road marking luminance contrast	5 levels per configuration
Driving speed	45 mph, 60 mph
Blocking Factors	Level
Subjects' age	20 – 40, 41 – 60, > 60 years old
Subjects' gender	Female, Male

* The marking width is 6 in. (150 mm). Skip markings consist of 10 ft. (3 m) line segments and 30 ft. (9 m) gaps.

Table 4 Measuring luminance contrast of white single skip marking on Route 1

Direction	*Westbound*		Weather Condition	*Sunny, partly cloudy*	
Pavement Condition	*Some cracking*	Marking Color	*White*	Marking Configuration	*Single skip*
Total Length (ft.)	*260*	Marking Material		*Epoxy*	

Sample	Location	Luminance Measurement								Luminance Contrast
		Marking				Pavement				
		1st	2nd	3rd	Average	1st	2nd	3rd	Average	
1	1	80	90	88		40	34	36		
	2	70	72	67		39	43	44		
	3	86	84	83		39	43	46		
	4					43	37	37		
	5					42	36	42		
	6				80.00	34	34	32	38.94	1.054
2	1	81	79	79		41	36	37		
	2	98	94	95		38	48	41		
	3	97	98	89		44	41	37		
	4					44	43	39		
	5					36	43	46		
	6				90.00	40	45	45	41.33	1.178
3	1	93	85	81		40	40	33		
	2	94	87	95		42	40	44		
	3	80	83	84		41	46	46		
	4					38	40	42		
	5					37	38	41		
	6				86.89	47	48	48	41.72	1.083
										1.105

Table 5 Measuring luminance contrast of white single solid marking on Route 1

Direction		*Westbound*			Weather Condition		*Sunny, partly cloudy*		
Pavement Condition		*Some cracking*	Marking Color	*White*	Marking Configuration		*Single solid*		
Total Length (ft.)		*260*	Marking Material				*Epoxy*		

Sample	Location	Luminance Measurement								Luminance Contrast
		Marking				Pavement				
		1st	2nd	3rd	Average	1st	2nd	3rd	Average	
1	1	129	131	130		25	26	22		
	2	138	132	137		34	40	39		
	3	130	141	141		29	33	34		
	4					38	32	37		
	5					32	35	38		
	6				134.33	33	32	29	32.67	3.112
2	1	122	127	133		28	29	21		
	2	116	119	122		22	29	31		
	3	127	127	127		26	29	31		
	4					23	21	19		
	5					30	32	30		
	6				124.44	31	36	34	27.89	3.462
3	1	138	138	138		36	38	36		
	2	137	134	148						
	3	132	133	137						
	4									
	5									
	6				137.22				36.67	2.742
										3.105

Table 6 Measuring luminance contrast of yellow skip solid marking on Route 2

Direction	*Northbound*		Weather Condition		*Sunny, no clouds*					
Pavement Condition	*Very good*		Marking Color	*Yellow*		Marking Configuration	*Skip and solid*			
Total Length (ft.)	*260*		Marking Material			*Epoxy*				
Sample	Location	Luminance Measurement								Luminance Contrast
		Marking				Pavement				
		1st	2nd	3rd	Average	1st	2nd	3rd	Average	
1	1	156	165	164		31	38	35		
	2	174	181	173		38	39	33		
	3	197	200	198		35	33	39		
	4	133	143	138		34	36	38		
	5	172	155	142		30	37	28		
	6	162	162	162	165.39	34	39	38	35.28	3.688
2	1	134	137	139		29	38	41		
	2	159	163	164		31	35	39		
	3	115	122	127		31	32	30		
	4	146	150	169		37	39	35		
	5	146	154	149		34	40	40		
	6	164	169	168	148.61	35	41	41	36.00	3.128
3	1	178	185	186		32	37	39		
	2	134	146	144		30	38	36		
	3	196	193	203		35	31	35		
	4	196	205	200		27	31	34		
	5	143	143	154		38	40	39		
	6	161	165	171	172.39	28	35	34	34.39	4.013
										3.610

Table 7 Measuring luminance contrast of yellow double solid marking on Route 2

Direction		*Northbound*			Weather Condition		*Sunny, no clouds*			
Pavement Condition		*Very good*		Marking Color	*Yellow*	Marking Configuration		*Double solid*		
Total Length (ft.)		*260*		Marking Material			*Epoxy*			
Sample	Location	Luminance Measurement								Luminance Contrast
		Marking				Pavement				
		1st	2nd	3rd	Average	1st	2nd	3rd	Average	
1	1	114	113	105		32	31	40		
	2	129	137	131		31	33	31		
	3	144	141	138		31	38	33		
	4	120	114	120		34	41	38		
	5	120	121	122		38	39	40		
	6	121	122	121	124.06	35	31	30	34.78	2.567
2	1	150	155	150		29	34	36		
	2	145	140	146		34	35	31		
	3	162	170	173		29	38	35		
	4	159	162	161		34	38	34		
	5	132	132	134		36	39	30		
	6	152	175	134	151.78	33	30	37	34.00	3.464
3	1	177	182	182		38	35	39		
	2	157	159	156		39	35	39		
	3	196	202	202		31	38	39		
	4	159	159	157		34	35	39		
	5	183	187	182		31	36	37		
	6	156	157	164	173.17	38	32	32	35.94	3.818
										3.283

Table 8 Road marking luminance contrast levels and values

Color	Configuration	Contrast Level	Contrast Value
White	Single skip	1	0.774*
		2	0.939*
		3	1.105**
		4	1.271*
		5	1.437*
	Single solid	1	2.174*
		2	2.639*
		3	3.105**
		4	3.571*
		5	4.037*
Yellow	Skip & solid	1	2.527*
		2	3.069*
		3	3.610**
		4	4.152*
		5	4.693*
	Double solid	1	2.298*
		2	2.791*
		3	3.283**
		4	3.775*
		5	4.268*

* Artificial luminance contrast values.
** Original/base luminance contrast values.

Table 9 Subject demographic information

Subject Number	Age	Gender	Wear Correction Lenses when Driving?	Driving Experience (in Years)
1	20~30	Female	Yes	5~10
2	20~30		Yes	> 10
3	20~30		No	5~10
4	20~30		Yes	1~5
5	31~40		Yes	1~5
6	31~40		No	< 1
7	20~30	Male	No	1~5
8	20~30		No	1~5
9	20~30		No	5~10
10	31~40		Yes	> 10
11	31~40		Yes	1~5
12	31~40		Yes	5~10
13	41~50	Female	No	> 10
14	41~50		No	> 10
15	41~50		Yes	> 10
16	51~60		Yes	> 10
17	51~60		Yes	> 10
18	51~60		Yes	> 10
19	41~50	Male	Yes	> 10
20	41~50		Yes	5~10
21	41~50		No	1~5
22	51~60		No	> 10
23	51~60		No	> 10
24	51~60		No	> 10
25	61~70	Female	Yes	> 10
26	61~70		No	> 10
27	61~70		Yes	> 10
28	61~70		Yes	> 10
29	61~70		Yes	> 10
30	61~70		Yes	> 10
31	61~70	Male	Yes	> 10
32	61~70		No	> 10
33	61~70		Yes	> 10
34	61~70		No	> 10
35	61~70		Yes	> 10
36	61~70		Yes	> 10

Table 10 Luminance contrast values and rankings of the selected routes for field experiment

Road Name	Luminance Contrast Value	Contrast Ranking
Dry Bridge Road (1)	0.11	1
Dry Bridge Road (2)	1.72	2
Indian Corner Road (1)	1.35	2
Indian Corner Road (2)	1.34	2
North Road	2.79	3*
Slocum Road	2.68	3
Stony Fort Road	4.83	4
Mill Pond Road	8.31	5
Bridge Road	8.87	5
Liberty Road	10.78	5

* The reference contrast level

Table 11 ANOVA based on response time for white marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast Level	4	12.4221	12.5105	3.1276	11.43	0.000*
Speed	1	7.4637	6.9543	6.9543	25.41	0.000*
Contrast Level×Speed	4	1.3497	1.3927	0.3482	1.27	0.279
Age	2	58.9607	61.6548	30.8274	112.63	0.000*
Gender	1	37.4753	37.9950	37.9950	138.82	0.000*
Age×Gender	2	16.3301	16.3301	8.1650	29.83	0.000*
Error	2039	558.0886	558.0886	0.2737		
Total	2053	692.0902				

* Significance level = 0.05

Table 12 ANOVA based on response distance for white marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast Level	4	75110	70966	17741	10.94	0.000*
Speed	1	296251	304543	304543	187.83	0.000*
Contrast Level×Speed	4	6101	6587	1647	1.02	0.398
Age	2	343670	359416	179708	110.84	0.000*
Gender	1	222533	225557	225557	139.12	0.000*
Age×Gender	2	96242	96242	48121	29.68	0.000*
Error	2039	3305957	3305957	1621		
Total	2053	4345864				

* Significance level = 0.05

Table 13 ANOVA based on response time for yellow marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast Level	4	17.5758	17.7803	4.4451	17.21	0.000*
Speed	1	2.5746	2.5008	2.5088	9.71	0.002*
Contrast Level×Speed	4	2.7913	2.9785	0.7446	2.88	0.021*
Age	2	53.4956	53.5174	26.7587	103.61	0.000*
Gender	1	31.4000	31.7280	31.7280	122.85	0.000*
Age×Gender	2	2.8135	2.8135	1.4067	5.45	0.004*
Error	2057	531.2539	531.2539	0.2583		
Total	2071	641.9046				

* Significance level = 0.05

Table 14 ANOVA based on response distance for yellow marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast Level	4	95187	97647	24412	15.92	0.000*
Speed	1	409623	411047	411047	268.15	0.000*
Contrast Level×Speed	4	10563	11776	2944	1.92	0.104
Age	2	317006	317110	158555	103.43	0.000*
Gender	1	180882	182962	182962	119.36	0.000*
Age×Gender	2	17806	17806	8903	5.81	0.000*
Error	2057	3153220	3153220	1533		
Total	2071	4184286				

* Significance level = 0.05

Table 15 ANOVA based on response time for white single skip marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	5.2432	5.2326	1.3081	6.54	0.000*
Speed	1	2.5791	2.4490	2.4490	12.24	0.000*
Contrast×Speed	4	0.1746	0.1683	0.0421	0.21	0.933
Age	2	20.4437	21.9542	10.9771	54.88	0.000*
Gender	1	14.2146	14.5703	14.5703	72.85	0.000*
Age×Gender	2	8.9113	8.9113	4.4557	22.28	0.000*
Error	1023	204.6155	204.6155	0.2000		
Total	1037	256.1820				

* Significance level = 0.05

Table 16 ANOVA based on response distance for white single skip marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	31887	30940	7735	6.41	0.000*
Speed	1	153166	155715	155715	128.99	0.000*
Contrast×Speed	4	1561	1911	478	0.40	0.812
Age	2	121046	129972	64986	53.83	0.000*
Gender	1	83516	85684	85684	70.98	0.000*
Age×Gender	2	53472	53472	26736	22.15	0.000*
Error	1023	1234920	1234920	1207		
Total	1037	1679570				

* Significance level = 0.05

Table 17 ANOVA based on response time for white single solid marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	8.9790	9.1555	2.2889	6.75	0.000*
Speed	1	5.2193	4.8244	4.8244	14.22	0.000*
Contrast×Speed	4	1.6523	1.8584	0.4646	1.37	0.242
Age	2	40.2876	41.3356	20.6678	60.93	0.000*
Gender	1	23.9956	23.8873	23.8873	70.42	0.000*
Age×Gender	2	8.5756	8.5756	4.2878	12.64	0.000*
Error	1001	339.5705	339.5705	0.3392		
Total	1015	428.2798				

* Significance level = 0.05

Table 18 ANOVA based on response distance for white single solid marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	53043	50152	12538	6.29	0.000*
Speed	1	141708	147055	147055	73.82	0.000*
Contrast×Speed	4	6472	7505	1876	0.94	0.439
Age	2	233046	239068	119534	60.00	0.000*
Gender	1	143601	142900	142900	71.73	0.000*
Age×Gender	2	49215	49215	24607	12.35	0.000*
Error	1001	1994172	1994172	1992		
Total	1015	2621256				

* Significance level = 0.05

Table 19 ANOVA based on response time for yellow skip & solid marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	20.9396	20.5679	5.1420	20.22	0.000*
Speed	1	3.7335	3.6897	3.6897	14.51	0.000*
Contrast×Speed	4	1.3304	1.3125	0.3281	1.29	0.272
Age	2	36.5437	36.1988	18.0994	71.16	0.000*
Gender	1	16.9156	16.9208	16.9208	66.52	0.000*
Age×Gender	2	0.2010	0.2010	0.1005	0.40	0.674
Error	1013	257.6636	257.6636	0.2544		
Total	1027	337.3273				

* Significance level = 0.05

Table 20 ANOVA based on response distance for yellow skip & solid marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	116928	115034	28758	18.84	0.000*
Speed	1	203059	202819	202819	132.85	0.000*
Contrast×Speed	4	3244	3141	785	0.51	0.725
Age	2	215080	213000	106500	69.76	0.000*
Gender	1	98720	98868	98868	64.76	0.000*
Age×Gender	2	969	969	485	0.32	0.528
Error	1013	1546500	1546500	1527		
Total	1027	2284501				

* Significance level = 0.05

Table 21 ANOVA based on response time for yellow double solid marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	1.7141	1.8468	0.4617	2.36	0.052
Speed	1	0.1220	0.1055	0.1055	0.54	0.463
Contrast×Speed	4	2.0396	2.2773	0.5693	2.91	0.021*
Age	2	19.4499	19.8264	9.9132	50.60	0.000*
Gender	1	13.8719	14.0934	14.0934	71.94	0.000*
Age×Gender	2	3.6349	3.6349	1.8174	9.28	0.000*
Error	1029	201.5779	201.5779	0.1959		
Total	1043	242.4102				

