Final Technical Report
Cycle 1

The University Transportation
Research Center, Region 2

IMPROVING SAFETY AT INTERSECTIONS

CONTROLLED

BY A TRAFFIC SIGNAL LIGHT

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GENERAL SUMMARY

The purpose of the following research was to determine whether conspicuity of an illuminated traffic signal lens could be increased with a modulating incandescent light source. Experiments were conducted both in the laboratory and a controlled field setting under normal and degraded viewing conditions using both static and dynamic testing situations.

Four experiments are reported here. There were four other experiments conducted which are not reported here. Some of these served as the basis for later studies. Briefly, the first study required drivers to perform a distractor task of operating a simulated vehicle generated on a monitor by a microcomputer in the presence of simulated sun backlighting on a traffic signal face. The second required subjects to identify their driving response (e.g., stop and wait, stop and go) when confronted with the standard non-modulating light, two patterns of a blinking light (one and two/sec), and a modulating light of 4/sec. The third study examined a driver's identification of range of modulation while wearing special glasses simulating early/moderate stages of cataract development. The fourth study examined the modulating bulb in a traffic signal face under degraded conditions of simulated fog produced by special "fog" glasses. These latter two studies were conducted at the automotive test track at the Pennsylvania Transportation Institute, Pennsylvania State University.

The results of the studies reported here showed that under a degraded viewing conditions of sun backlighting the modulating bulb was more effective in increasing the conspicuity of the illuminated lens than the standard bulb now in use. The next step in the research process is to test the modulating bulb at an actual intersection. Plans are underway to conduct such a study in the City of Oneonta.

Concern was raised as to whether the modulating light source may initiate photosensitive induced epileptic seizures. Previous research was examined and neurological expert evaluations were sought to explore this possibility. Briefly, the literature and experts' opinions indicated that the unique lighting pattern would not trigger a photosensitive induced epileptic seizure. Attached is a report submitted to the FHWA concerning photosensitive induced seizures.

Two of the experiments described in this final report were accepted for presentation at the Human Factors Annual Conferences (1990 and 1991). Copies of these two papers are appended. The latter paper was published in the Proceedings of the 35th Annual Conference of the Human Factors Society, 1991.

A number of individuals and organizations were directly responsible for the successes of this project and they deserve a special note of appreciation. To my collaborators, Herschel W. Leibowitz, Ph.D., Evan Pugh Professor of Psychology, Pennsylvania State University, and Richard Brugger, P.E., the inventor of the modulating bulb who have offered endless support and assistance; To my wife, Joyce Ann, who assisted in all aspects of the projects; To SUNY-Oneonta, the City of Oneonta and the Pennsylvania Transportation Institute for their encouragement and use of their facilities; To my students who spent countless hours constructing equipment, revising procedures, and data collecting (Nancy Pena-Reynolds, Sean Suib, Cheryl Streif, Jim Berger, Christa Hrachian, Don Herbert, Ray Poggoli, Erick Gonzalez, Nicole Zapata, Heather Connors, Amy Del Vecchio, and Colin Jones); To the SUNY-Oneonta Research Foundation and Sponsored Programs, the State and Regional (Oneonta) DOT offices, the UTC-Region 2 who offered technical assistance and support; and finally to the FHWA, who with their financial support made all of this possible.

Improving Safety at Intersections

Controlled by a Traffic Signal Light

INTRODUCTION

At intersections controlled by a traffic signal light, the ability to detect the presence of a signal face and respond appropriately is a critical activity in a vehicular oriented environment. On occasion, drivers and pedestrians may respond inappropriately. These situations may be the result of risk taking, inattention, distraction, or “looking but failing to see” (Hills, 1980), and these are compounded by competing environmental arrays that reduce the conspicuity of the illuminated signal lens.

