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Pedestrian Conspicuity: The Effects of Retroreflector Placement and Retroreflectivity

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PEDESTRIAN CONSPICUITY AT NIGHT:
THE EFFECTS OF RETROREFLECTOR PLACEMENT AND RETROREFLECTION

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ABSTRACT

One factor that has been causally linked to nighttime pedestrian-vehicle collisions is pedestrians being insufficiently conspicuous to drivers. Pedestrian conspicuity can be enhanced by use of retroreflective material, and this on-road experiment investigated the influence of retroreflector configuration, the coefficient of retroreflection (R_A) of those retroreflectors, and pedestrian motion on conspicuity. There were two retroreflector configurations, three levels of R_A, and the test pedestrian either walked or stood in place. Data from 121 participants are reported. The pedestrian was detected by more participants and at greater distances when the pedestrian was walking and wearing retroreflectors on the wrists and ankles (W+A). Response distances to the walking pedestrian wearing the W+A configuration increased as R_A increased. Increasing R_A did not, however, increase response distances to the standing pedestrian wearing the W+A configuration, the standing pedestrian wearing the torso configuration, or the walking pedestrian wearing the torso configuration. These results suggest that R_A may increase pedestrian conspicuity when biological motion information is present but R_A may not increase pedestrian conspicuity when biological information is not present.

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INTRODUCTION

Collisions between vehicles and pedestrians are a significant problem, and substantial evidence indicates that the problem is closely linked with low illumination. Between the years 1998 through 2001 of 18,000 recorded pedestrian road fatalities 11,000 (61%) occurred in conditions of low illumination (NHTSA, 2003). In the year 2004 there were 4,641 recorded pedestrian road fatalities in the United States, and 66% of these fatalities occurred at night (NHTSA, 2004). Nighttime pedestrian road fatalities have even been linked with fluctuations in illumination provided by the different moon phases. Pedestrian fatalities are 22% higher on nights with a new moon compared to nights with a full moon (Sivak, Schoettle, & Tsimoni, 2007). Under full daytime illumination pedestrian road fatality rates are lower than nighttime rates even after controlling for incidents involving alcohol and fatigue (Owens & Sivak, 1996). Owens and Sivak (1996) report that nighttime pedestrian road fatalities, occurring at the same time during the day, are greater during the darker winter months than during the brighter summer months; fatal traffic incidences not involving pedestrians do not show this trend. Pedestrian traffic fatalities can be attributed to pedestrians having low contrast during low light levels. It has been shown that reduced visibility due to low illumination and low contrast negatively affects driver's ability to detect objects (Plainis & Murray 2002). A possible but expensive solution that could increase the conspicuity of pedestrians is to increase roadway illumination as it has been shown that increased road light intensity leads to significant reductions in nighttime pedestrian crashes (Retting & Ferguson, McCartt, 2003). A less expensive approach to enhancing the conspicuity of pedestrians involves using retroreflective material – material that has been engineered to passively reflect light back in the direction of its source. Retroreflective material is widely used to increase legibility distance for road signs at night and to enhance the contrast of lane delineators (Olson & Bernstein, 1977; Schnell, Aktan & Lee, 2004). Similarly, retroreflective material can be applied to pedestrians as nighttime visibility aids for drivers (Langham & Moberly, 2003; Moon & Warring, 1935; Shinar, 1985).

In comparison to other methods of increasing visibility distance (e.g. by using flashlights) retroreflective material has the practical advantage of having a long lifespan and being independent from having an internal power source (Blomberg, Hale & Preussser, 1986). There are some disadvantages to using retroreflective material. Consequently, it is important to understand the reflective properties of retroreflective material because it is almost never functioning at optimal performance. Non-retroreflective surfaces reflect light diffusely or like a mirror. Retroreflective surfaces, however, have higher reflected light in the direction of the light source. Reflected light leaves a retroreflective surface as a cone that is centered in the direction of the light source. Thus the greatest amount of light is located at the center of the cone and decreases as eccentricity increases. Because of this distribution the amount of retroreflected light reaching the observers' eyes depends on viewing geometry (Figure 1). Specifically, two angles are relevant: observation angle and entrance angle. Observation angle is the angle between the observer's eye, the retroreflector, and the headlamp. Observation angle increases as the separation between the viewer and the light source grows. Entrance angle is the angle between the headlamp and the perpendicular to the retroreflector. Entrance angle is zero when the retroreflector is perpendicular to the light source (FHWA, 2003).