* Significance level = 0.05

Table 22 ANOVA based on response distance for yellow double solid marking

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Contrast	4	8056	9294	2323	1.99	0.094
Speed	1	206152	207859	207859	177.82	0.326
Contrast×Speed	4	10483	11912	2978	2.55	0.038*
Age	2	116028	118276	59138	50.59	0.000*
Gender	1	78785	80127	80127	68.55	0.000*
Age×Gender	2	23432	23432	11716	10.02	0.000*
Error	1029	1202801	1202801	1169		
Total	1043	1645737				

* Significance level = 0.05

Table 23 Summary of the p values of the factors for the markings

Factor or Interaction	P Value (on Response Time/Response Distance)			
	White Single Skip	White Single Solid	Yellow Skip & Solid	Yellow Double Solid
Contrast	0.000*/0.000*	0.000*/0.000*	0.000*/0.000*	0.052/0.094
Speed	0.000*/0.000*	0.000*/0.000*	0.000*/0.000*	0.463/0.326
Contrast×Speed	0.933/0.812	0.242/0.439	0.272/0.725	0.021*/0.038*
Age	0.000*/0.000*	0.000*/0.000*	0.000*/0.000*	0.000*/0.000*
Gender	0.000*/0.000*	0.000*/0.000*	0.000*/0.000*	0.000*/0.000*
Age×Gender	0.000*/0.000*	0.000*/0.000*	0.674/0.528	0.000*/0.000*

Table 24 Regression analysis to investigate the correlation between response distance and marking luminance contrast values

Marking	R^2	R^2 (Adj.)	Correlation
White single skip marking	1.8%	1.7%	No
White single solid marking	1.5%	1.4%	No
Yellow skip & solid marking	5.3%	5.2%	No
Yellow double solid marking	0.5%	0.4%	No

Table 25 Responses to survey question 1

Question: Did you notice that the road markings were presented in different luminance contrast?		
Responses	Frequency	Percentage (%)
Yes	27	75.0
No	5	13.9
Not Sure	4	11.1

Table 26 Responses to survey question 2 and the comparison with the responses in the laboratory experiments

Question: In the experiment, which marking color was easier to identify?			
Responses	Frequency	Percentage (%)	Accuracy of Responses in the Lab Experiments
Yellow	22	61.1	95.1
White	9	25.0	95.9
No difference	5	13.9	-
Not sure	0	0.0	-

Table 27 Responses to survey question 3

Question: In real driving at daytime, which marking color was easier to identify?		
Responses	Frequency	Percentage (%)
Yellow	19	52.8
White	9	25.0
No difference	6	16.7
Not sure	2	5.6

Table 28 Responses to survey question 4

Question: In real driving at night, which marking color was easier to identify?		
Responses	Frequency	Percentage (%)
Yellow	13	36.1
White	16	44.4
No difference	3	8.3
Not sure	4	11.1

Table 29 Responses to survey question 5

Question: Please rank the importance of road marking in assisting your driving in the following weather condition(s). Using a number from 1 to 5 for each weather condition (1 means the most important and 5 the least important).			
Weather Condition	Responses	Frequency	Percentage (%)
Sunny day	1	1	2.7
	2	2	5.4
	3	4	10.8
	4	7	18.9
	5	23	62.2
Cloudy day	1	3	8.2
	2	7	18.9
	3	9	24.3
	4	16	43.2
	5	2	5.4
Rain day	1	16	44.4
	2	11	30.6
	3	7	19.4
	4	1	2.8
	5	1	2.8
Night/Wet	1	30	83.3
	2	3	8.3
	3	1	2.8
	4	0	0.0
	5	2	5.6
Night/Dry	1	10	27.8
	2	11	30.6
	3	13	44.4
	4	2	5.6
	5	0	0.0

Table 30 Responses to survey question 6 and the comparison with the responses in the laboratory experiments

Question: In which of the following driving speed can you best identify a road marking configuration?			
Responses	Frequency	Percentage (%)	Accuracy of Responses in the Lab Experiments
45 mph	18	50.0	95.2
60 mph	4	11.1	95.8
No difference	9	25.0	-
Not sure	5	13.9	-

Table 31 Responses to survey question 7 and the comparison with the responses in the laboratory experiments

Question: When looking at the white single solid markings on the left of the traveling lanes, which one is the easiest to identify?						
Slide #	Marking Luminance Contrast	Real Ranking	Frequency of Subjects' Response	Percentage (%)	Accuracy of Responses in the Lab Experiments	Average Response Time in the Lab Experiments (second)
#1	3.571	4	3	8.3	94.4	1.594
#2	2.639	2	2	5.6	92.1	1.647
#3	2.174	1	2	5.6	93.1	1.653
#4*	4.037	5	29	80.6	96.3	1.397
#5	3.105	3	0	0.0	94.4	1.589

* Indicates the correct response

Table 32 Responses to survey question 8 and the comparison with the responses in the laboratory experiments

Question: When looking at the yellow double solid markings on the left of the traveling lanes, which one is the easiest to identify?						
Slide #	Marking Luminance Contrast	Real Ranking	Frequency of Subjects' Response	Percentage (%)	Accuracy of Responses in the Lab Experiments	Average Response Time in the Lab Experiments (second)
#1	2.791	2	0	0.0	95.8	1.393
#2*	4.268	5	17	47.2	96.3	1.302
#3	3.283	3	3	8.3	98.1	1.362
#4	2.298	1	0	0.0	96.3	1.398
#5	3.775	4	16	44.5	96.8	1.309

* Indicates the correct response

Table 33 Responses to survey question 9 and the comparison with the responses in the laboratory experiments

Question: When looking at the white single skip markings on the left of the traveling lanes, which one is the easiest to identify?						
Slide #	Marking Luminance Contrast	Real Ranking	Frequency of Subjects' Response	Percentage (%)	Accuracy of Responses in the Lab Experiments	Average Response Time in the Lab Experiments (second)
#1*	1.437	5	16	44.5	97.2	1.365
#2	0.939	2	3	8.3	96.3	1.535
#3	0.774	1	0	0.0	94.9	1.529
#4	1.105	3	5	13.9	96.3	1.456
#5	1.271	4	12	33.3	95.8	1.382

* Indicates the correct response

Table 34 Responses to survey question 10 and the comparison with the responses in the laboratory experiments

Question: When looking at the yellow skip & solid markings on the left of the traveling lanes, which one is the easiest to identify?						
Slide #	Marking Luminance Contrast	Real Ranking	Frequency of Subjects' Response	Percentage (%)	Accuracy of Responses in the Lab Experiments	Average Response Time in the Lab Experiments (second)
#1	2.527	1	1	2.8	96.8	1.899
#2	3.610	3	3	8.3	95.8	1.714
#3	4.152	4	10	27.8	97.2	1.568
#4*	4.693	5	21	58.3	89.8	1.508
#5	3.069	2	1	2.8	96.3	1.793

* Indicates the correct response

Table 35 ANOVA for the differences between real rankings and subjects' responses to survey questions 7 to 10

Survey Question #	Marking Configuration	ANOVA						
		Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
#7	White single solid	Age (A)	2	0.722	0.722	0.361	0.25	0.780
		Gender (G)	1	0.028	0.028	0.028	0.02	0.890
		A×G	2	1.056	1.056	0.528	0.37	0.696
		Error	30	43.167	43.167	1.439		
		Total	35	44.972				
#8	Yellow double solid	Age (A)	2	0.3889	0.3889	0.1944	0.24	0.786
		Gender (G)	1	0.4444	0.4444	0.4444	0.56	0.462
		A×G	2	0.3889	0.3889	0.1944	0.24	0.786
		Error	30	24.0000	24.0000	0.8000		
		Total	35	25.2222				
#9	White single skip	Age (A)	2	0.3889	0.3889	0.1944	0.22	0.806
		Gender (G)	1	1.3611	1.3611	1.3611	1.52	0.227
		A×G	2	0.3889	0.3889	0.1944	0.22	0.806
		Error	30	26.8333	26.8333	0.8944		
		Total	35	28.9722				
#10	Yellow skip & solid	Age (A)	2	0.389	0.389	0.194	0.19	0.825
		Gender (G)	1	0.694	0.694	0.694	0.69	0.413
		A×G	2	1.056	1.056	0.528	0.52	0.597
		Error	30	30.167	30.167	1.006		
		Total	35	32.306				

Table 36 The follow-up field experiment result and analysis

Subjects' Information		Road Name	North Road*	Stony Fort Road	Slocum Road	Bridge Road	Mill Pond Road
		Marking Contrast	2.785	4.833	2.678	8.865	10.302
Age	Gender	Real Ranking	3*	4	3	5	5
20-40	Female	Subjects' Rankings on Road Marking Contrast Level	3	3	4	5	5
			3	4	5	5	5
	Male		3	3	3	5	5
			3	4	5	5	5
41-60	Female		3	4	4	5	5
			3	4	4	5	5
	Male		3	4	4	5	5
			3	4	4	5	5
Over 60	Female		3	3	4	5	5
			3	4	3	5	5
	Male		3	4	4	5	5
			3	4	4	5	5
Percentage of Correct Ranking (%)			100	75.0	16.7	100	100
Paired t-test result	T-Value		-	1.91	-5.74	-	-
	P-Value		-	0.082	0.00**	-	-
	Difference between the real ranking and subjects' rankings?		No	No	Yes	No	No

* The reference ranking (to be continued)

** Significance level = 0.05

Table 36 The follow-up field experiment result and analysis (continued)

Subjects' Information		Road Name	Liberty Road	Dry Bridge Road (1)	Dry Bridge Road (2)	Indian Corner Road (1)	Indian Corner Road (2)
		Marking Contrast	10.780	0.107	1.720	1.350	1.339
Age	Gender	Real Ranking	5	1	2	2	2
20-40	Female	Subjects' Rankings on Road Marking Contrast Level	4	1	3	2	3
			5	1	3	2	2
	Male		5	1	2	2	2
			4	1	3	2	2
41-60	Female		4	1	2	2	2
			5	1	2	2	2
	Male		5	1	3	2	2
			5	1	3	2	3
Over 60	Female		5	1	3	3	2
			5	1	3	2	2
	Male		5	1	3	2	2
			5	1	3	2	3
Percentage of Correct Ranking (%)			75.0	100	25.0	91.7	75.0
Paired t-test result	T-Value		1.91	-	-5.74	-1.00	-1.91
	P-Value		0.082	-	0.000**	0.339	0.082
	Difference between the real ranking and subjects' rankings?		No	No	Yes	No	No

** Significance level = 0.05

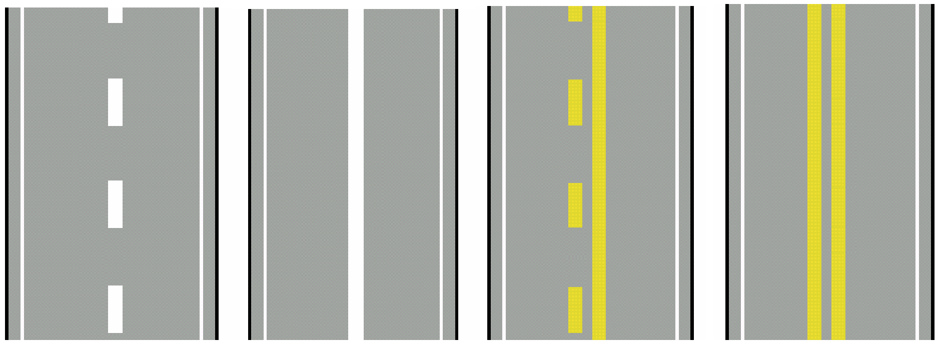


Figure 1 Common color and configuration of pavement markings

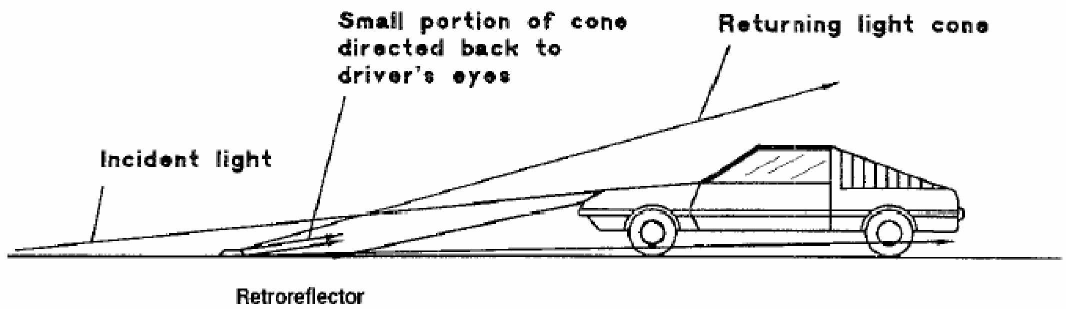


Figure 2 Retroreflectivity of pavement marking (Migletz, Fish, and Graham, 1994)

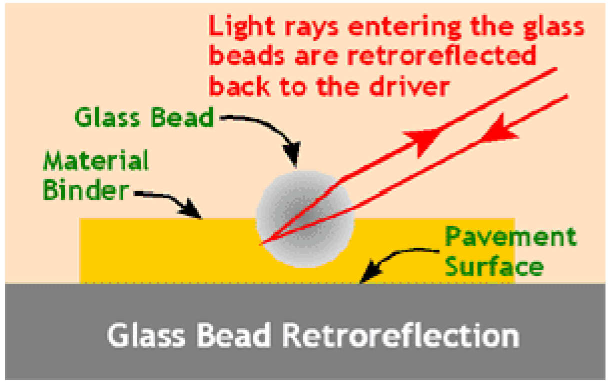


Figure 3 Glass bead retroreflection (Thomas and Schloz, 2001)