If a signal head is not detected or the lens erroneously identified, the driver may "run a red light" or "stop for a green light" and these could have serious consequences for transportation safety. For example, the New York State Department of Motor Vehicles indicated that in 1986, 314,784 motorists were convicted of running a red light and 1,394 red light violations were associated with accidents. Levinson (1989; 1990) reported that in Israel, using a 24 hour surveillance system at intersections controlled by a traffic light, a total of 41,259 violations were identified of which 16,370 were “red light runners” From these data, red light passing possess a serious traffic problem.

These red light violations are usually attributed to the driver and are most certainly compounded by unfavorable environmental conditions, e.g., fog, sun glare, and sun backlighting. However, drivers who are well-intentioned may perform incorrectly at an intersection. If they failed to detect a signal head or erroneously identified an unlit signal lens as illuminated may indication that the traffic signal lacks the necessary conspicuity to override both human and environmental conditions.

One technique to enhance signal conspicuity is the use of flashing lights. The psychological literature documents the value of moving lights regardless of whether that movement is real or apparent in detection (Exner, 1888; see Sekuler & Blake, 1990 for a review). The use of flashing lights has been successfully used to improve the conspicuity of two traffic control devices. Strybel & Nassi (1986) improved the recognition of a lane-reversing signal under conditions of sun glare by placing a rotating beacon above the signal; and a strobe light strip has been attached to the face of the red lens which pulsed when the red signal was illuminated (MUTCD, 1988). Although effective, potential problems do exist. These alerting devices are tangential to the signals and their failure could result in misidentification of the signal lights from observers who are familiar with their operation. Further, individuals who are exposed to these signals for the first time may respond unexpectedly and inappropriately, e.g., reducing speed when the surrounding traffic is familiar with the light's operation and are responding appropriately.

Recently, Brugger (1989) designed a dual-filament traffic signal light bulb where the warning was inherent in the signal's normal lighting pattern. By alternately energizing each filament, a modulation pattern was generated which observers describe as a "flickering or shimmering" light. A copy of the patent is appended to this report.

Initial research was conducted at the Pennsylvania Transportation Institute's automotive test track to determine whether drivers would respond to the modulating light in the same way as they would to the standard, non-modulating bulb presently in use. Driver were exposed to three different illumination patterns: 1) a blinking light (one hertz), 2) a constant light, and 3) a shimmering/modulating light (four hertz). Drivers were not informed of the effects associated with the shimmering light. Whether the light was illuminated by the non-modulating or modulating/shimmering bulb, drivers responded appropriately to the red and green signal lights, i.e., stopped for a red light and waited for the green, or traveled through a green light. With the blinking red, drivers exhibited stop and go driving behavior. The observers independently reported that the modulation pattern was qualitatively different from what they have previously experienced with a blinking light.

A second study identified the optimum modulation rate for the shimmering bulb. Two factors entered into the decision: 1) the alternation rate must be relatively low so that the modulation could be seen at a maximum distance from the signal head, and 2) the modulation rate must be faster than one per second so as not be confused with a blinking or flashing traffic signal light. An optimum rate of four hertz was identified.

Three of the four experiments that are reported in this Final Report focused on sun backlighting and the conspicuity of the illuminated signal lens, while the fourth study examined the role of aging and the perception of the modulation pattern. All studies were approved by an institutional review board and all subjects received remuneration for their participation.

Sun Backlighting

The sun's rays cause a significant problem in recognizing an illuminated lens due to indirect lighting of the lens(es), i.e., sun backlighting. Sun backlighting (a.k.a. sun phantom) occurs when the rays enter the lens and bounce off of the internal reflector generating the impression that a non-lit lens is apparently illuminated. Backlighting depends on sun elevation and azimuth and may produce differential effects depending on distance from the traffic signal light. Thus, while one driver is affected by backlighting, others traveling in the same direction may not. A driver who sees all three lenses simultaneously illuminated may delay responding and this reaction may not be shared by the other drivers traveling in the same direction. Or the driver incorrectly identifies a non-illuminated lens as illuminated may inappropriately respond by "passing a red light" or "stopping for a green light." The potential for an accident varies and is dependent upon the presence of other vehicular and pedestrian traffic.

