BICYCLE REFLECTOR PROJECT

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I. Introduction

The bicycle safety requirements in 16 Code of Federal Regulations (CFR) Part 1512, developed by the U.S. Consumer Product Safety Commission (CPSC), became effective in 1976 [1]. The section specifically addressing reflectors is defined in 16 CFR Part 1512.16. It requires that bicycles be equipped with reflective devices to permit recognition and identification under illumination from motor vehicle headlamps. The regulation includes mechanical and photometric requirements, and testing techniques for front, rear, side and pedal reflectors.

In June 1994, the CPSC published a report, *Bicycle Use and Hazard Patterns in the United States* [2]. This report was based on 1991 nationwide surveys that collected information on bicycle-related injuries and characteristics and use patterns of the general population of bicyclists. The study revealed that a large disproportionate share of deaths occurred at night, strongly indicating that riding after dark is more hazardous than riding during the day. During 1994, the National Highway Traffic Safety Administration (NHTSA) reported that 802 bicyclists died in crashes with motor vehicles. About 320 of these deaths (40 percent) occurred during non-daylight conditions, although a 1993 CPSC study indicated that only 12 percent of U.S. bicyclists ride after dark [3,4]. CPSC staff has estimated that riding after dark is about four times riskier than riding during the day [5].

In November 1994, the CPSC sponsored a conference on nighttime bicycle safety to explore ways of reducing the risks of nighttime riding. The conference brought together 50 distinguished bicycle experts from around the country, representing the scientific community, industry, user groups, and all levels of government. The conference focused on the role of bicycle lighting, reflectors and consumer education in reducing nighttime riding risks. Participants agreed to work with the CPSC to make bicycle riding safer, and to begin a voluntary standard for bicycle lighting. Participants also supported a CPSC project to evaluate current CPSC reflector requirements.

In June 1995, the Commission approved the Bicycle Reflector Project. The objective of the project was to evaluate the current CPSC reflector requirements, and determine if they could be improved. In March 1996, the CPSC staff hosted a public meeting to discuss the project objectives and invite participants to contribute suggestions and reflector products to be used in field-testing. The project scope was refined to reflect input received.

The Bicycle Reflector Project consisted of three major efforts: (1) an analysis of the incident data to determine the hazard scenarios for bicycle and motor vehicle crashes that occurred during non-daylight conditions; (2) an investigation and selection of reflective treatments that could potentially improve bicycle nighttime conspicuity; and (3) a controlled field test of driver detection and recognition of existing and prototype reflectors. This study also examined one type of combination light/reflector.

II. Hazard Analysis

The CPSC staff analyzed available information on nighttime bicycle/motor vehicle incidents. The purpose of the analysis was to develop hazard patterns that could be used to evaluate the current CPSC reflector requirements. This information was obtained primarily from four data sources:

(1) NHTSA Fatal Accident Reporting System (FARS) [3];
(2) *Pedestrian and Bicycle Crash Types of the Early 1990's* [6],
(3) *Bicycle Crash Types: A 1990's Informational Guide* [7]; and
(4) *A Study of Bicycle/Motor-Vehicle Accidents: Identification of Problem Types and Countermeasures Approaches* [8].

The FARS data provided general information about light conditions, victims, motorists, and roadways involved in fatal crashes. The other three sources provided further details about circumstances involved in fatal and non-fatal incidents.

In 1994, NHTSA reported that 802 pedalcyclists (primarily bicyclists) died in the United States in crashes involving motor vehicles [3]. About 320 or 40%, of these fatalities occurred during non-daylight conditions, which are dusk, night, and dawn. Sixty percent of the non-daylight fatalities involved pedalcyclists over age 25. About one-half (51 percent) of the motorists involved in fatal non-daylight incidents were ages 25-44 years. More than half of the incidents involved alcohol use by either the motorist and/or the cyclist. The median posted speed limit on roads on which fatal, non-daylight incidents occurred was 40 miles per hour, and over one-fourth of the fatalities occurred on roadways with posted speed limits of 55 miles per hour or greater. However, the actual speed of the vehicle at the time of the incident was not known.

The University of North Carolina's Highway Safety Research Center studied about 3000 bicycle/motor vehicle crashes from six states in the early 1990s [6, 7]. "Crossing path" and "parallel path" crash types accounted for about 53% and 40% of the non-daylight incidents, respectively. Crossing path crash types were defined as incidents that occurred at intersections, driveways, and other junctions when the bicyclist crossed the path of the motorist. Parallel path crash types were defined as incidents that occurred when bicyclist and motorist were approaching on parallel paths, either heading in the same or opposite directions.

Cross and Fisher studied over 900 bicycle/motor vehicle incidents that occurred in four areas of the United States in 1975 [8]. This study identified a major nighttime "problem type" that involved motorists overtaking a bicyclist because they failed to see the bicyclist in time to avoid the crash. This scenario occurred more frequently at night than during the day. In these cases, 63 percent of the non-fatal incidents and 71 percent of the fatal incidents occurred during darkness.