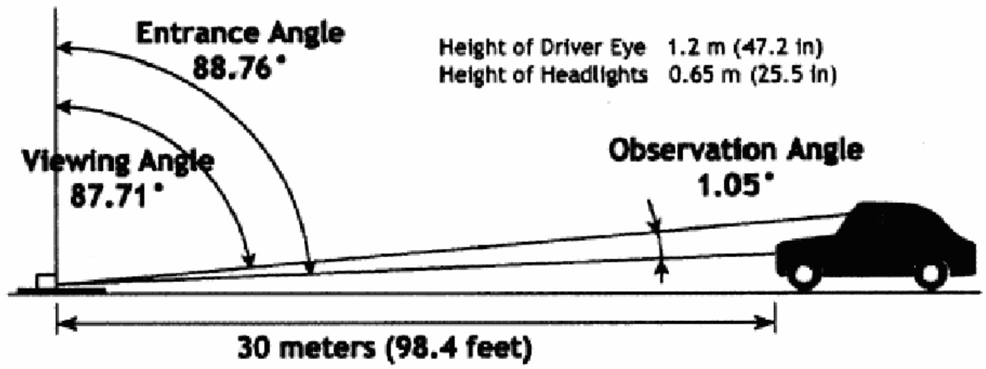


Figure 4 The Standard 30-m measurement geometry for pavement marking retroreflectivity (Hawkins and Womack, 2002)

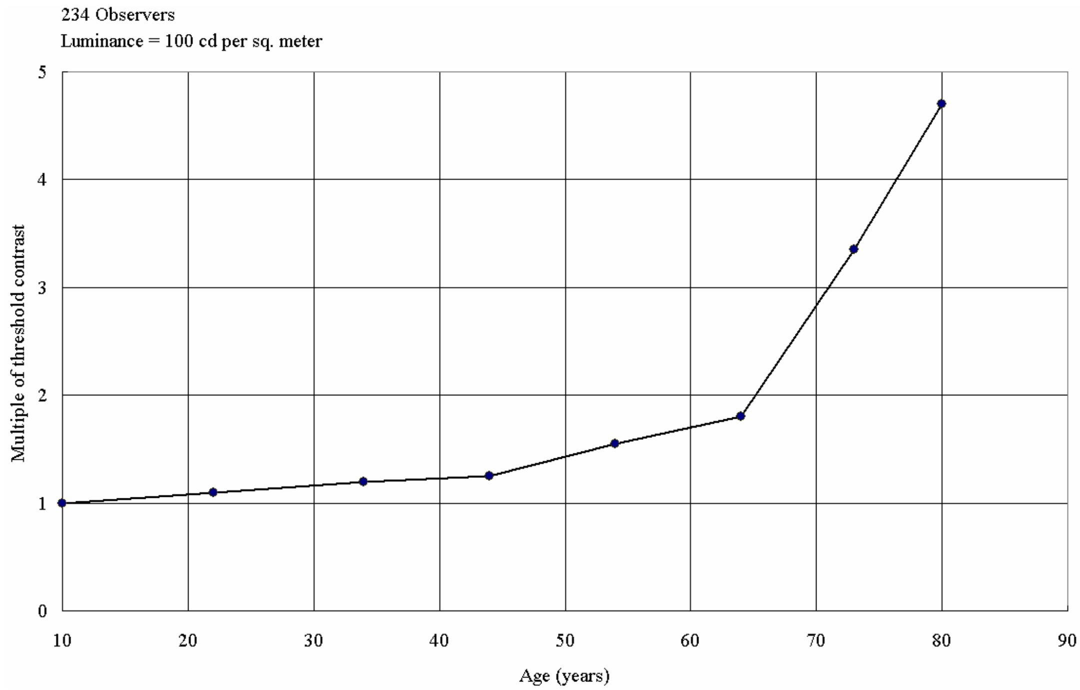


Figure 5 Increasement of contrast threshold with age (Adrian, 1989)

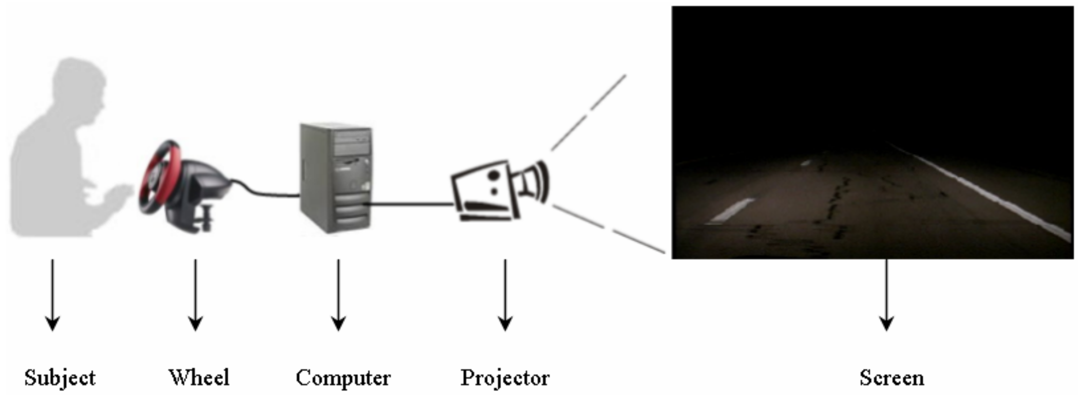


Figure 6 Experiment setup

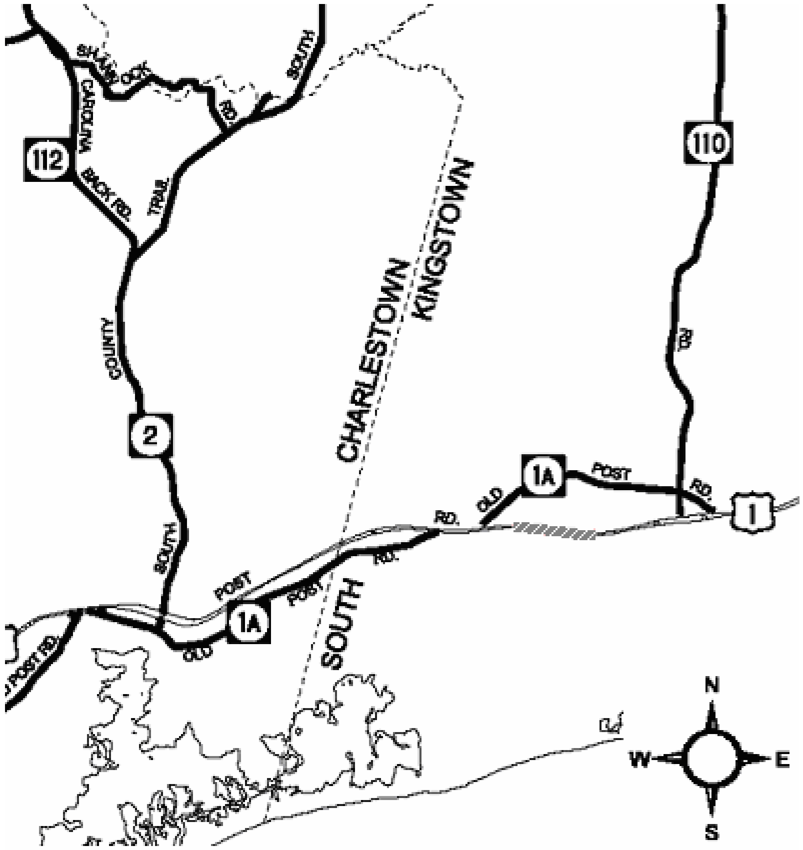


Figure 7 Marking luminance contrast measurement locations in Route 1 of Rhode Island (shaded section)

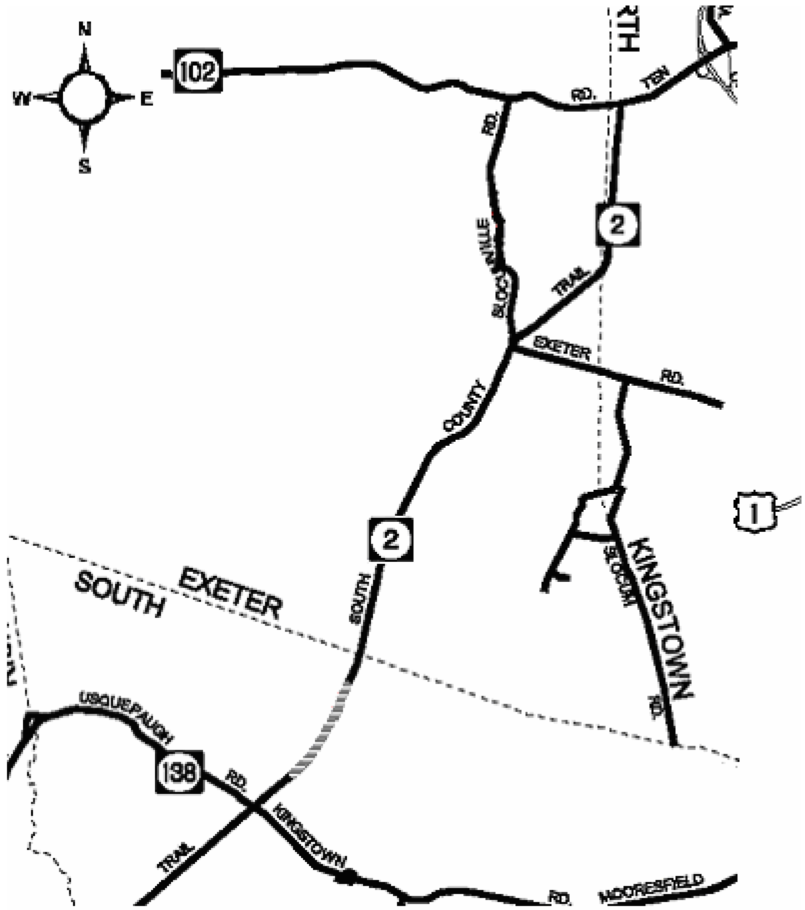
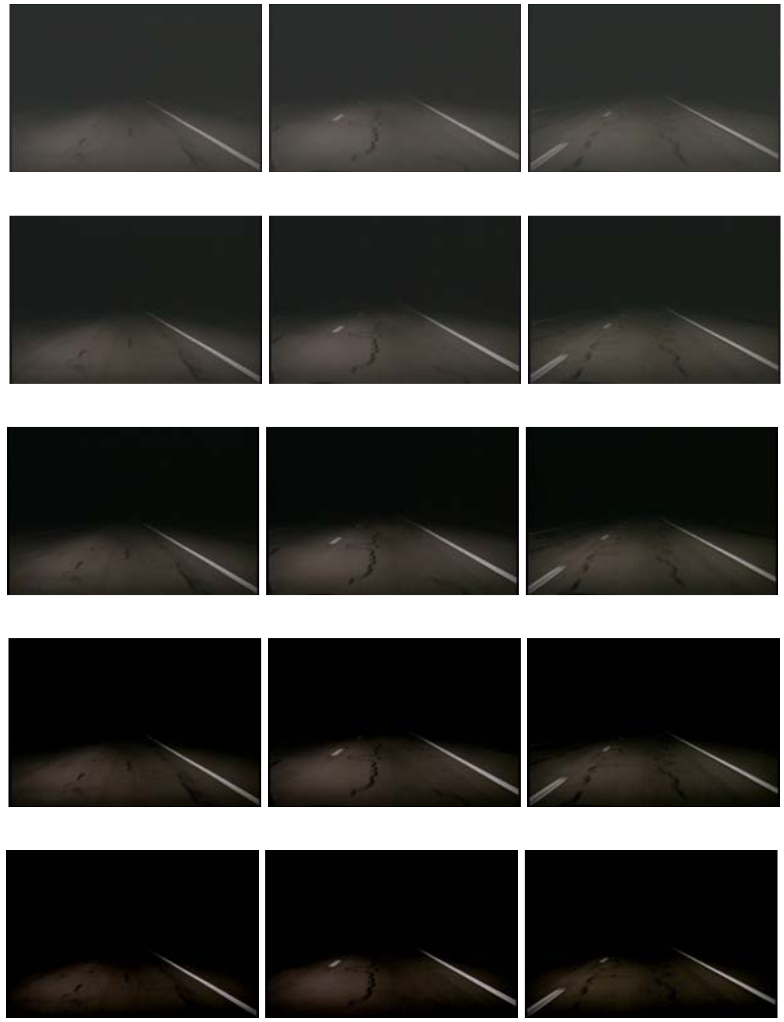


Figure 8 Marking luminance contrast measurement locations in Route 2 of Rhode Island (shaded section)



-30% (Level 1)

-15% (Level 2)

Original (Level 3)

+15% (Level 4)

+30% (Level 5)

0 ~ 4 second | 4 ~ 5.5 second | 5.5 ~ 10 second

Figure 9 Still images of a 10-second video showing the white single skip marking lines in different time and contrast levels