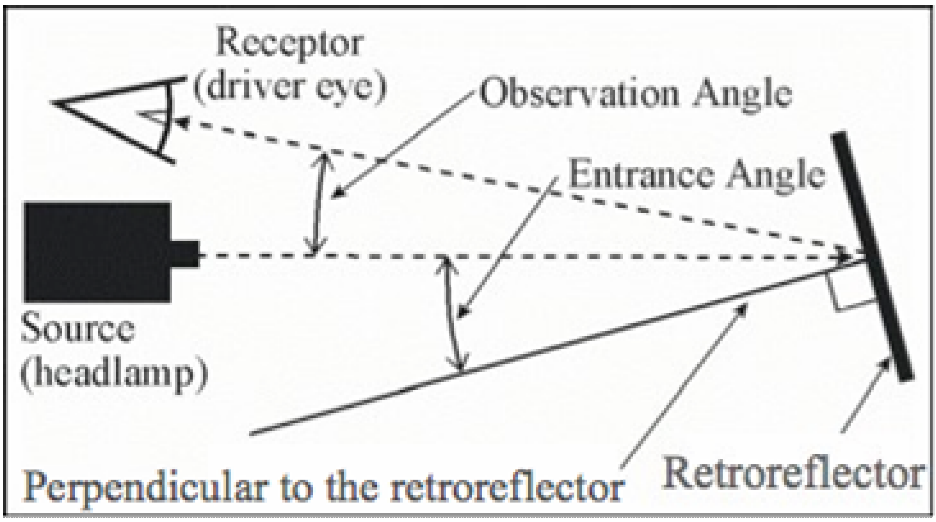

Figure 1. Retroreflector viewing geometry (from FHWA, 2003).

Retroreflection is quantified as a ratio of retroreflected luminance at the observer's eyes to the illuminance at the retroreflector ($cd/lux/m^2$); this is also known as the coefficient of retroreflection or R_A (Rennilson, 1982). As can be seen in Figure 2, changes in observation angle have a dramatic effect on R_A; even small deviations outward from center result in a large drop in retroreflected luminance reaching the observer. Empirical measurements of the distance at which human observers detect retroreflective material have shown that the distance required to see retroreflective material is sensitive to these fluctuations in retroreflectivity (Rumar, 1990).