The sun visors placed over the lenses do reduce the duration of backlighting. However, at some point, when the sun is at about 15 degrees, the visor is no longer effective in shielding the signal lens from the sun's rays. One technique where the sun visor is lengthened does reduce the duration and effect of backlighting for the driver. However, at the same time the elongated visor increases problems for the pedestrian in viewing the signal light and requires additional maintenance of the support system caused by wind related wear and increased frequency of cleaning of the recessed lenses.

The purpose of the present research was to examine the effectiveness of an incandescent bulb where “activity” or a scanning effect was inherent in the bulb's operation. The bulb fits the existing socket and requires a minor electrical circuit to be connected inside the signal head. The modulating bulb has a number of economical and safety features: a) It is assumed that the bulb will have a longer operating life with respect to lower heat generated by each of the filaments; b) With the filaments shorter and better supported, they can sustain handling and installation abuse more successfully; and c) When one of the two filaments fails, the other assumes the modulation rate. The reduced illumination and changed modulation effect would serve as a warning to replace the bulb prior to total failure. This is not the case presently where the bulb operates on an all-or-nothing principle.

EXPERIMENT ONE

The purpose of Experiment 1 was to determine whether the modulating light could overcome the effects of a simulated sun backlighting of the traffic signal lenses. Several questions were addressed: 1) Would artificial lighting be effective in generating sun backlighting in a laboratory-type setting? 2) Would the modulating light source enhance signal recognition as compared with the standard bulb now in use? 3) Would angle of viewing effect the amount of backlighting and signal recognition? 4) If not inform about the modulation effect of the dual-filament light, how would observers interprete this shimmering and react to it, i.e., “stop and go” or “stop and wait for the green light."

METHOD

Subjects: Eight women and two men volunteered their participation. Observers ages ranged from 21 to 61 years, with a mean age of 37.7 years. All observers were tested and found to have normal visual acuity (ranging from approximately 20/16 to 20/30) and normal color vision.

Apparatus. A signal head containing a red and green plastic signal lens (Kentron, Inc.) was fastened to a wall with the bottom edge of the signal head 10 feet above the floor. The signal head measured 15 x 29 inches, with the plastic lens diameters being 12 inches.

Each lens was illuminated with either a standard single filament, 120 volt, 150 watt incandescent bulb or a dual filament bulb approximating 150 watt intensity (Brugger, 1988). Circuitry of the dual filament bulb was so designed to alternately illuminate each filament with a brief overlap. The bulbs were matched for reflectance.

The sun phantom was simulated with a 1,000 watt halogen lamp with a color temperature of 3,200 degrees. The light was spot projected through an eight inch Fresnel white light lens placed 66 inches from the red lens and aimed at the center of the signal head between the two lenses.

Procedure: Upon entering the test room, the subject was administered the Sloan Visual Acuity 40 cm chart test (Good-Lite Co., 1961) and the Dvorine Pseudo-Isochromatic Plates for color blindness (Scientific Publishing Co., 1958)

Using the point on the floor directly beneath the traffic light, a half circle with a radius of 16 feet was scribed on the floor. Two viewing stations were identified on the half circle. One represented a direct approach to the signal (90 degrees) while the other simulated a vehicle entering the street from an angle, e.g, driveway or side street, or a pedestrian preparing to cross a street (45 degrees). The subject was instructed to stand with support at each of these locations and when instructed to begin viewing, the subject flipped an opaque shield fastened to a pair of goggles, looked at the traffic signal light and imagined that he/she was at an actual intersection.