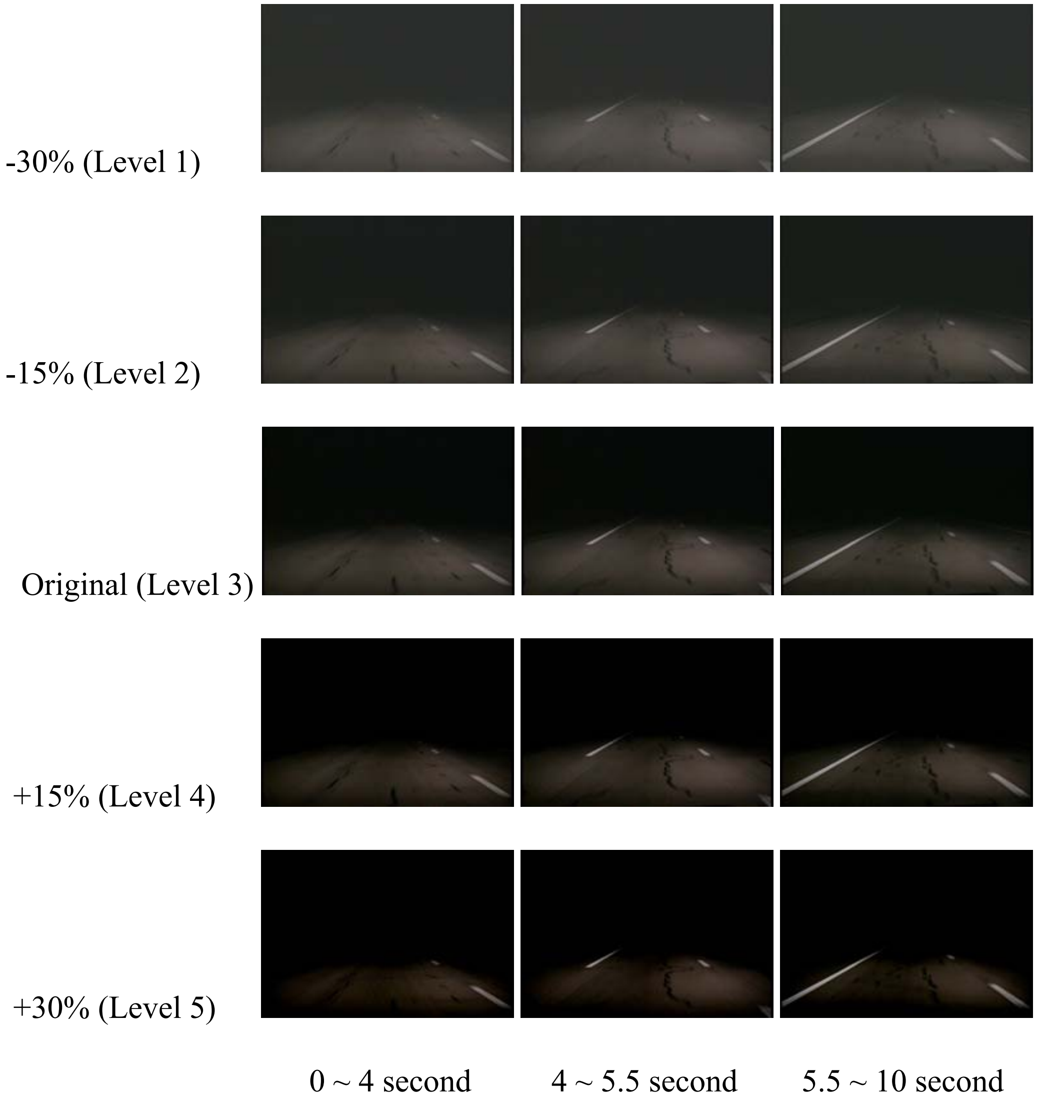
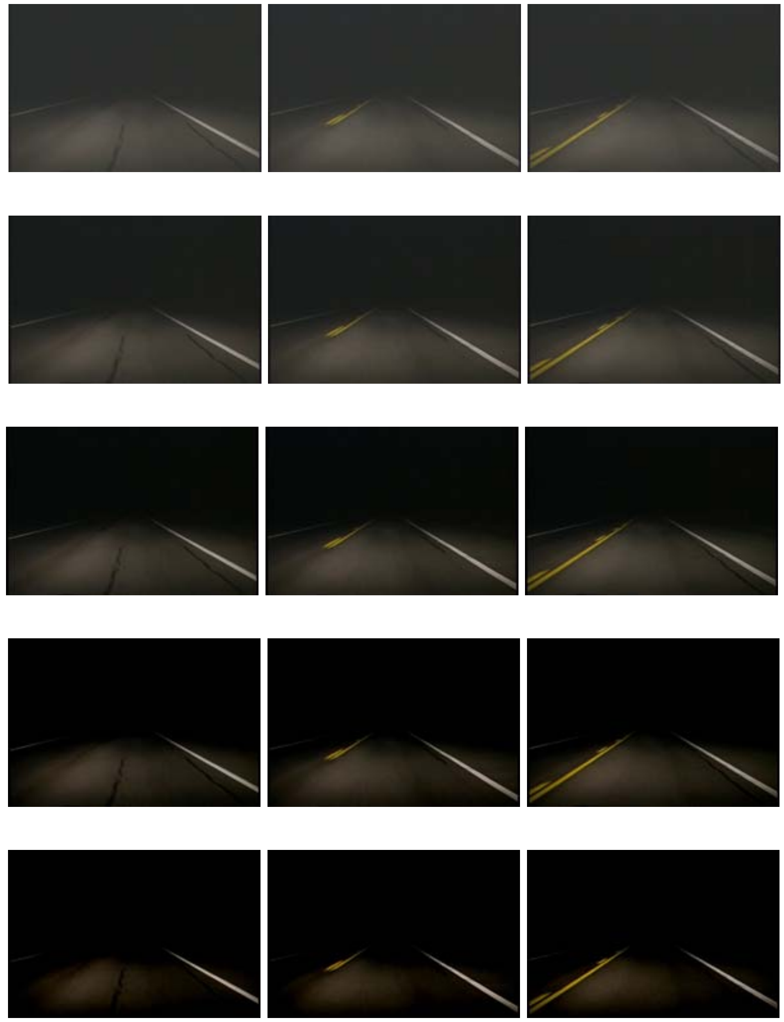


Figure 10 Still images of a 10-second video showing the white single solid marking lines in different time and contrast levels



-30% (Level 1)

-15% (Level 2)

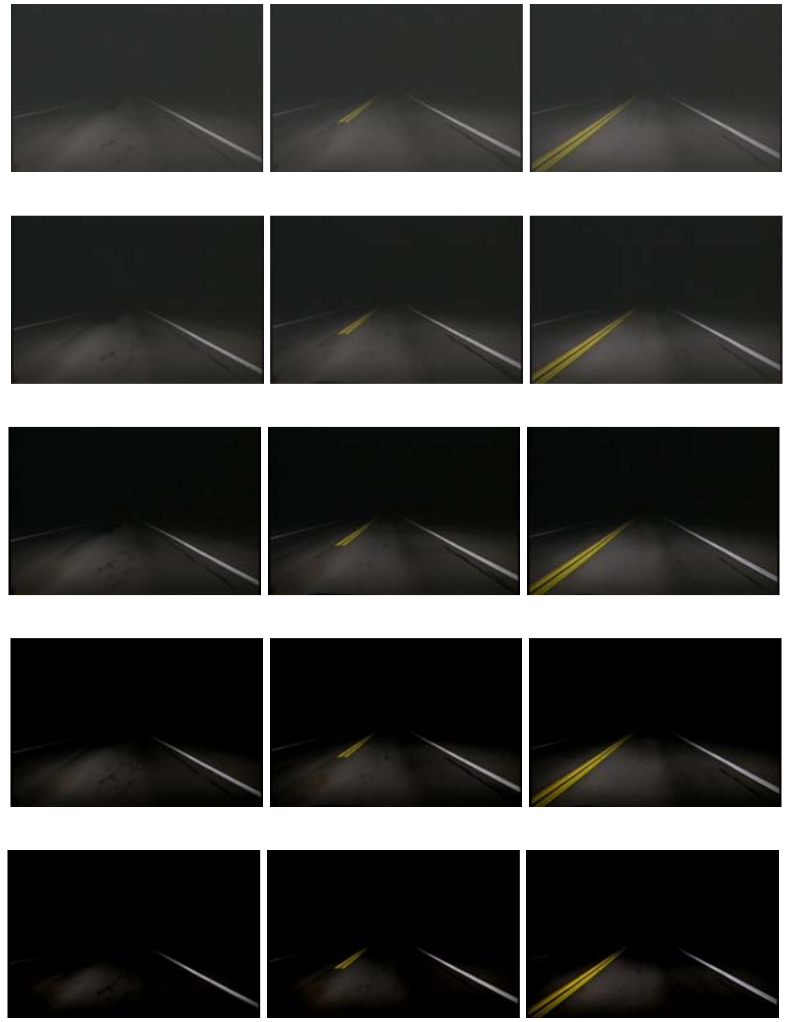
Original (Level 3)

+15% (Level 4)

+30% (Level 5)

0 ~ 4 second | 4 ~ 5.5 second | 5.5 ~ 10 second

Figure 11 Still images of a 10-second video showing the yellow skip & solid marking lines in different time and contrast levels



-30% (Level 1)

-15% (Level 2)

Original (Level 3)

+15% (Level 4)

+30% (Level 5)

0 ~ 4 second 4 ~ 5.5 second 5.5 ~ 10 second

Figure 12 Still images of a 10-second video showing the yellow double solid marking lines in different time and contrast levels

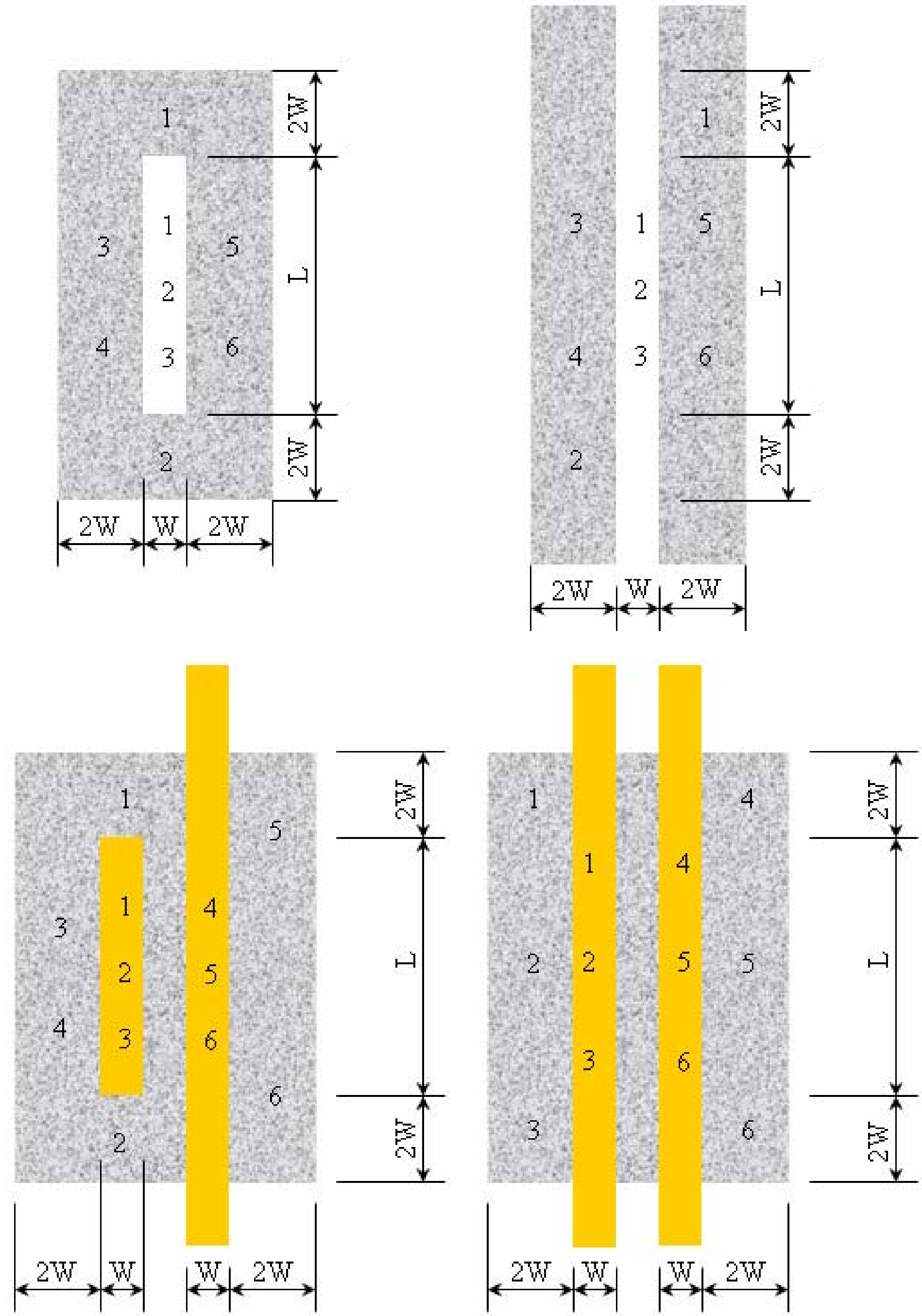


Figure 13 Road marking luminance contrast measurement (not drawn to the scale)
(In Rhode Island, W = 6 inches, L = 10 feet)