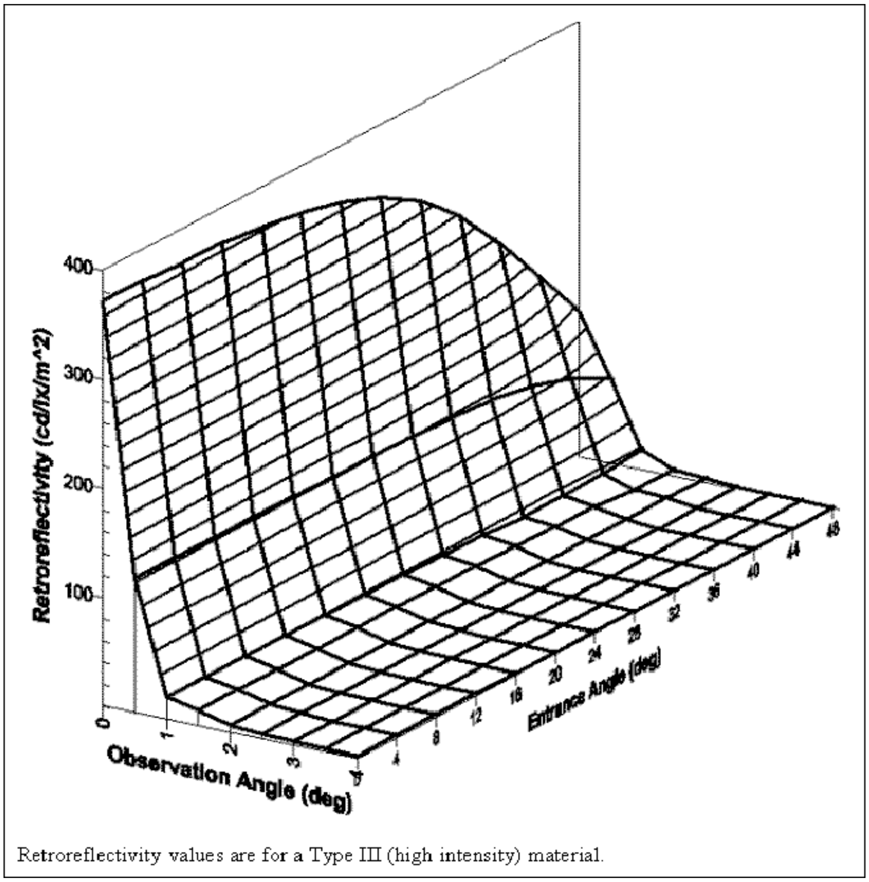

Figure 2. The effect of changes in observation angle and entrance angle on retroreflectivity or the coefficient of retroreflection (R_A), (from FHWA, 2003).

Sivak, Flannagan and Gellatly (1991) measured driver eye height and headlamp height from a sample of 445 vehicles and calculated observation angles for viewing a road sign. The results show that at a distance of five hundred feet from a retroreflective road sign the amount of luminance reaching the eyes of a truck driver is 68% of the luminance reaching the eyes of a car driver. At a thousand feet distance this value drops to 25%. Although these results were calculated for road-sign retroreflectors it is reasonable to assume similar results for pedestrian retroreflectors.

Two other factors that can decrease retroreflection are the accumulation of dirt on a retroreflector and retroreflector age. Dirt and grime accumulation on semi-trailer markings have been shown to decrease retroreflectivity by 28% (Olson, Campbell, Massie, Battle, Traube, Aoki, Sato, & Pettis, 1992). Dirt attenuates retroreflectivity by reducing both incident light and retroreflected luminance. In dark conditions, dirt accumulation on semi trailer retroreflectors has been shown to affect rear impact crashes where clean retroreflective tape showed a greater reduction (53%) in crashes compared to dirty tape (27%). In dark conditions absent of streetlight illumination, clean tape showed a 62% reduction in crashes where dirty tape showed a 33% reduction (Morgan, 2001).

Exploring the effects of retroreflector age, Olson et al. (1992) found that retroreflectivity starts degrading almost instantly and over 5 years retroreflective performance can degrade by nearly 30%. The current study will be using retroreflective material that simulates approximately a 76% decrease and a 98% decrease in retroreflectivity. It is believed that using these values will generate data with relevance to the combined degrading effects of relatively large observation angles, accumulation of dirt, and aging retroreflectors.

Retroreflected luminance may increase the contrast of pedestrians donning garments with retroreflective markings but the usefulness of this increased contrast may depend on environmental factors. Sayer and Mefford (2004a) found that when pedestrians wore safety garments with higher R_A values observers' detection distances increased in a condition of low ambient light (1 lux). Thus low levels of retroreflectivity can lead to shorter detection distances in conditions of low ambient light. Paradoxically, in a condition of high ambient light (60 lux) higher R_A did not increase detection distance compared to lower R_A. Cassidy, Brooks and Anderson (2005) conducted an experiment on detection distance for two different retroreflective garment designs and three different levels of retroreflectivity. The two garments were different in the total amount of retroreflective area. One garment, called area-reflective, consisted of retroreflective material distributed evenly across a silhouette of a static human. The second garment, called conventional trim, consisted of eight stripes of retroreflective material in locations on a human silhouette akin to the elbows, wrists, chest, waist and ankles. Retroreflectivity was equated across the garment designs at three different levels (low, moderate and high). Increases in retroreflectivity lead to drivers having increased detection and recognition distance for both garment designs. Averaged over the three different retroreflective levels, detection distance and recognition distance were greater for the conventional trim silhouette compared to the area-coverage silhouette. The greatest detection distance was for the conventional trim design at the highest level of retroreflection. Lower levels of retroreflectivity were associated with shorter detection distances. A problem uncovered by Sayer and Mefford (2004a), and Cassidy et al. (2005) is that detection and recognition distances for retroreflective garments are poor when R_A is low. It is possible that this problem could be overcome by pedestrian motion. Walking has been shown to increase the distance at which observers respond to pedestrians across various reflective garment designs (Balk, Tyrrell, Brooks, & Carpenter, in press; Moberly & Langham, 2002).