III. Existing Standards

In the United States, most bicycles are required to be sold with reflectors that meet the mandatory requirement, 16 CFR 1512.16. The regulation requires bicycles to be equipped with reflective devices to permit recognition and identification under illumination from motor vehicle headlamps. Bicycles are required to have a red rear-facing reflector; an essentially colorless front-facing reflector; and amber or essentially colorless pedal reflectors. These reflectors are intended to provide increased visibility of the bicycle for motorists approaching the bicycle from both the rear and the front.

Bicycles are also required to have spoke-mounted side reflectors that are amber or essentially colorless for the front wheel and red or essentially colorless for the rear wheel. Reflective tire sidewalls or rims can be used instead of spoke reflectors. Most bicycles sold in the United States are equipped with the spoke reflectors rather than the reflective tire sidewalls. There are no spoke reflector load requirements, but reflective rim and tire sidewalls must resist an abrasion test.

Photometric performance requirements and testing techniques are also specified in 16 CFR 1512.16. The regulation specifies minimum coefficients of luminous intensity (R_I) . The coefficient of luminous intensity is the measure of photometric performance as it relates to the perceived brightness of a reflector. A temperature and humidity cycling test for plastic reflectors are also specified in 16 CFR 1512.16. This type of testing ensures the product does not degrade due to exposure to the outdoor environment.

European and Asian countries have developed reflector requirements based on 16 CFR 1512.16. Reflective tire sidewalls are commonly used in some European countries, such as the Netherlands. Germany has standards for larger front and rear reflectors than CPSC's regulation reflectors. The reflector performance requirements in the International Standards Organization (ISO) 6742/2 Cycles - Lighting and Retro-reflective Devices - Photometric and Physical Requirements standard are the same as the CPSC requirements.

The CPSC's bicycle regulation does not require lights on bicycles sold in the United States. A 1990 review of state laws by the League of American Wheelmen, showed that all fifty states require a front white light and a rear red reflector, but the laws are inconsistently enforced [9]. Many European countries require bicycles to have lights that meet or exceed ISO 6742-1, which is a voluntary standard that specifies the minimum photometric, color, mounting, and power requirements for front and rear lighting.

IV. Bicycle Reflector Operation and Technology

Reflector Operation

Bicycle reflectors, which are more properly called retroreflectors, are devices that operate by returning light back to the light source along the same light direction. They are made using a cube corner element or a spherical element with reflector as shown in Figure 1. The coefficient of luminous intensity(R_I) is the measure of a reflector performance. It is defined as the ratio of the strength of the reflected light (luminous intensity) to the amount of light that falls on the reflector (normal illuminance). A reflector will appear brighter as its R_I value increases.

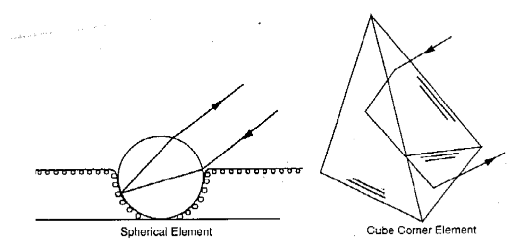

Figure 1. Retroreflector Design.

The R_I value of the reflector is a function of the color, size, and condition of the reflector. Clear or white reflectors are the most efficient, and appear brighter than other colors. The surface area of the reflector is proportional to the R_I value and will increase as the reflective surface increases. A worn or dirty reflective surface will degrade the reflector's performance and lower the R_I value.

The R_I value is also a function of the spatial geometry between the driver, headlight, and reflector. Figure 2 shows the observation angle and entrance angle between the automobile's headlights, bicycle, and driver. The observation angle is the angle formed by the light beam and the driver's line of sight. Observation angle is a function of the distance between the headlights and the driver's eye, and the distance to the reflector. Traffic engineers use an observation angle of 0.2 degrees to simulate a reflector target about 800 feet in front of a passenger automobile. As the observation angle increases, the reflector performance decreases. For example, a truck has a large separation between the headlight and the driver's eye compared to a passenger vehicle. A bicycle reflector will appear brighter to the passenger car driver than to the truck driver at the same distance from the vehicle to the reflector.