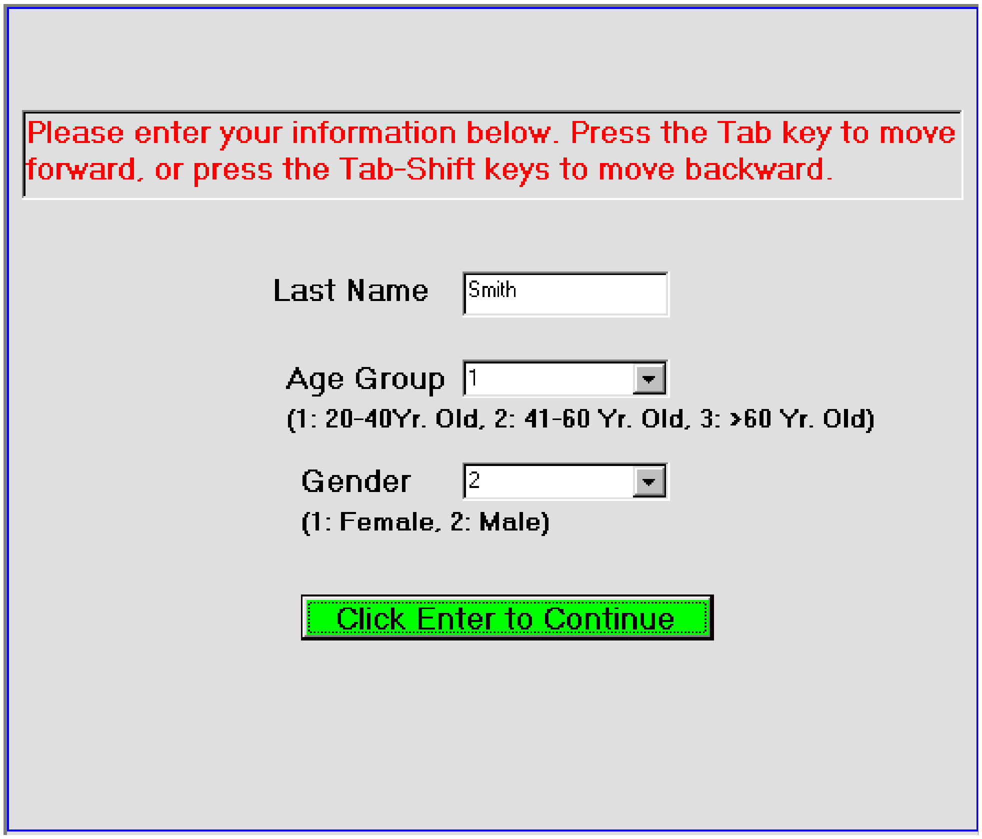


Figure 14 The subject demographic information input window

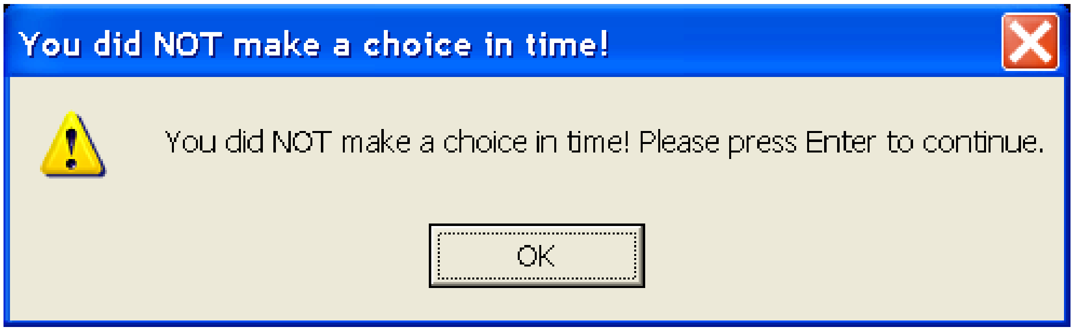


Figure 15 The error message window when a response was not made in time

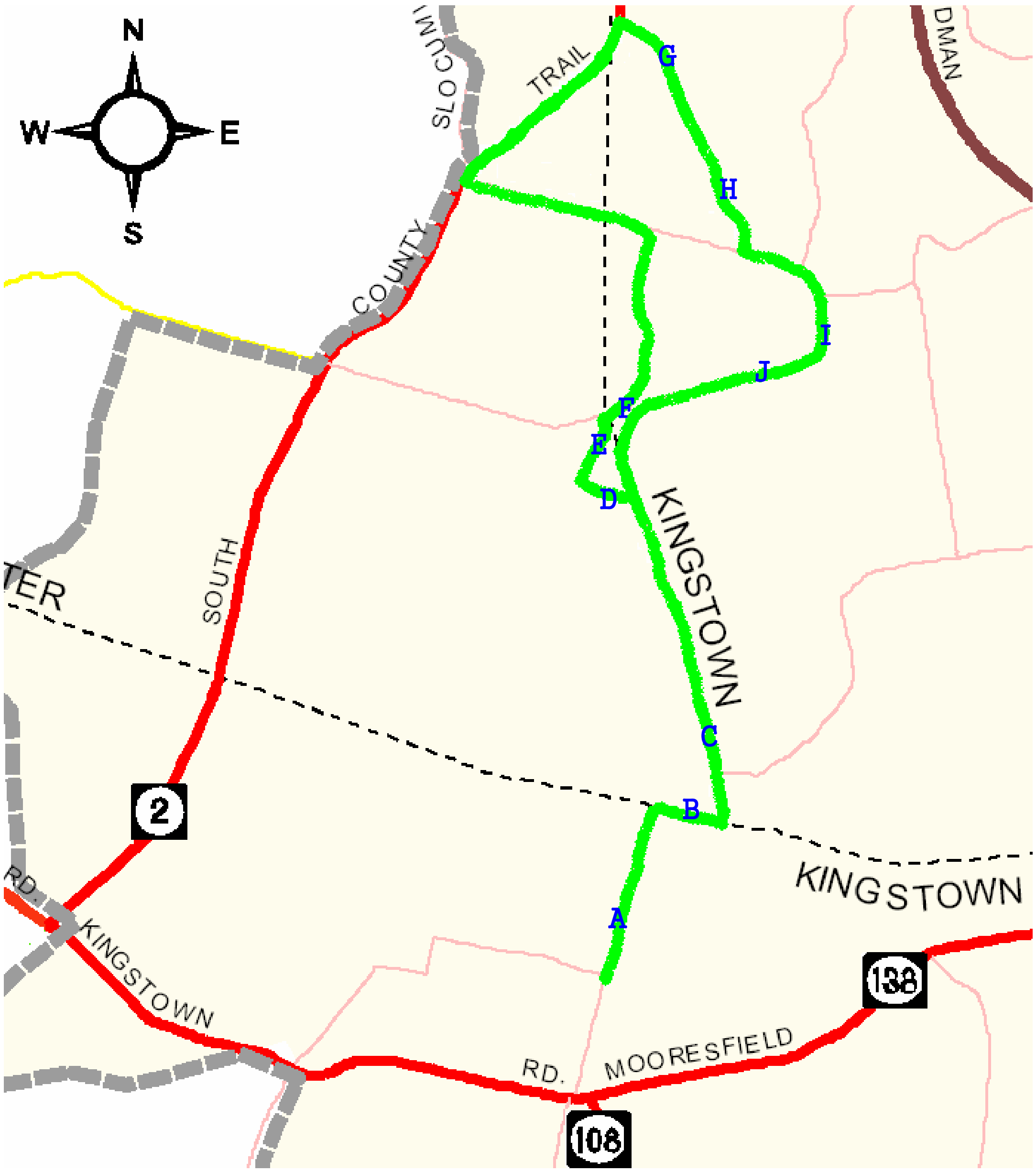


Figure 16 Selected routes (in green color) and marking assessment sections (in blue capital letters) in the field experiment*

* A – North Road; B – Stony Fort Road; C – Slocum Road; D – Bridge Road; E – Mill Pond Road; F – Liberty Road; G – Dry Bridge Road (1); H – Dry Bridge Road (2); I – Indian Corner Road (1); J – Indian Corner Road (2).