For each trial, the subject was required to report: a) which lens(es), if any was (were) illuminated, b) confidence in the response(s) ranging from (1) no confidence to (5) complete confidence, and c) the driving response to the signal that was illuminated. If the subject reported more that one lens illuminated, two confidence ratings were required. After supplying these responses the subject was instructed to close the opaque screen in preparation for the next trial. The subject was presented with four lighting patterns with the red (R) and green (G) signal lenses, and the modulating (M) and standard (S) bulbs, i.e., RM/GM, RM/GS, RS/GM, and RS/GS. These four patterns were randomly presented for each of the two viewing angles.

At each viewing angle, the subject received two randomized blocks of three trials for a subtotal of six trials. A trial consisted of either: red light illuminated, green light illuminated, or neither light illuminated. After the 12 trials were administered at each of the two viewing angles, the subject was escorted to a waiting room while bulb positions were changed for the next pattern. A total of 48 trials were presented.

RESULTS

Effectiveness of Artificial Backlighting. From the responses of the observers, the artificially-generated backlighting was effective in replicating the effects of the sun.

There was no effect for angle of viewing. The spotlight produced a phantom at all angles. However, subjective reports of the sensations elicited by the two angles were qualitatively different. When neither light was illuminated, viewing the signal face at 90 degrees, observers reported the entire lens surface appeared illuminated. With the 45 degree viewing angle, the full lens surface was not involved except for a bright spot emanating from the location of the bulb within the face giving the appearance that the bulb's filament was illuminated. These effects appeared for all lighting conditions. Subjects did report that the activity from the modulating filaments aided in the recognition of the light as being illuminated.

Finding no quantitative difference between the two viewing angles, the results for the same illuminated lens, e.g., red modulating at 45 degrees and 90 degrees, were summed across the viewing angles producing a total of 80 trials.

Illuminated Red Modulating Signal Light. On 45 trials observers correctly identified that the red light was illuminated. For the remaining 35 trials, observers reported both lights were illuminated. However, observers identified greater confidence with seeing the red light as illuminated than the non-illuminated green light.

Concerning the type of response that they would initiate if they actually approached this light, on 78 of the 80 trials, the subjects said they would "wait for the green light." On two trials, subjects indicated confusion as to what they would do, but said they would definitely stop and "maybe proceed cautiously" through the intersection.

Illuminated Red Standard Signal Light. For 32 trials observers identified the red light as illuminated. For 44 trials, they identified both lights as illuminated, and for the remaining four trials they thought neither light was illuminated. Observers indicated that they would stop for all 80 trials.

Illuminated Green Modulating Signal Light. For 78 of the 80 trials, observers reported that only one light, i.e., the green light was illuminated and they would drive through the intersection. On the remaining two trials, they reported both lights as illuminated.

Illuminated Green Standard Signal Light. For 75 of the trials, observers reported the green light as illuminated. For the remaining five trials both lights were identified as illuminated. For 69 of the 80 trials, subjects said they would drive through the intersection. On the remaining 11, they said they were confused and would stop.

Neither Light Illuminated. In each series of illuminated lights at each angle, two trials were presented where neither signal was illuminated. Eighty trials were associated with the modulating light and the non-modulating light series. No differences were found between trials associated with the modulation and non-modulation series. For the combined 160 trials, on 76 trials the green light was reported to be the only signal illuminated, on 21 trials both were reported as illuminated, and for the remaining 63 trials, observers correctly identified that neither light was illuminated.

Concerning their driving responses, on 78 trials, subjects said they would drive through the intersection, while the remaining 82 were confused and said they would stop and proceed with caution.

DISCUSSION

From the results a number of findings emerged. First, our artificial backlighting of the signal face proved to be effective. Several observers spontaneously recalled seeing the signal face under such degraded conditions. Second, observers indicated that they would stop for the red modulating bulb as they would for a non-modulating red signal. Third, the red modulating signal was identified more successfully than the non-modulating red. Fourth, due to the modulating bulb's novel lighting pattern, subjects may not have been using the modulation as a reliable cue for identifying lens color. Fifth, the red and green lenses were differentially affected by backlighting. The green lens produces more backlighting than the red. And sixth, a blacked-out signal being backlighted is a very dangerous condition. In this latter case, the Brugger bulb offers a special advantage as compared with the standard, non-modulating bulb in that when one filament fails, the other continues to operate. This situation would allow for the light to continue to operate and serve as a warning to be replaced.