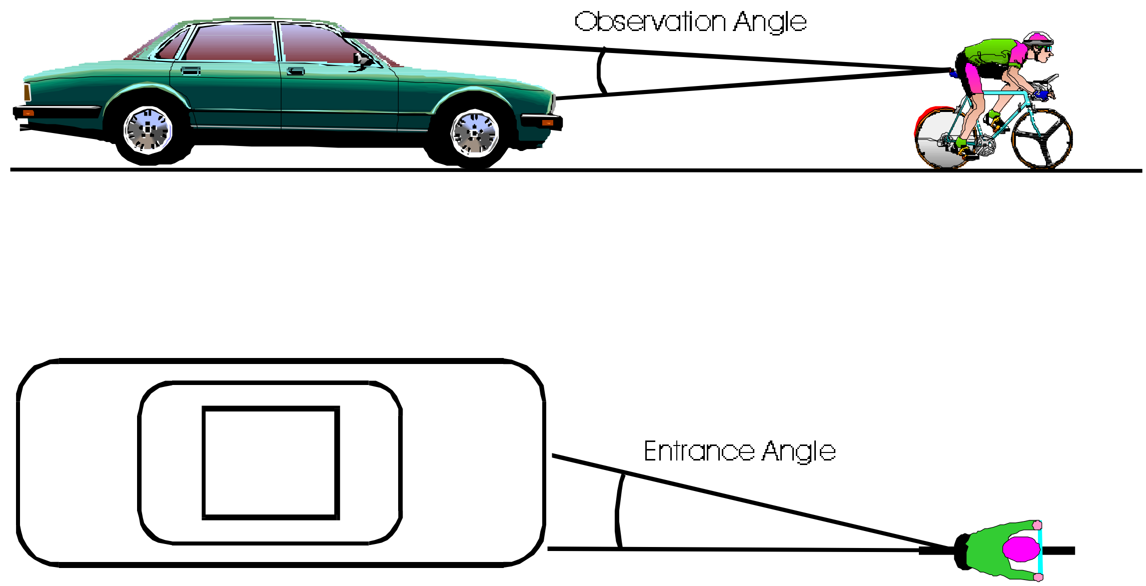

Figure 2. Observation and Entrance Angle

The light beam and the normal axis of the reflector as shown in Figure 2 form the entrance angle. The entrance angle is a function of the orientation of the reflector to the light source. For example, the entrance angle between an automobile approaching a bicycle at an intersection 90 degrees apart will be larger than the entrance angle for a bicycle directly in front of an automobile on a straight road. The bicycle reflector will appear brightest to the driver when it is directly in line with the headlight beams.

The brightness of a reflector is also a function of the distance between the light source and the reflector. Generally, as the vehicle approaches the bicycle reflector, the light that falls on the reflector increases, which increases the amount of light returned to the driver and the bicycle reflector will appear brighter.

The performance of the light source will affect the brightness of the reflector. The intensity of reflected light is proportional to the illuminance, or the light that falls on the reflector from the light source. If the light source is a vehicle's headlights, it should be clean and properly aimed for maximum illumination of the reflector. Atmospheric conditions such as rain or fog will scatter the headlight beam and reduce the amount of light that reaches the reflector. Rain and fog will also reduce the amount of light returned from the reflector to the driver.

Reflector Technology

Current reflectors can be categorized as reflective paints, hard molded plastic reflectors or flexible thin film reflectors. Reflective paints are commonly used for highway delineation stripping. Cube corner molded plastic reflectors are commonly used on bicycles, automobile lenses, mailbox/driveway markers, and in some highway pavement markers. The film reflectors are cube corner or spherical element design and are used on road signs, reflective apparel, and reflective tape. Generally, film reflectors perform better than molded plastic reflectors as the entrance and observation angles increase. Plastic reflectors perform better at small entrance and observation angles and require less surface area than film reflectors to achieve the same R_I value. Both types of reflectors can be colored. Improvements in plastic reflectors have resulted in decreased surface area size without a decrease in photometric performance. Bicycle reflectors have decreased in size over the past 20 years as shown in figure 3, but continue to meet the CPSC photometric requirements. Thin film reflectors have also increased in photometric performance per area and are now available in fluorescent colors.

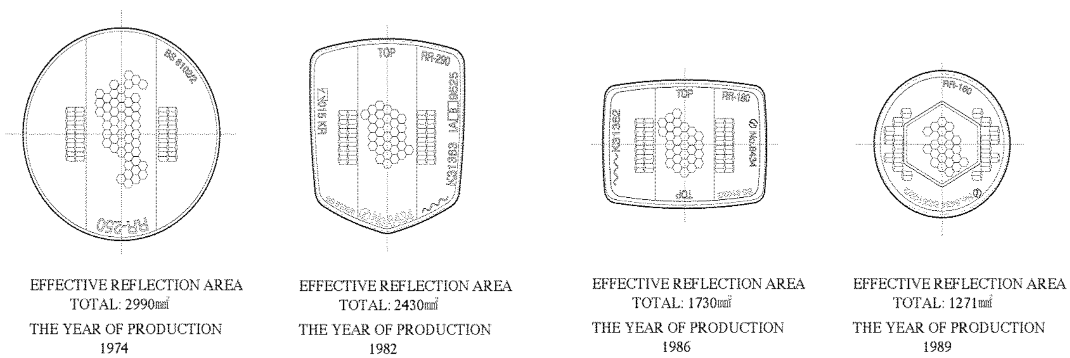

Figure 3. Evolution of the Bicycle Reflector (figure provided by Cateye Co., LTD)