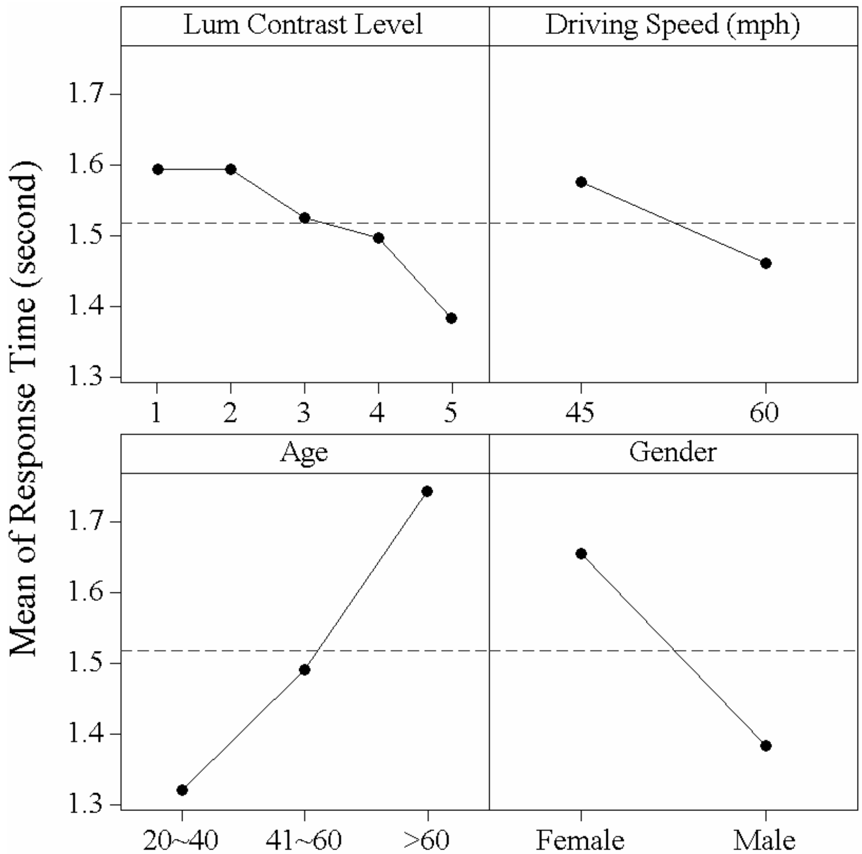


Figure 17 Main effect plots w.r.t response time for white marking

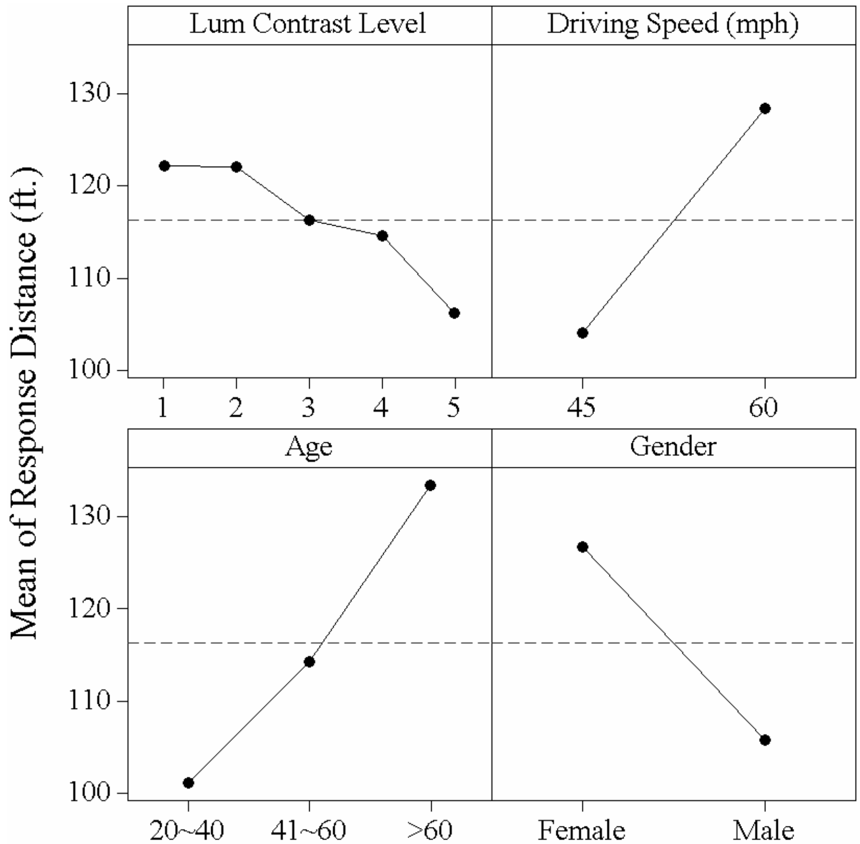


Figure 18 Main effect plots w.r.t response distance for white marking

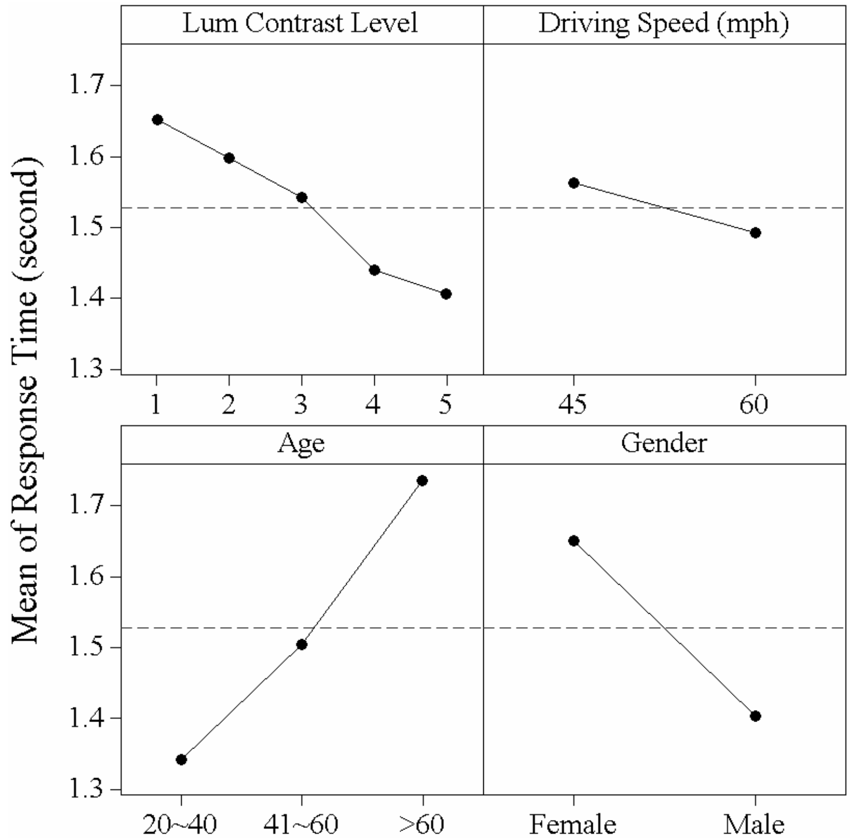


Figure 19 Main effect plots w.r.t response time for yellow marking

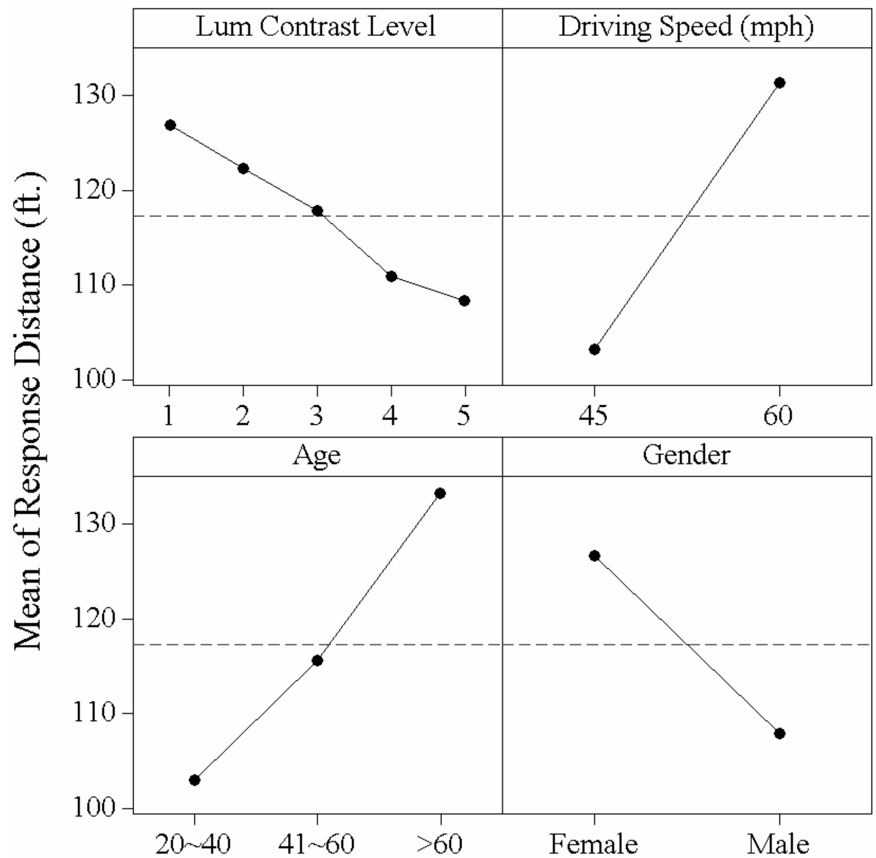


Figure 20 Main effect plots w.r.t response distance for yellow marking

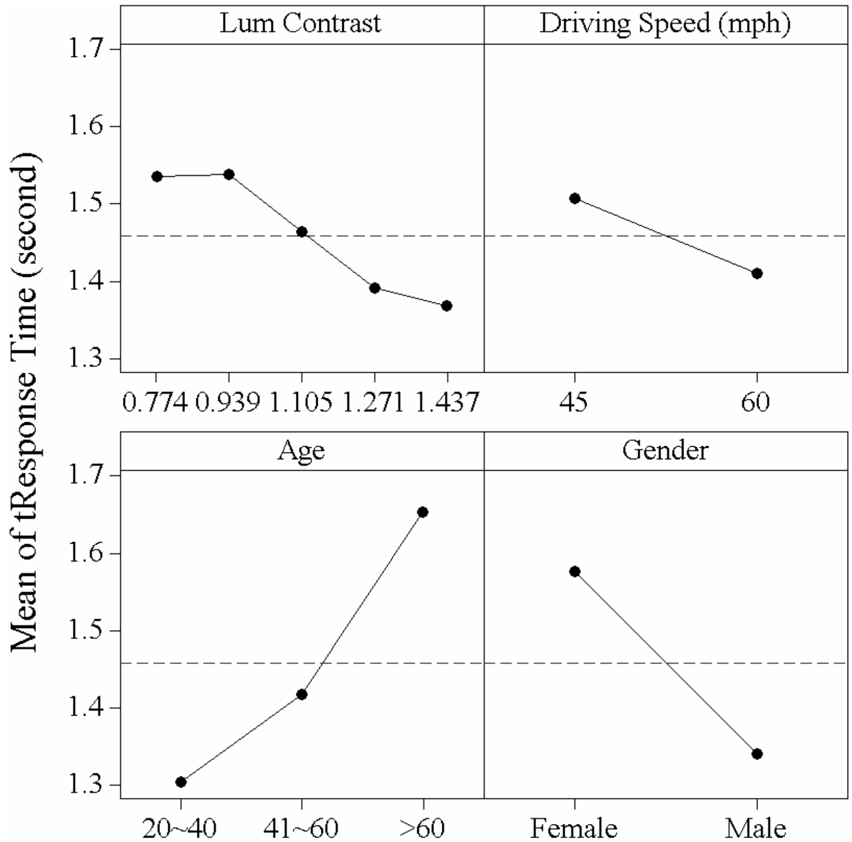


Figure 21 Main effect plots w.r.t response time for white single skip marking

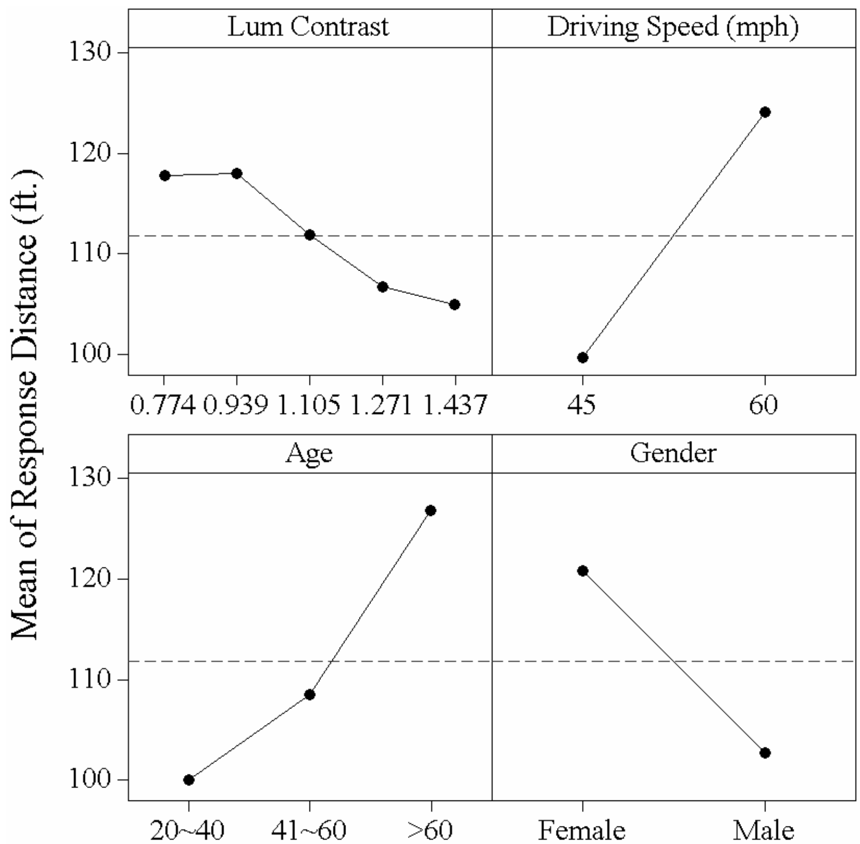


Figure 22 Main effect plots w.r.t response distance for white single skip marking

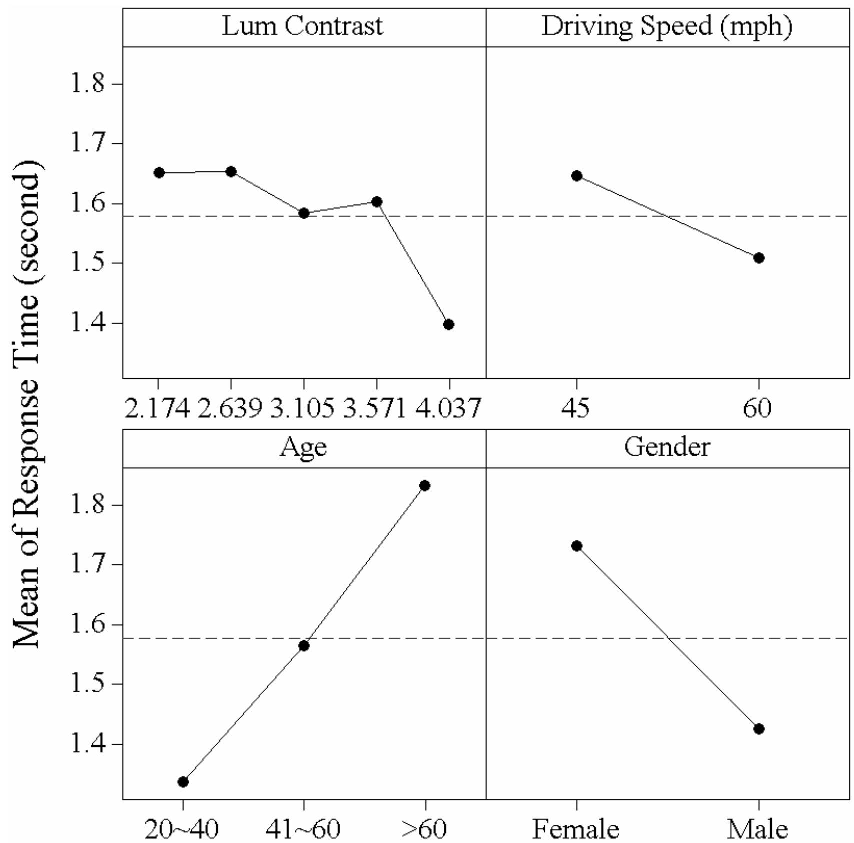


Figure 23 Main effect plots w.r.t response time for white single solid marking

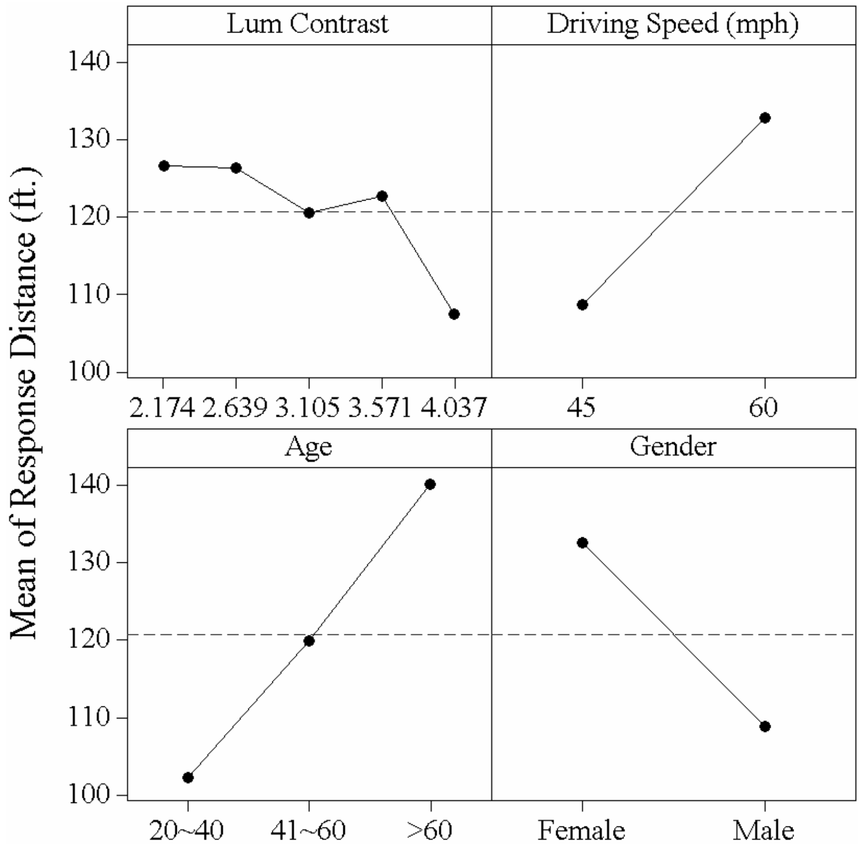


Figure 24 Main effect plots w.r.t response distance for white single solid marking