A post-test interview showed that all subjects reported a preference for the modulating bulb as compared to the standard bulb now in use as it aided the identification of the illuminated signal.

EXPERIMENT TWO

Experiment 2 investigated the role of signal conspicuity with the modulating lights under a dynamic viewing condition. In this experiment subjects were required to drive a three-wheeled vehicle towards a traffic signal face and perform tasks similar to what would be expected in the natural environment.

Method

Subjects. Twelve men and two woman volunteered their participation. Participants ranged in age from 21 to 69 years, with a mean age of 35 years.

Apparatus. The standard condition used a 150 watt Hytron traffic signal bulb. The modulating bulb employed a brief overlap between the two filaments. The phantom was generated with a 2000 watt halogen bulb. A highway traffic signal face with 12 inch diameter glass lenses was suspended fifteen feet above the floor in a ballroom on the school's campus. The halogen spotlight was placed three feet in front of and slightly above the red traffic light.

Visual Screening. Visual acuity and color deficiencies were determined with a Bausch and Lomb Orthorater and the Dvorine Pseudo-Isochromatic Plates.

Procedure. The participants were required to drive a small three-wheeled electric cart on a simulated roadway in a ballroom. To prevent subjects from focusing their attention solely on the traffic signal, they were instructed to drive with the front wheel of the vehicle on a three inch wide stripe for the entire 70 foot length of the runway and to call out locations of the openings of the Landolt Cs. Landolt Cs were 6.5 inches with an opening of one inch and were placed five feet from the centering line, at intervals of 10 feet, alternating left and right. When confident of the illuminated lens, subjects were required to identify the color of the illuminated lens. Upon reaching the simulated intersection, they were required to respond to the signal light by either stopping and waiting for the green or driving through. One subject failed to follow directions and his data were discarded.

Each subject received a total of 12 trials, six with the modulating light series and six with the non-modulating light series. Half of the subjects received one series first before receiving the other. The order was reversed for the other half of the subjects. For the six trials, red and green lights were each illuminated twice and for the remaining two trials no lights were illuminated. These six trials were randomly determined. For each trial, the experimenter walked (jogged) behind the subject recording the reported color of the light, distance when color of lens was identified, and the response to the signal.

RESULTS

Errors in recognizing the actual illuminated light occurred infrequently. There were only seven errors out of 56 total trials and these recognition errors were found only with the non-modulating light source. There were no recognition errors associated with the modulating light.

Distance recognition as a function of the modulation and standard lights showed no systematic effect. However, with standard lighting, subjects failed to call out the color of the light while driving towards the intersection on 15 of the 56 trials. With modulation, subjects failed to provide a distance judgment on only 3 of 56 trials.

Twelve of the 14 subjects spontaneously reported a definite preference for the modulating light. Several drivers reported that the modulation "grabbed" their attention. The two subjects who did not indicate a preference for the modulating lights failed to notice the shimmer. They indicated that they were very concerned with identifying the Landolt C openings and did not recall seeing any modulation. One of these subject was responsible for three recognition and subsequent driving errors in the standard condition, but no such errors occurred in the modulation condition.

When the lenses were not illuminated with either type of bulb and were exposed to backlighting, subject always identified one of the two unlit lens as illuminated. Red and green were identified equally often and the driving responses were appropriate for the apparently illuminated lens.

DISCUSSION

The results with modulation were very encouraging with respect to signal and lens conspicuity. Drivers were completely successful in identifying and responding to the modulating light pattern as compared to the standard bulb in a degraded condition involving backlighting.