V. Field Study Methodology

A. Background

A 1978 study by McGee, *Decision Sight Distance for Highway Design and Traffic Control Requirements* [11] describes a model of a driver's perception based on his/her's ability to detect, recognize, and react to a hazard. McGee defined detection time as the period from onset of the hazard (stimulus) to the moment when the image of the hazard is "registered on the brain. Recognition occurs when the driver can identify the object, and decision occurs when the driver identifies alternative actions based on driving experience and knowledge. The response occurs when the driver applies the vehicle controls such as removing the foot from the accelerator to step on the brake or to initiate steering. The final component is the evasive or corrective maneuver such as a change in speed and/or path. McGee's study led to the formulation of a model to quantify the sight distances based on the driver's perception and reaction process. He used this model to develop Decision Sight Distance (DSD) tables to provide guidelines for designers of highways, and traffic control devices.

Researchers have argued that detection and recognition are not equally important in the driving process. Some researchers believe that increasing the target's detection distances without increasing the recognition distances may be of little safety value and may be a distraction [12]. For example, if a driver detects a target, he expects to recognize it in a reasonable time. If he or she can not recognize it, the driver may ignore the target having incorrectly concluded that the target is stationary and not a hazard. During daylight hours, drivers receive visual cues, such as color and shape that assist them in identifying objects. However, during non-daylight hours visual cues are greatly reduced, colors are less distinguishable, and field of vision is dependent on car headlights or street lighting. Because of these limitations, drivers' preview times are compromised.

Bicycle reflectors are crash avoidance safety devices intended to increase bicycle conspicuity. As part of this project, hazard scenarios were studied to evaluate situations in which reflectors might be more effective if changes were made to their design. For example, in a situation where a motorist is overtaking a bicycle from the rear, would improving the reflectors provide the driver more reaction time and help avoid a collision? In another situation, where a bicyclist and motorist are approaching an intersection from perpendicular directions, would improving the reflectors allow the motorist to notice the bicycle sooner? In these potential crash situations, improving the bicycle's conspicuity could reduce the number of nighttime bicycle incidents. If a new or modified bicycle reflector system could be detected and recognized at significantly greater distances than the reflector currently required by the CPSC regulations, then there maybe a way to reduce the number of nighttime riding incidents.

The CPSC staff was not aware of any quantifiable correlation between photometric performance and a motorist's ability to see and avoid a hazard. Therefore, laboratory photometric testing alone could not be used to evaluate a bicycle reflector system. The most feasible evaluation would be to compare the relative performance of the reflectors that met the CPSC regulation to other types of bicycle conspicuity treatments through field-testing. The Directorate for Engineering Sciences, Division of Human Factors (ESHF), developed a field test methodology similar to a 1984 study conducted by R. D. Blomberg, A. Hale, & D. F. Preusser, Ph.D., for the National Highway Traffic Safety Administration (NHTSA)[13].

B. Overview

The objective of the field study was to compare the performance of various bicycle reflectors and or light systems (hereafter referred to as "treatments") to the CPSC reflector regulation. This was done by measuring detection and recognition responses for subjects as they drove a vehicle through a roadway system. Testing was conducted on the campus of the National Institute of Standards and Technology (NIST). The campus provided dark and lighted streets, crossing roadways, and background visual clutter such as building lights and traffic on roadways near the facilities. This setting simulated a typical neighborhood environment and a dark rural environment.

Two tests were conducted in this field study. The Parallel Path test simulated a motorist overtaking the bicyclist from the rear. The Crossing Path test simulated a potential motorist and bicycle collision at a street intersection. Decoys, such as traffic warning devices were set up along the course to distract from the main targets and reduce false positive responses. Figure 4 is a schematic of the test site showing the placements of the bicycles and decoys throughout the four mile test track.