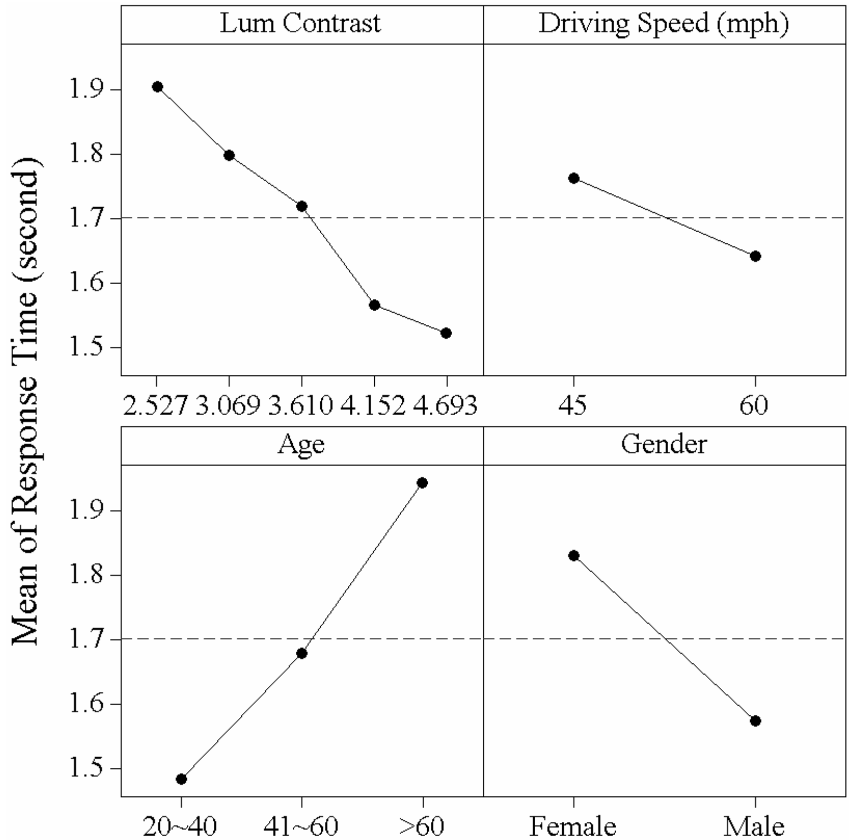


Figure 25 Main effect plots w.r.t response time for yellow skip & solid marking

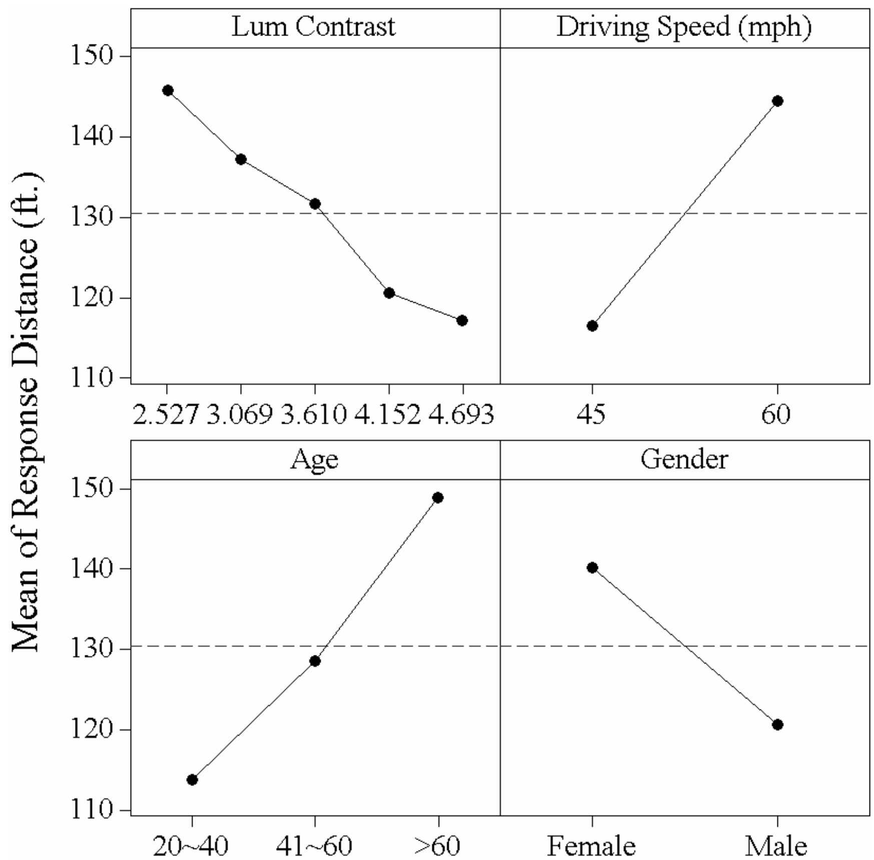


Figure 26 Main effect plots w.r.t response distances for yellow skip & solid marking

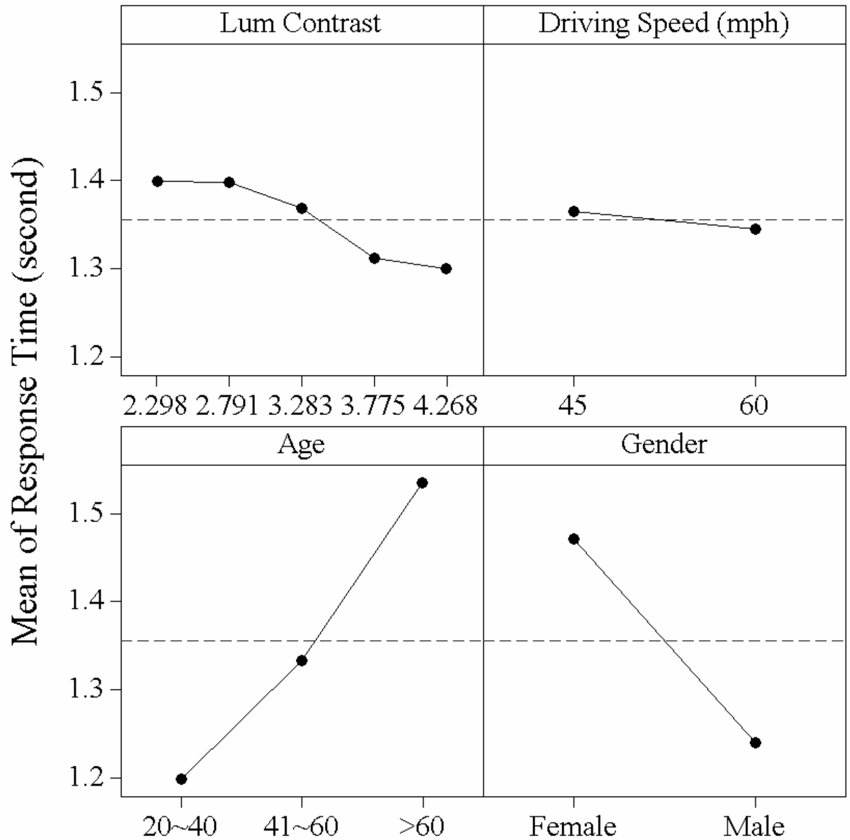


Figure 27 Main effect plots w.r.t response time for yellow double solid marking

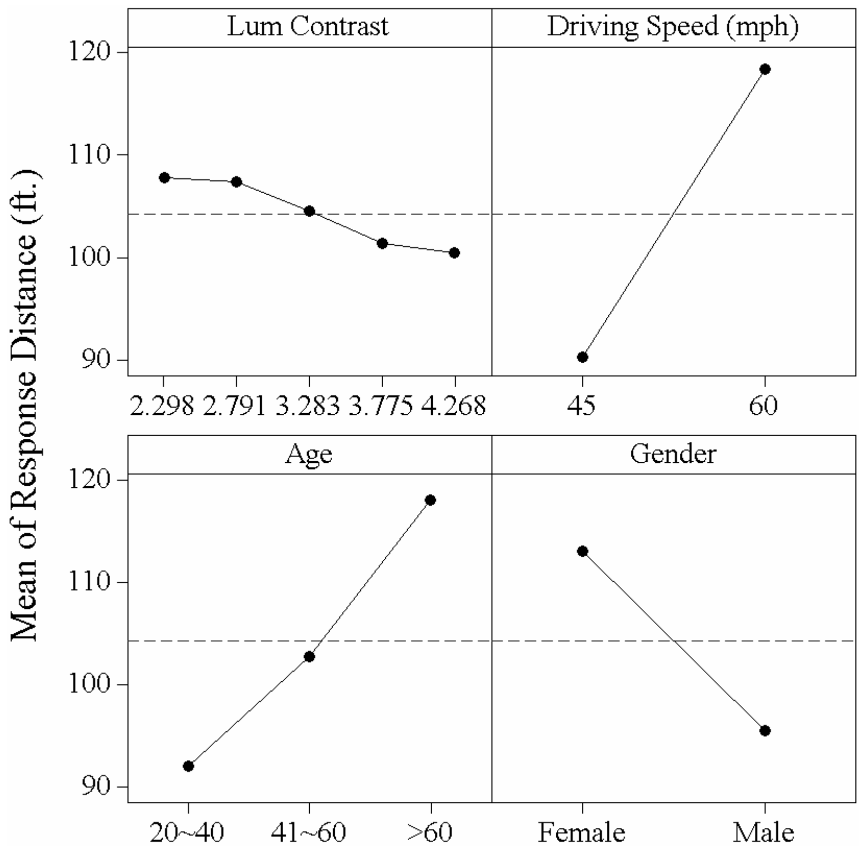


Figure 28 Main effect plots w.r.t response distance for yellow double solid marking

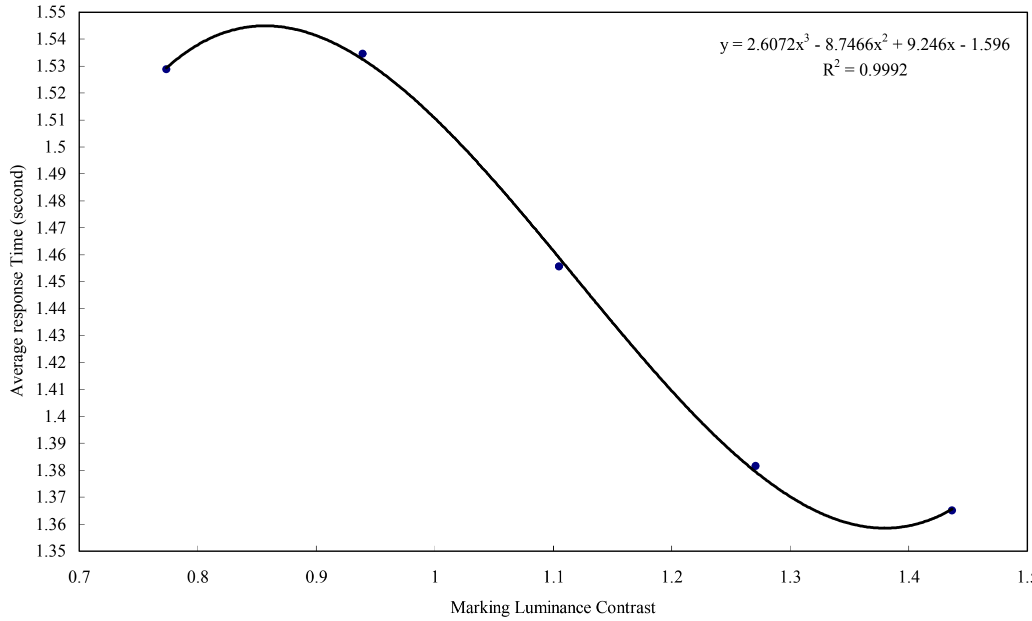


Figure 29 Marking luminance contrast w.r.t response time for white single skip marking

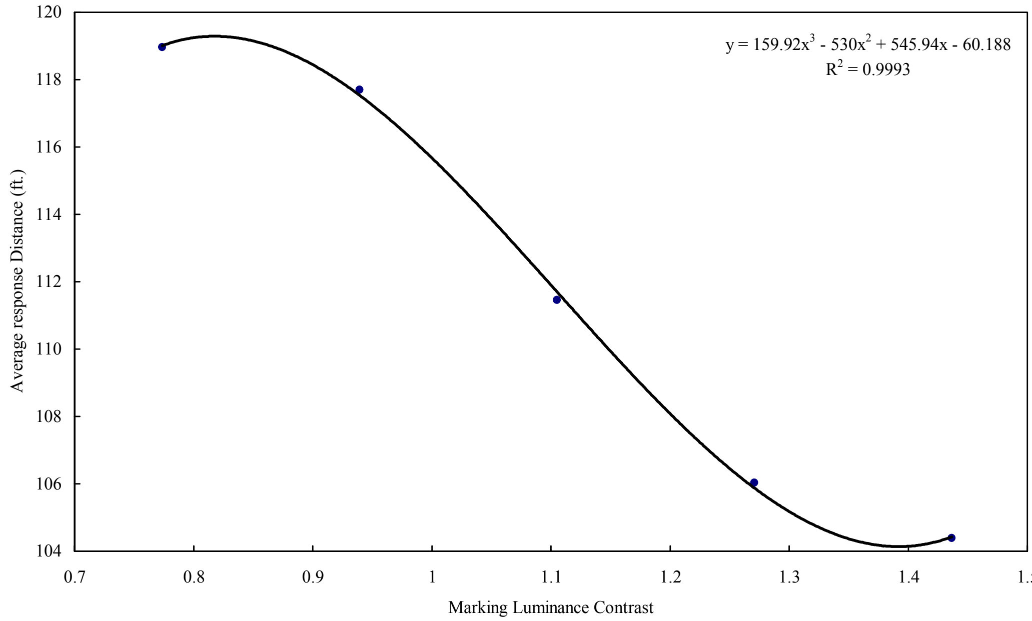


Figure 30 Marking luminance contrast w.r.t response distance for white single skip marking