Concerning color deficiencies, two of our subjects tested positive for red-green color deficiencies. No errors in identifying color were found with our color deficient subjects. Whillans (1983) reported that some color deficient individuals see the illuminated red lens as amber and the illuminated green lens as a street light. Further research is necessary to determine the extent of red-green color deficiency and lens identification under all conditions of viewing. There was only one error in color naming, i.e., the illuminated red was called yellow, and this was made by a normal color-visioned subject.

EXPERIMENT THREE

The previous experiments showed 100 percent accuracy when the signal lens contained a modulating light source as compared to the standard bulb now in use. With this greater recognition accuracy, it was expected that observers would require less time to identify the illuminated signal under degraded viewing conditions than with the standard bulb under conditions of simulated sun phantom.

METHOD

Subjects. Seven observers, three men and four women, ranging in age from 18 to 35 volunteered their participation. Two subjects were red-green color deficient.

Procedure. In a ballroom on campus, the subject was seated at a desk placing his/her chin on an adjustable chin rest. The subject was instructed to grasp two upright handles which controlled an aiming device five feet from the chin rest. The far end of the aiming device contained two upright dowels 4.5 inches apart. The subject was to move the aiming device from side to side keeping a moving upright target, 60 feet away, in the center of the aiming device. The moving target was fastened to an arm 19 inches long which was rotated horizontally.

An electronic blindfold was placed in line with the traffic light at the front of the desk. The subject could not see the signal until the blindfold was opened. The experimenter operated a switch which simultaneously opened the electronic blindfold, turned on the traffic light, and activated the stop clock. When the subject called out a response through the voice key the electronic blindfold closed and the clock was stopped. The reaction durations for each trial were recorded and the procedure was repeated until all trials from a block randomized trial sheet were completed.

While the subjects tracked the moving target, the experimenter triggered the electronic blindfold allowing the subject full view of the lens.

Only one signal lens was presented during a trial. The lens was placed on a platform 14 feet above the floor and 71 feet from the subject, subtending an angle of 20 degrees.

Subjects were presented with the red and green lenses with both modulating and standard bulbs. For one-half of the trials backlighting was present and for the other half backlighting was not present. A control condition was administered where backlighting was presented to the unlit lens. The phantom was created by suspending a 1000 WATT floodlight 24 inches from the traffic light at an angle of approximately 16 degrees to the light.

RESULTS

A series of t-tests showed no statistical differences in reaction times between the modulating and non-modulating bulbs. There were differences between artificially-induced backlighting and non-backlighting conditions.

When backlighting was present, subjects identified the illuminated modulating green lens correctly (100 percent) and 93 percent for the modulating red. In comparison, when the phantom was paired with the standard traffic light bulb subjects responded correctly 93% for the green light and 87% for the red light.

When the artificial sun-backlighting condition was paired with neither light internally activated, subjects were consistent with the previous studies.

The non-lit red light was reported illuminated 48.3% of the time. The non-lit green light was reported illuminated 50% of the time. A non-backlit, non-illuminated lens, on the other hand, was never identified as illuminated.

DISCUSSION

No differences were found in reaction time between the modulating and non-modulating bulbs. Errors of recognition, although rare, were associated more so with the non-modulating light source. One subject who was red-green color deficient was responsible for numerous color recognition errors.

All of the subjects reported that they preferred the modulating light as compared with the non-modulating light, especially under degraded viewing.

The use of the voice key may have been inappropriate. As soon as the electronic blindfold was opened, subjects would react initially with an inappropriate vocal utterance and this was followed by color-naming. Efforts to have the subject respond only with appropriate verbalizations were not effective.

EXPERIMENT FOUR

As compared with younger drivers, older drivers may benefit more from the modulating light source placed in the signal head. Whereas accidents involving younger drivers are attributed to such factors as speeding and driving while intoxicated, the older driver fails to heed signs, yield the right of way, or turn properly (Planek, 1973; Huston & Janke, 1986). The modulating light bulb may improve signal recognition and reduce such driving errors. The present research was designed to examine whether age related visual changes affect the recognition, distance, and quality of the modulation effect. As older drivers prefer daylight hours for driving, the research was conducted under photopic conditions.