Retroreflectors placed on the extremities of a moving pedestrian can increase detection and recognition distances by providing information that specifies human gait (Blomberg, Hale & Preusser, 1986; Luoma, Schumann & Traube, 1995; Owens, Antonoff & Francis, 1994; Sayer & Mefford, 2004b). This phenomenon is typically attributed to Johansson's (1973) discovery that humans can identify other humans when the only visible information is that of points-lights placed on an actor's major joints.

Johansson (1973) found that observers could identify point-light walkers almost instantaneously. This phenomenon has been attributed to the rigid relationship between human joint endpoints where the point-light markers are positioned. Each marker moves relative to the other markers placed on the joints. The resulting "biological motion" disappears when the point-lights are stationary. Bertenthal and Pinto (1994) claim that the detection of point-light walkers is not dependent on realizing the local relationships between point-lights but rather emergent global motion patterns that specify human gait. In an inverted display of a point-light walker the local relationship between point-lights are kept constant but observers do not recognize the walker as a human. Accordingly, perception of a human in a point-light display must rely on coherent human motion that disappears when the display is inverted. Understandably the position of the point-lights on an actor can affect the perception of it. Point-lights at the wrists and ankles provide the most useful movement information, perhaps because these joints have the greatest amounts of displacement compared to point-lights on the shoulders, elbows, hip and knees. Eliminating point-lights at the ankles and wrists has a greater negative impact on recognition compared to eliminating point-lights at the shoulders, elbows, hip and knees

(Mather, Radford, & West, 1992). While research using point-light displays has informed researchers interested in the perception of biological motion this research also has the potential to be applied to the problem of pedestrians being inconspicuous to drivers at night.

Owens, Antonoff and Francis (1994) applied the biological motion theory proposed by Johansson in an experiment on pedestrian visibility at night. They found that observers could identify pedestrians wearing retroreflective markings placed on the major joints quicker than pedestrians wearing markings placed only on the torso. They also found that observers elicited similar recognition times for pedestrians wearing retroreflective markings on all the major joints compared to pedestrians wearing markings on each arm, each leg, and the torso. It has also been shown that pedestrians may not have to don retroreflectors on all of their major joints in order to be identified by drivers. Positioning retroreflectors on the wrists and ankles appear to be similar in effectiveness compared to applying retroreflectors to major joints (Balk et al., in press; Luoma & Penttinen, 1998; Luoma, Schumann & Traube, 1995). Motion is a key element to the effectiveness of retroreflectors placed on the joints. Positioning retroreflectors on the major joints increases driver response distance for a stationary pedestrian but has the largest effect while the pedestrian is in motion (Balk et al. in press; Balk, Graving, Chanko & Tyrrell, 2007; Sayer & Mefford, 2004b). Retroreflective markings on the major joints may also have benefit stationary pedestrians. Balk et al. (in press) found that standing pedestrians wearing retroreflective markings on the major joints were seen at approximately 4 times the distance of a standing pedestrian wearing a rectangular torso marking. These data suggest that the placement of retroreflectors on the joints may increase conspicuity even in the absence of pedestrian motion. But the Balk et al. (in press) data also reveal the importance of pedestrian motion; response distances were clearly increased when the pedestrian walked as long as there were retroreflectors on the extremities. Balk et al. (in press) concluded that the conspicuity advantage that is typically attributed to "biological motion" is actually a combined effect of facilitating form perception by highlighting the static human form and facilitating motion perception by highlighting the pedestrian's natural movement.

Sayer and Mefford (2004b) found a 32% increase in detection distance for walking pedestrians compared to standing pedestrians wearing either retroreflective arm markings or a retroreflective vest. There was a non-significant trend showing that retroreflective arm markings were detected at greater distances than the retroreflective vest. This trend was attributed to biological motion information provided by the arm treatments. Moberly and Langham (2002) also found an effect of pedestrian motion. They found that the probability of detecting a pedestrian increased with motion and that successful detection was moderately dependent on garment design because detection accuracy was greater for pedestrians donning retroreflectors in a biological motion configuration. Paradoxically, detection distances for biological motion garments were shorter in comparison to detection distances for a vest condition. This result was later attributed to low levels of statistical power (Langham & Moberly, 2003) that resulted from detection failure rates being almost two times greater for the vest condition compared to the biological motion condition. Wood, Tyrrell and Carberry (2005) found similar effects where pedestrians wearing retroreflective markings in a full biological motion configuration were detected at a much higher frequency but at greater distances than pedestrians wearing a retroreflective panel on their chest. Moving pedestrians in a biological motion condition were seen by drivers in 93.3% of the trials at an average distance of 165.5 m but pedestrians wearing a retroreflective panel on their chest were seen in 83.8% of the trials at an average distance of only 55.5 m. Pedestrians wearing all black were seen on only 33.8% of the trials and at an average distance of only 12.8 m. These data are consistent with the hypothesis that positioning retroreflectors on the joints of a pedestrian enhances visibility by facilitating the perception of biological motion.