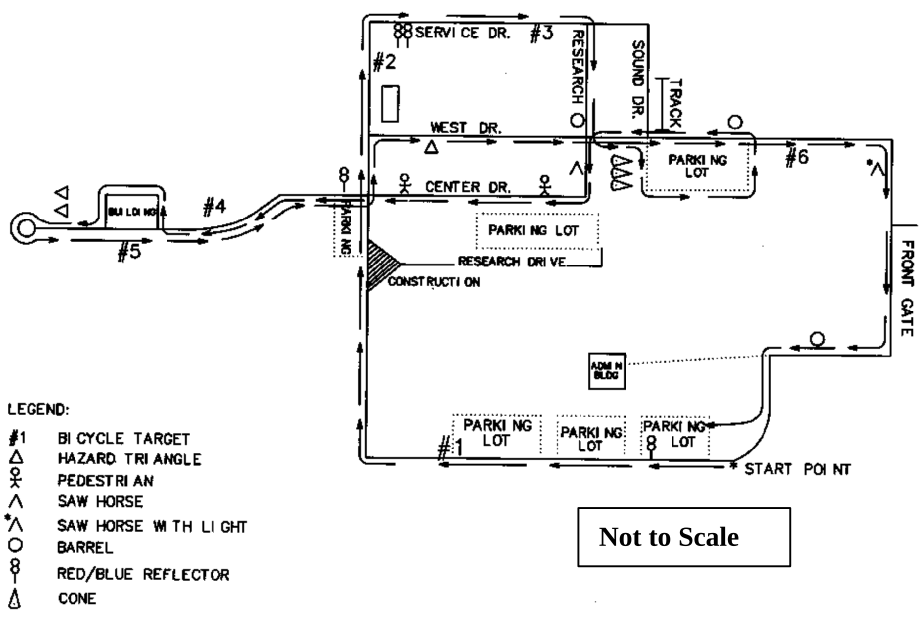

Figure 4. Schematic of the Test Track

The parallel path test consisted of six stationary bicycles located at specific locations on the right side of the road. Figures 5 and 6 show the daylight and nighttime conditions at a parallel path location. Mannequins were placed on the bicycles to simulate actual bicycle riders. For safety reasons, real people could not ride the bicycles during testing. An electric motor powered the bicycle pedals and wheels at a uniform speed to simulate the normal pedal rotation of a bicyclist traveling at 10 miles per hour. A metal frame held the bicycle with the wheels just barely off the ground.

Figure 5. Daytime View of Parallel Path Location

Figure 6. Nighttime View of Parallel Path Location

Each bicycle was equipped with a different treatment.   While the locations for the bicycles were the same for each subject; the treatments on the bicycles were changed in a specific order for location after each subject's observation based on a latin-square, cross-over design matrix. The placement order for the treatments was established so that each treatment followed each other treatment exactly once.

The crossing path test simulated a potential collision situation at an intersection by pulling a bicycle along a 100 foot track as shown in Figure 7. The intersection was a two-way stop, with the right-of-way to the subject and a stop sign to the bicyclist. Two parking lots lined the street on the left, trees were on the right, a building was one block further down the road on the right, and street lights were down the full length of the street. Figures 8 and 9 show the daylight and nighttime conditions at the track location. The bicycle traveled at a speed of 7 mph and the subject was instructed to maintain a speed of 20 mph. An optical sensor was placed 390 feet from the intersection. When the test car passed the sensor, the bicycle was triggered to travel down the track. The track was set up so that the bicycle stopped 10 feet before entering the intersection to prevent a collision. Under these conditions, the subject's peripheral viewing angle of the bicycle was between 15 - 20 degrees.

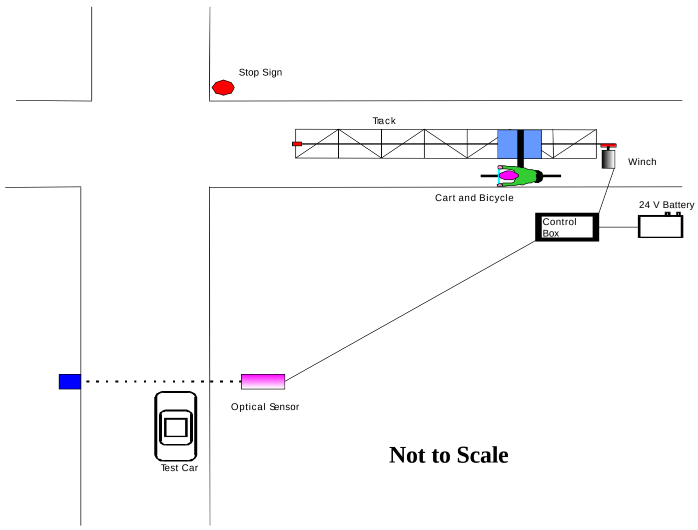

Figure 7. Schematic of the Crossing Path Tests

Figure 8. Daytime View of the Crossing Path Test Location (bicycle target not shown)

Figure 9. Nighttime View of the Crossing Path Test Location (bicycle target not shown)

C. Test Subjects

Forty-eight subjects (24 females and 24 males) between the ages of 25 and 44 years were selected to participate in the study. This age group was chosen because 51% of non-daylight bicycle and motor vehicle incidents involved motorists in this range. To analyze the effects of age on driving responses at night, the subjects were subgrouped into age groups of 25 to 34 and 35 to 44 years. The subjects were assigned to specific test nights based on their age. Four of the eight test nights had subjects from 25 to 34 years, and the other nights had subjects from 35 to 44 years. The mean age for each group was 29.5 years and 37.8 years, respectively.