METHOD

Subjects. Twenty-eight licensed men and women drivers were paid $5.00 for their participation. Subjects formed three age groups: a) young-ages 20 to 32, n = 9, mean age of 22 years, b) mid-ages 38 to 54, n = 9, mean age of 46 years, and c) older-ages 59 to 80, n = 10, mean age of 66 years. Nine men were found to be red-green color deficient. Each age group had at least two red-green color deficient observers.

Visual Screening. Visual acuity was determined with a Bausch and Lomb Orthorater using only the far visual acuity plates. Color deficiencies were identified with the Dvorine Pseudo-Isochromatic Plates color vision test.

Procedure. Observers sat on the passenger side of a full-sized vehicle driven at a speed of approximately 26 km. toward a three light traffic signal face. The bottom of the signal face was 4.92 m. from the road surface. Green and red lenses, 30.5 cm. dia., of the traffic light were illuminated by either a 150 watt Hytron bulb or a dual filament bulb modulating at a rate of 4 hz. Bulbs were matched for brightness.

Subjects began viewing the traffic light from a distance of 262 m. and were required to identify the color and amount of flicker, if any, using a five point scale, and any other unusual aspects of the traffic light. Distances from the light were recorded with a NuMetrics Roadstar Model 20 computer connected to the vehicle's transmission.

Eight different lighting conditions were administered twice for a total of 16 trials. Each colored lens was placed in the top position of the traffic signal face for eight trials and in the bottom for the remaining eight trials. The modulating and standard bulbs appeared equally often in each of these positions. Trials were block randomized. A post-test interview focused on observers impressions of the modulating light bulb.

RESULTS

The modulating effect of the dual-filament bulb produced reports of both quantitative and qualitative changes as subjects approached the traffic signal face. No significant differences were found among the three age groups. Within each age group large inter-subject variability was found.

With the Orthorater, visual performance on the far distance plates decreased with increasing age. However, the perception of the modulation pattern showed no relationship with Orthorater performance.
The modulating pattern in the green and red lenses produced differential distance effects. The green lens was perceived as showing “some” modulation significantly farther away (171 m., sd = 38.8) than the

red lens (130.8 m., sd = 53.5), $F(1,54)=16.2$, $p<.001$). A change in the reported modulation pattern to "more" followed a similar pattern, $F(1,51)=8.6$, $p<.05$.

During inclement weather, i.e., rain, fog, and overcast skies, the modulation pattern was seen farther away than under sunny conditions. A significant inverse relationship was found between the report of “some” modulation and weather for both the green and red lenses, $r=-.47$, $df=26$, $p<.01$, and $r=-.35$, $df=26$, $p<.05$, respectively.

A post-test interview showed that 64 percent of the subjects preferred the modulating light over the standard light. Two observers reported that the modulating light "attracted their attention” and found it "annoying.”

Of the nine red-green color deficient participants, none incorrectly identified the color of the illuminated lens regardless of the lens' position in the traffic signal face. All of these observers reported a preference for the modulating red lens while the normal color visioned subjects were mixed with respect to their preference.

DISCUSSION

The modulation effect showed no differences among the three age groups in both the range of modulation and in the qualitative changes associated with the modulation pattern.

The large variabilities found within each age group may be attributed to the difficulty in conveying precise terminology to characterize the modulating light pattern and any subsequent changes as viewing distance decreases. When asked to supply their own descriptors to define the effect, observers showed little consistency. The most commonly elicited terms included "shimmering", "flickering", and "modulating."

Changes in the weather from photopic to mesopic conditions increased the range of influence of the modulating light. Regardless of the weather conditions, the overall range of the modulating light was limited. However, perception of the modulation would allow ample time for drivers to initiate an appropriate response under both normal and degraded viewing conditions.