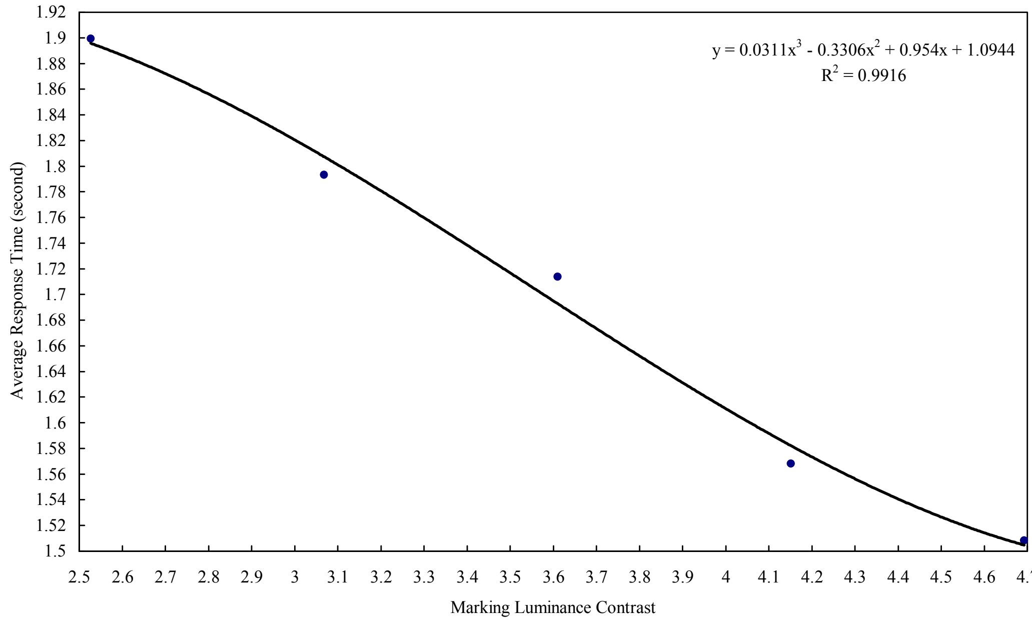


Figure 31 Marking luminance contrast w.r.t response time for yellow skip & solid marking

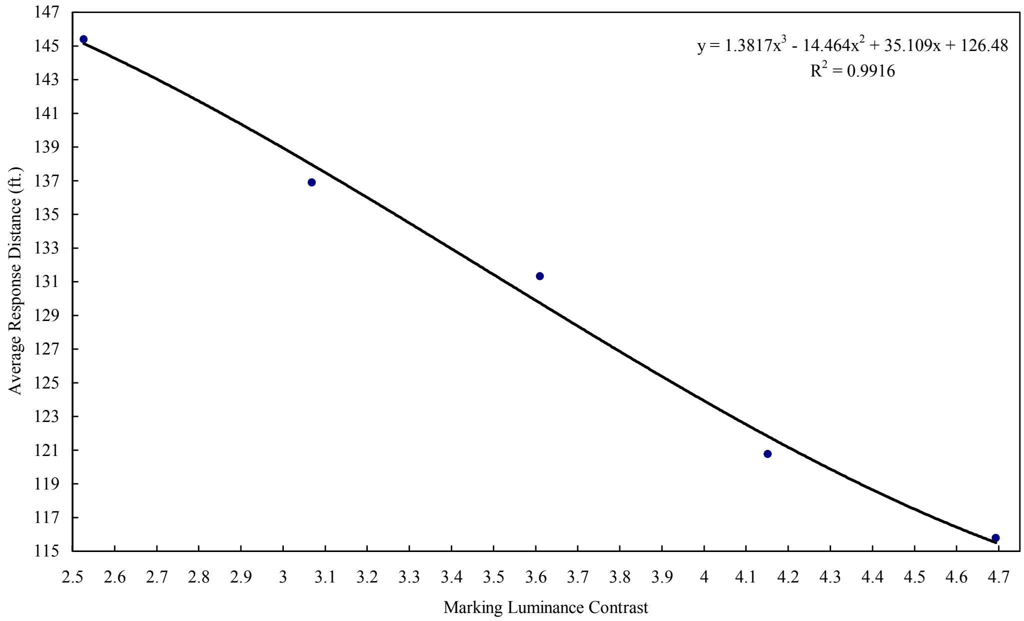


Figure 32 Marking luminance contrast w.r.t response distance for yellow skip & solid marking

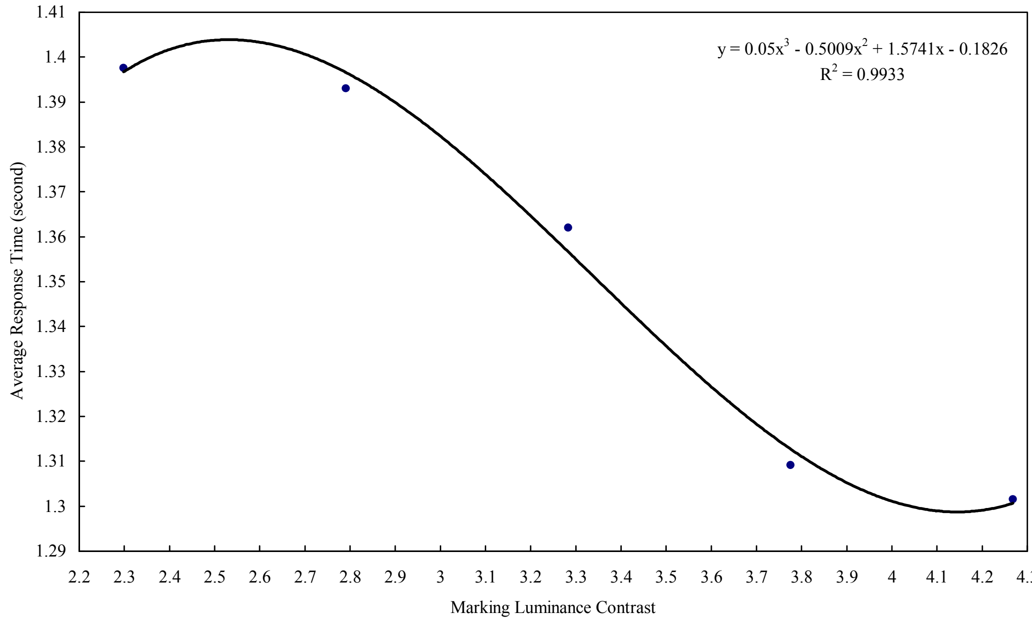


Figure 33 Marking luminance contrast w.r.t response time for yellow double solid marking

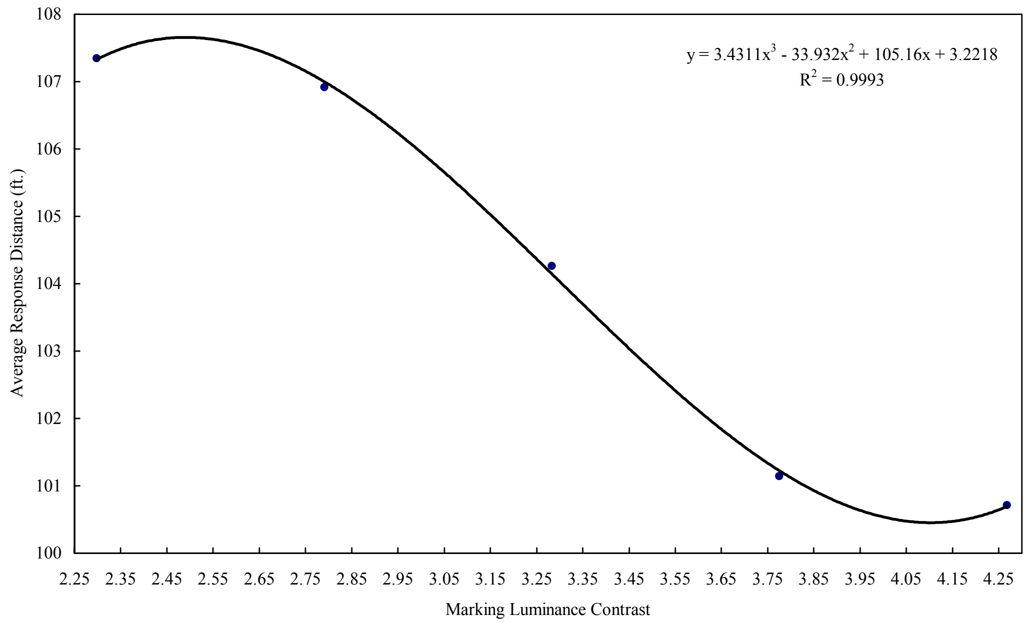


Figure 34 Marking luminance contrast w.r.t response distance for yellow double solid marking

APPENDIX A

Consent Form for the Experiments on Road Marking Luminance Contrast

The University of Rhode Island

Department of Industrial and Manufacturing Engineering

103 Gilbreth Hall

Kingston, RI 02881

Title of Project: Effects of Road Marking Luminance Contrast on Driving Safety

Dear participants,

You have been asked to take part in a research project described below. The researcher will explain the project to you in detail. You should feel free to ask questions. If you have more questions later, Prof. Jay Wang, the person mainly responsible for this study, Phone 874-5195, will discuss them with you. You must be at least 18 years old to be in this research project and hold a valid RI driver's license.

Description of the Project:

You have been asked to take part in the study to help investigate the effects of luminance contrast of road marking on driver response. A simulation study and a field study will be employed in the experimentation. People who participated in the simulation study can participate in the field study on a voluntary basis. Those who choose to participate in the field study shall use their own vehicles with proper automobile insurance.

What will be done:

In the simulation study, you will sit in the driver's seat of a motionless vehicle and make responses to a series of computer-digitized video clips showing various road markings displayed on a screen in front of the vehicle. The overall experiment will last about 20 minutes. If you decide to take part in the field study, you will drive your own vehicle on selected course of state and interstate highways with various markings. An investigator, sitting in the passenger seat, will survey your opinions regarding your satisfaction about the road markings. The whole trip should take less than an hour.

Risks or Discomfort:

There isn't any foreseeable risk or discomfort associated with the experiment.

Benefits of this Study:

Although there will be no direct benefit to you for taking part in this study, the researcher may learn more about drivers' responses to various road marking luminance conditions through these experiments. The research findings obtained from this project will benefit the general public and promote safer and smoother driving on state and interstate highways.

Confidentiality:

Your part in this study is confidential. None of the information will identify you by name. All records will be kept in a computer that is only accessible to the project investigators. The responses made by you will only be used in statistical analysis.

In Case there is any Injury to a Subject: (If Applicable)

If injury occurs in the lab, the investigator will call the campus emergency service to handle the situation. If injury occurs in the field study, the investigator will call the state police to seek help. If this study causes you any injury, you should write or call the office of the Vice Provost for Graduate Studies, Research and Outreach, 70 Lower College Road, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

Decision to Quit at any Time:

The decision to take part in this study is up to you. You do not have to participate. If you decide to take part in the study, you may quit at any time. Whatever you decide will in no way penalize you or affect your grade, etc. If you wish to quit, you simply inform the principal investigator, Prof. Jay Wang (874-5195) of your decision.

Rights and Complaints:

If you are not satisfied with the way this study is performed, you may discuss your complaints with Dr. Wang (874-5195), anonymously, if you choose. In addition, you may contact the office of the Vice Provost for Graduate Studies, Research and Outreach, 70 Lower College Road, Suite 2, University of Rhode Island, Kingston, Rhode Island, telephone: (401) 874-4328.

You have read the Consent Form. Your questions have been answered. Your signature on this form means that you understand the information and you agree to participate in this study.

______________________	______________________
Signature of Participant	Signature of Researcher
______________________	______________________
Typed/printed Name	Typed/printed name
______________________	______________________
Date	Date

APPENDIX B

Road Marking Luminance Contrast Survey

Dear participants,

In this survey, we try to obtain a better understanding of your experience with the experiment and your actual driving in Rhode Island. Your participation in the survey will help us gather necessary information to study road markings in RI highways and to seek technical possibilities for improvement.

Please take a few minutes to complete this survey. In the first page, please supply the requested information by filling in blanks or by circling the most appropriate answer. In the second page, you will need to view slides projected on the screen first and then make your choice accordingly. We deeply appreciate your help and cooperation. Your answers will be kept confidential and anonymous. Please feel free to contact Prof. Jay Wang at 401-874-5195 if there are any comments or suggestions.

Thank you for your cooperation.

Name: ________________________ **Date:** ____________________________

Age: a) 20~30 b) 31~40 c) 41~50 d) 51~60 e) 61~70 f) 71~80

Gender: a) Male b) Female

Do you wear correction lenses when driving? a) Yes b) No

Driving experience: a) Less than 1 year b) 1~5 years c) 5~10 years d) More than 10 years

Questions

1. Have you noticed that the road markings presented in the experiment were having different luminance contrasts?

   a) Yes b) No c) Not sure

2. Which of the following marking color was easier to identify in the experiment?

   a) Yellow b) White c) No difference d) Not sure

3. Which of the following marking color was easier to identify in real driving in daytime?

   a) Yellow b) White c) No difference d) Not sure

4. Which of the following marking color was easier to identify in real driving at night?

   a) Yellow b) White c) No difference d) Not sure

5. Please rank the importance of road marking in assisting your driving in the following weather condition(s). (Please write down a number from 1 to 5 in the blank before each answer where 1 be the most important and 5 be the least important)

   _____ Sunny day _____ Cloudy day _____ Rain day _____ Night/Wet

   _____ Night/Dry

6. In which of the following driving speed can you best identify a road marking configuration?

   a) 45 mph b) 60 mph c) 75 mph d) No difference e) Not sure

In each of the following questions, you will first view five slides presented sequentially. Please select the best one (the easiest one to identify the marking) by circling its number. Feel free to ask the lab attendant to repeat the slide presentation if necessary.

7. When looking at the solid white line on the left side of the screen, which of the following five is the easiest one to identify?

   a) #1 b) #2 c) #3 d) #4 e) #5

8. When looking at the double solid yellow lines on the left side of the screen, which of the following five is the easiest one to identify?

   a) #1 b) #2 c) #3 d) #4 e) #5

9. When looking at the skip white line on the left side of the screen, which of the following five is the easiest one to identify?

   a) #1 b) #2 c) #3 d) #4 e) #5

10. When looking at the skip & solid yellow lines on the left side of the screen, which of the following five is the easiest one to identify?

    a) #1 b) #2 c) #3 d) #4 e) #5