The subjects were provided by a contractor who screened the subjects for age, gender, valid driver's license, color blindness, and night blindness. Candidates who reported to be color blind, and/or had restrictions on driving at night were not supposed to be selected as subjects. The CPSC staff tested each subject's vision for near and far acuity, color, peripheral and contrast sensitivity under daylight and dark conditions.

D. Process

The testing occurred on eight days during period of October 22 - November 14, 1996. Six subjects were scheduled for testing on each night. The subjects' arrivals were at 1 hour 45 minutes intervals with two subjects scheduled for each time period. The first subjects were scheduled to arrive at 7:00 p.m. Upon arrival, the subjects' consent forms were submitted, their driver's licenses were examined and their license number was recorded. The subjects were then given a vision screening exam and placed in a darkened room for 20 minutes to visually adapt for nighttime driving. During this time, the CPSC facilitator instructed the subject about the driving portion of the testing. The CPSC facilitator instructed the subject to say when s/he first saw and then recognized temporary roadside objects such as hazard indicators (safety cones), pedestrians, bicyclists, parked or standing vehicles, etc. The subject was told to keep talking and telling the facilitator what s/he is observing during the entire driving time.

After the subject was dark adapted, s/he was seated in the driver's position of the test vehicle. The facilitator sat in the front passenger side and the data collection operator sat in the rear seat, behind the facilitator. Last minute reminder/instructions were given, and then the subject was directed to drive the car through the parking lot to the starting line. The 500 feet drive to the starting line allowed the subject to become familiar with the vehicle. After the facilitator received permission to proceed from the crew maintaining the bicycle targets, the subject drove at 20 - 25 mph through the course. As the subject reported object detection and recognition, the facilitator register distances traveled by pushing a remote button attached to the distance measuring instrument in the car. The subject's data were stored real time on a laptop computer.

There was minimal vehicle traffic on the course. However, there were occasional encounters with other vehicles during a test drive. When these other vehicles were observed by the facilitator, the subject was advised to safely stop the car and let the other vehicle pass. If the other vehicle was coming toward the subject, the subject was told to safely stop the car and to not look at the oncoming headlights. While preventing or limiting glare due to oncoming traffic creates an ideal situation, this was necessary in order to avoid an additional variable in the testing. At the end of the drive, the purpose of the testing was described to the subject. The subject was given an opportunity to comment on the experiment.

E. Treatment Selection

The bicycle reflector treatment selection criteria were based on product functional characteristics that had the potential for increasing driver's detection and recognition distances. Staff hypothesized that increased photometric performance, or brightness, could increase detection. Therefore, treatments with photometric performances greater than the CPSC's reflectors were considered for this study. Motion or form cues were also predicted to increase recognition, so treatments with these features were considered. Since the CPSC reflectors are passive treatments, that is, once they are on the bicycle consumers do not have to turn them on or maintain them, staff preferred passive treatments over active treatments for this study. Staff judged products currently on the market or products that could be easily brought to the market more acceptable for consideration than prototype treatments. Finally, staff regarded the cost of the product to be an influential factor in terms of consumer use, therefore, treatments with no or minimal costs were considered. Table 1 and Table 2 show the parallel path and crossing path treatments, respectively, that were selected for the study and their potential visibility improvements .

Table 1 Field Study Parallel Path Treatments

Treatment No.	Rear Treatment	Potential Improvement[1]
1	Red blinking tail light/reflector	not dependent on car headlight, unique signature, increased detection
2	Larger area Yellow/Green fluorescent sheeting on rear and pedals	2-4 x brighter, high angularity, unique color, form cue, increased detection/recognition
3	Amber rear reflector	3 x brighter, increased detection/recognition
4	White pedal reflectors	1.5 x brighter, increased detection/recognition, motion cue
5	CPSC regulation reflectors	none
6	Large red rear reflector	3.5 x brighter, increased detection/recognition

[1] Potential improvement refers to the photometric measurement of each treatment as compared to the actual reflector representing the CPSC regulation used in the field testing.

Table 2. Field Study Crossing Path Side Treatment Selection

Treatment No.	Side Treatment	Potential Improvement[1]
1	Wheel circles reflectors	form cue, increased recognition
2	CPSC spoke reflectors	none
3	2 CPSC spoke reflector per wheel,	2 x brighter, increased detection/recognition
4	Head light (2.4 W halogen) and blinking red tail light/reflector with CPSC spoke reflectors	brighter, not dependent on car headlight
5	Blinking white front head light (LED) and blinking red tail light/reflector, with CPSC spoke reflectors.	brighter, not dependent on car headlight
6	Large area Yellow/Green fluorescent sheeting on front, rear and pedals, reflective tires	brighter, high angularity, unique color, form cue, pedal motion, increased detection/recognition

[1] Potential improvement refers to the photometric measurement of each treatment as compared to the actual reflector representing the CPSC regulation used in the field testing.