Placing retroreflective markings on the joints in a way that facilitates the perception of biological motion may alleviate the need for drivers to infer that a retroreflector indicates the presence of a pedestrian. Retroreflector detection distance far surpasses the distance required to recognize a pedestrian wearing a retroreflector (Blomberg, Hale & Preusser, 1986). Shinar (1985) compared pedestrian detection distances under different levels of observer expectancy. During low levels of expectancy, when drivers were unaware of where or when a pedestrian would appear on the roadway, observers were able to detect a retroreflector at a much greater distance compared to having to recognize a pedestrian wearing the same retroreflector. The difference between detection distance and recognition distance disappeared when expectancy levels were increased. Telling participants where and when the pedestrian would appear in a roadway increased expectancy. In Shinar's (1985) study detection distance for pedestrians wearing non-retroreflective material and retroreflective material were increased to distances well beyond stopping distance for a car going 90km/h. This only occurred when observers expected that a pedestrian was located in the roadway or when observers knew that a retroreflector signified the presence of a pedestrian. The value of retroreflective markings is greater when drivers do not have to infer the meaning of the retroreflective markings. These findings highlight the need to distinguish between simply detecting retroreflective markings and recognizing that the markings represent a human. In an on-road study of nighttime pedestrian visibility Luoma and Penttinen (1998) compared driver recognition distances for moving pedestrians under four different clothing conditions. Responses from Finnish participants and participants from Michigan were compared for recognition distances of pedestrians that either did not wear retroreflectors, or wore retroreflectors on the torso, on the ankles and wrists, or major joints. A significant interaction was found between the region of testing and retroreflector configuration. Finnish participants recognized pedestrians in the torso clothing condition from greater distances then participants from Michigan. Michigan and Finnish drivers recognized pedestrians in the wrists and ankles condition from similar distances. This interaction was explained by the fact that at the time of the study Finnish drivers had more experience with pedestrian retroreflectors because Finland required that pedestrians and bicyclists wear retroreflective markings when traveling near traffic at night. Luoma and Penttinen's (1998) results suggest that pedestrian recognition distance can be influenced by experience with pedestrian retroreflectors but that retroreflector placement on the wrists and ankles may reduce the dependence on experience. Thus strategic placement of retroreflectors on the major joints may diminish the need for drivers to infer the meaning of retroreflective markings.

While retroreflective material increases detection distances as a result of increased contrast between the retroreflector and the surrounding environment in which it is placed it does not always follow that the use of retroreflective material increases object recognition. An object's conspicuousness depends on the similarity between its features relative to its background. Engle (1971) offers this definition of conspicuity, as it is the, "…properties of a visible object in its background by which it attracts attention via the visual system, and is seen in consequence." Engel (1971) found that the probability of detecting a *defined* target at an *unknown* location was dependent on the features of *the target* and its background. Participants were instructed to indicate if they detected a square amid an array of hundreds of random lines during a 75 msec exposure period. The probability of detecting the target was the greatest when the disparity between the target's shape and the background increased (i.e. detecting a square occurred more often compared to detecting a small line). Accordingly, pedestrian conspicuity at night should depend on the disparity between pedestrian features and background elements. Manipulating contrast by using retroreflective material is the most common practice for creating disparity. The most effective method to increase pedestrian conspicuity is to place retroreflectors in positions that facilitate biological motion perception.