In the present study, with uncompromised viewing conditions, 64 percent of the subjects indicated a preference for the modulating light in the traffic signal face. In a previous study which used a degraded viewing condition involving simulated sun backlighting of the traffic signal lenses, 12 of 14 subjects who reported seeing the modulation were unanimous in their preference for the modulation. Of the two subjects who could not recall seeing the modulation, one committed several recognition and driving errors with the standard light source, but not with the modulating light (Guzy, et al., 1990). The difference in preferences may be attributable to a difference in procedures. In the earlier study, subjects were required to drive a three-wheeled vehicle along a prescribed route, identify signs placed along a simulated roadway, report the color of the illuminated lens, and at a simulated intersection respond accordingly, i.e., drive through or stop. The procedure in this study required the subject to identify the presence of modulation and to report any changes. Several of the passengers indicated that they had fixated on the illuminated lens for the entire duration of the trial (approx. 35 seconds) to the exclusion of all other visual information. Without these distractor tasks, the singular task of viewing the illuminated signal may account for the reduced preference and in two cases, annoyance.

Given the difficulties associated with the older drivers, e.g., heeding signs and responding to information in the periphery (Kosnik, Sekuler, & Kline, 1990), the use of the modulating light may possibly improve intersection safety by enhancing the detection of the traffic signal face and recognition of the illuminated lens.

GENERAL DISCUSSION

In general, the modulating light enhanced signal lens conspicuity in a variety of situations. In the backlighting experiments, no errors were found with the modulating light source. This was not the case with the standard light source now in use. Although infrequent, both errors of recognition and driving responses were found and these included driving through a red light and stopping for a green light. No differences across the life span were found. Regardless of age, subjects saw the modulation at about the same distance. This distance, although apparently limited, would appear to be in the appropriate area where drivers should begin to address the signal light to allow sufficient time for a response.

Concerning the pedestrian, Experiment One showed that at a 45 degree viewing angle with a backlighted traffic signal, identification of the illuminated lens was enhanced with a modulating signal.
In post-test interviews, drivers observations were mixed and these were dependent on the viewing condition. If viewing was degraded, observers unanimously preferred the modulating light source. Under normal viewing, the responses were positive, but less than unanimous.

The question of whether drivers who were not informed about the modulation effect would stop for a modulating red light needs further study at an actual location. The present results strongly suggest that drivers do respond to the modulating red light as if it were a standard, non-modulating red light. However, the demands of the experiment may have played a role. Some subjects identified the modulation as similar to a loose connection or some other electrical defect with the signal equipment. If this is the case, a few drivers may interpret this as a malfunctioning light and respond inappropriately.

The issue of red-green color deficient observers needs to be additionally addressed. Whillan's reported that from his survey, these subjects had a number of difficulties, i.e., mistaking yellow for red and street lights for green. However, a more comprehensive study needs to be conducted with normal visioned drivers as well.

At present, in vivo testing of the modulating light is being planned for the City of Oneonta. Two locations have been identified and baseline observations are presently being conducted. Plans are to have the modulating bulb inserted in the signal face in easrly 1992.

As most signals contain 100 watt bulbs, a 100 watt modulating bulb needs to be designed and manufactured to allow a more universal testing of the bulb.

I have identified the azimuth reading of all the traffic lights in Oneonta, NY. Using a computer program to plot the angle and azimuth of the sun, I am able to identify the critical times when sun backlighting will occur and correlate this with the appropriate signal face. Teams will be assigned to these locations to observe drivers' responses in a naturalistic setting. Depending on the seriousness of the problem found at these location, it would be possible to alert drivers prior to their encountering the signal face of the potential hazard that exists.

In summary, the modulating bulb with its unusual visual effects improved the conspicuity of an illuminated signal and merits testing in the environment and further testing on the subject variables identified above and others, as well, e.g., cataract development.

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