VI. Results and Discussion

CPSC staff performed the field test data analysis using statistical techniques to determine the effects of each factor on the outcome of the experiment. Staff was primarily interested with effects of the treatments on detection and recognition distances. Particularly, determining if the mean detection or recognition distance of a target was statistically significantly different than CPSC standard reflector target (Target 5).

This study was conducted with primed subjects, that is, they were instructed and prepared to see "temporary roadside objects." Therefore, the results for the detection and recognition distances should be viewed as better than the average unsuspecting driver. In addition, the subjects were driving at a low speed (approximately 20-25 mph), which allowed them more time to scan the driving environment. Finally, the subjects were instructed to scan the environment and give a running commentary of what they were observing. All these factors prepared the subjects in this study to be more aware of their driving environment. However, the subjects did not know exactly when or where a "target" would appear. In addition, they were aware of conditions (i.e., animals, pedestrians, and other vehicles) on the course that were beyond the control of the facilitator and, therefore, they had to drive with caution.

A. Vision Screening Results for Subjects

All the subjects met the study entrance criteria for at least 20/40 binocular distance photopic acuity. Four did not meet the requirements of the Maryland Motor Vehicle Administration for 20/40 distance acuity when each individual eye was tested. There was a decrease in acuity under reduced light conditions that was more noticeable in the older subjects. Two subjects were found to be color blind. Originally it was thought that because treatments varied by color, color blind individuals might have difficulty identifying colors, but that was not found to be the case for these two individuals, so their results were kept in the study.

B. Parallel Path Test Results

Location, target, and subject were found to be statistically significant for detection distances of the bicycles. The factors found to be significant for the recognition distances of the bicycles were location, test night, and subject. Table 3 shows the mean values and standard deviation of the detection and recognition distances by target.

Table 3. Parallel Path Mean Detection and Recognition Distances and Standard Deviation by Treatment in Descending Order by Detection

Treatment No.	Rear Treatment	Mean Detection/Standard Deviation (in feet)	Mean Recognition/Standard Deviation (in feet)
1	Red blinking tail light/reflector	847/36	702/36
4	White pedal reflectors	786/32	706/31
6	Large red rear reflector	759/36	703/36
5	CPSC regulation reflectors	744/36	712/35
3	Amber rear reflector	726/37	670/36
2	Larger area Yellow/Green fluorescent sheeting on rear and pedals	708/39	657/40

When comparing treatments to the CPSC regulation reflectors, only the bicycle with the red blinking tail light/reflector was detected at a statistically significant longer distance. This treatment utilized the benefits of lights and reflectors. At long distances, the blinking light was visible before the reflector and at short distances the reflector function gave the appearance of a steady red light.

CPSC staff attributes the increased detection of the blinking light/reflector over the reflector targets to the performance of the active light source. The light treatment was not dependent on the car's headlights for illumination and was visible at longer distances. The flashing of the light may have also contributed to increased detection by focusing the subjects' attention to the object and away from the background noise. Researchers have shown that flashing lights used in a background absent of flashing lights are more conspicuous than a steady light [14].

While detection of this light/reflector treatment was statistically significantly different from the CPSC regulation reflector, recognition was not. Some of the subjects incorrectly identified the flashing red light as a police car, or a hazard signal; it was not until they got closer and could see more of the bicycle form that they identified it correctly. The motion of the reflective pedals was the feature most attributed to recognition of the bicycles. Many subjects commented that they recognized the up and down movement as being associated with pedals, and thus, identified the object as a bicyclist.

The mean detection distances for reflective treatments of the CPSC study were fairly consistent with the mean detection distances (approximately 800 feet) achieved in the study conducted by Blomberg, et. al.[12]. However, the CPSC's mean recognition distances (approximately 700 feet) were much higher than for Blomberg's study (approximately 450 feet). In Blomberg's study, detection occurred roughly 400 feet before recognition for reflective treatments. In the CPSC study, the range between mean detection and recognition distances was only between 30 and 80 feet for reflective treatments.

The small distance between detection and recognition for the CPSC study as compared to the Blomberg study is probably due to a critical difference in the nature of the subject's cognitive task between the two studies. That is, the recognition task for CPSC subjects was less complex than for the Blomberg subjects. Both studies placed decoys in the course. However, the identification task for the subjects in the Blomberg study was more difficult because they had to identify pedestrian as well as bicycle targets placed randomly on the driving course. This methodology is more conservative than CPSC's methodology, in which the subject's recognition task was only to recognize bicycles. Clearly, the cognitive processing time will be less for a CPSC subject who only has to decide whether the identified stimulus is a bicycle than the greater processing time needed for a Blomberg subject who has to identified a stimulus as a pedestrian or bicycle.

C. Crossing Path Test Results

Table 4 shows that the crossing path mean detection and recognition distances for all of the targets were less than 200 feet. Also, for each subject, detection and recognition distances were the same. As soon as the subject detected the bicyclist, s/he also recognized it as a bicyclist.

Table 4. Crossing Path Mean Detection/Recognition Distances and Standard Deviation by Target

Treatment No.	Side Treatment	Mean Detection / Recognition (ft)	Standard Deviation(ft)
6	Large area Yellow/Green fluorescent sheeting on front, rear and pedals, reflective tires	146	21
1	Wheel circles reflectors	140	27
2	CPSC spoke reflectors	139	29
3	2 CPSC spoke reflector per wheel,	120	24
4	Head light (2.4 W halogen) and blinking red tail light/reflector with CPSC spoke reflectors	118	27
5	Blinking white front head light (LED) and blinking red tail light/reflector, with CPSC spoke reflectors.	114	23

Note: Comparisons can not be made between individual targets because of the probable test subject and night influence on the distances.

Staff believes that the subjects did not detect the bicycle target until the vehicle was close enough to illuminate the mannequin and bicycle. At that time, the subject immediately recognized the object as a bicyclist. Staff believes that the 15-20 degree viewing angle between the driver and bicycle and the background visual noise in this simulation contributed to the low detection and recognition results. However, these conditions would be typical of many real street crossing situations.

VII. Conclusions

CPSC staff determined that the risk of death and injury from nighttime bicycle riding is considerably higher than riding during the day. Risk analysis shows that a cyclist riding during non-daylight hours is about four times more likely to be killed than a cyclist riding during the day. Alcohol use by either the motorist or the bicyclist was common in fatal incidents. Over one-half of the fatal incidents involved alcohol.

Fatal incidents occurred at high posted speeds, over one fourth occurred at posted speeds of 55 mile per hour or greater. Higher speeds require increased preview time for a driver to avoid a crash. At 40 mph, a driver needs to detect a bicyclist at 325 feet to avoid a collision according to stopping sight distance tables which are applicable to a crossing path collision. At 40 mph, a driver needs to see a bicyclist at 600-825 feet to avoid a collision, according to the decision sight distance table which may be more applicable then the stopping sight distance table in a rear run over crash.

The CPSC's field study compared driver perception of various reflector and light treatments. The study simulated a potential rear run over crash and a potential intersection crash. Treatments were selected to improve detection and recognition of the bicycle. The results of the study showed that there was no statistically significant difference in performance among the various reflector treatments and the current CPSC regulation reflectors. Therefore, improvement to the existing reflector requirement does not appear warranted.

The parallel path crash simulation showed that the flashing red LED taillight used in the evaluation could significantly improve a driver's detection distance over the CPSC regulation reflectors. Recognition distance was not improved with this or any of the treatments tested. CPSC staff believes that this type of lighting has potential to improve nighttime bicycle safety. Currently, rear LED lights are available in a variety of styles. Additional research is required to determine minimum requirements for rear lighting.

The crossing path crash simulation results showed that none of the reflector or light treatments tested improved detection or recognition. All treatments were detected and recognized at less than 200 feet. The results of this portion of the study demonstrate the difficulties for effective countermeasure for a crossing path collision. Even the large area reflective sheeting target with good angularity characteristics did not perform well. Limitations of a driver's peripheral vision, limited headlight beam spread and background visual noise are known factors that contribute to decreasing detection and recognition distance. CPSC staff believes a bicycle side treatment with significantly increased signal strength may be necessary to improve detection distances under these conditions.

VIII. Recommendations

Based on the above findings, the CPSC staff did not recommend amending the existing reflector requirements in 16 CFR Part 1512.16. Staff recommended conducting additional research, testing, and evaluation of bicycle nighttime visibility. At a minimum, the research should look to evaluate rear, front, and side lighting features that could possibly lead to a voluntary standard. This testing and evaluation program could use techniques similar to the CPSC field test and should be performed with industry and other government agencies that have an interest in furthering the limited data on this subject.

According to representatives from the Federal Highway Administration (FHWA), research using ultra violet (UV) headlamps on automobiles to increase visibility is ongoing. Initial field-testing showed an improvement in detection and recognition of pedestrians with light colored clothing and bicycles treated with fluorescent paint. NHTSA representatives reported that in Fiscal Year 1998, NHTSA awarded F&S of Blacksburg, Virginia, a Small Business Innovated Research (SBIR) contract to develop methods to substantially increase bicycle/cyclist conspicuity from all directions. The feasibility of prototype systems will be examined. NHTSA is also conducting a literature review of research and other programs related to pedestrian and bicycle conspicuity. In FY 2000, NHTSA plans to develop and conduct a test and evaluation program to determine the effectiveness of various pedestrian and bicycle treatments.

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