As discussed earlier in regards to Shinar (1985) and Luoma and Penttinen (1998) research finding that conspicuity can also be dependent on the observer's expectancy. Hughes and Cole (1986) found that the probability of detecting an object while driving depended on the instructions given to drivers. Drivers were either; provided cues and instructed to search for specific objects under a condition termed *search conspicuity*, or drivers were not provided cues and were only told to report objects seen while driving. This second condition was called *attention conspicuity*. Under the conditions of attention conspicuity object identification is specific to the features of detected objects. Thus, attention conspicuity can be dependent on luminance as a feature. In Hughes and Cole's (1984) study a black disk was detected at a much lower frequency compared to a grey and white disk of equal size. When expectancy was elevated in the search conspicuity condition, the effect of luminance was apparent but the probability of correct detection increased by a factor of approximately six. Data from Hughes and Cole (1984) and Shinar (1985) show that driver expectancy can increase detection distance regardless of the features of the object that is to be detected. As a result, expectancy should be carefully controlled in pedestrian conspicuity experiments to ensure that learning the significance of a retroreflector does not spuriously increase pedestrian response distance.

Using a between-subjects experimental design can mitigate expectancy. Moberly and Langham (2002) relied on a single-stimulus between-subjects design in their experiment comparing detection distance for pedestrians wearing retroreflectors on the major joints to pedestrians wearing retroreflectors on the torso. In this type of experimental design pedestrian detection is not confounded by expectancy to the same degree as within-subjects designed studies. Because participants in a single-stimulus between-subjects design respond to only one stimulus presentation their responses cannot be influenced by their experiences with previous trials of the experiment. Langham and

Moberly (2003) state that single-stimulus between-subjects designs have stronger ecological validity where within-subjects designs introduce "artificially high levels of expectancy" (p. 355). Other research has successfully used single-stimulus between-subjects designs with promising results for experiments on drivers' response distances for pedestrians wearing retroreflective material in a biological motion configuration (Balk et al, 2007; Balk, et al., in press). Although a between-subjects design requires many more participants than a within-subjects design the results from a between-subjects study have a reduced risk of being affected by learning effects. For this reason the present study will rely upon manipulations that are varied between-subjects.

While retroreflective material has been shown to be useful in increasing the visibility and conspicuity of pedestrians at night, retroreflective material is not always optimally retroreflective. As described previously, reduced retroreflectivity can reduce the distance at which drivers detect and respond to the presence of pedestrians at night. However, strategic placement of retroreflectors on the joints of a pedestrian may help overcome this problem. That is, the problems associated with decreased retroreflectivity may be smaller when retroreflective markings are configured to facilitate the perception of biological motion. One goal of the present study was to determine whether biological motion configurations could help mitigate the undesirable effects of reduced retroreflection. The results indicate that R_A may have a slight influence on conspicuity for walking pedestrians wearing retroreflectors on their limbs but little influence otherwise, i.e. while standing or wearing retroreflectors only on the torso.

The present study quantified the separate and combined effects of retroreflectivity (R_A), retroreflector configuration, and pedestrian motion on the nighttime conspicuity of pedestrians. Retroreflectivity was manipulated by screen-printing black ink on the outer surface of beaded retroreflective material (see Appendix A). Three levels of R_A (10, 138, and 581 cd/lux/m^2) were chosen. Two configurations of retroreflective markings were constructed with these materials. One configuration placed retroreflectors on the wrists and ankles (W+A) and the other placed markings on the torso. The torso markings were designed to be consistent with the ANSI class-II vest design and consisted of two vertical stripes from the shoulder to the middle of the torso and one horizontal stripe at the bottom of the two vertical stripes that crosses the torso. Responses to these manipulations were collected at night from participants seated in a car driven down a rural roadway.

METHODS

Participants

One hundred-fifty nine (age 18-23, 73 male) Clemson University undergraduate students having 20/40 (0.3 logMar) or better binocular visual acuity participated in this study. Acuity was assessed using a Bailey-Lovie chart. Participants received course-credit in exchange for participating and did not know the intention of the study prior to participation. Two participants volunteered and did not receive compensation. Data from 38 participants had to be eliminated and replaced for one of two possible reasons, the trial contained extraneous vehicles that likely interfered with participants' ability to see the test pedestrian, or the participant's button press resulted in a void response due to complications with the response system. Data from 121 participants are reported.

Design

The experiment had a single-stimulus between-subjects 3-way factorial design. Three variables were investigated: R_A (10, 138, and 581 cd/lux/m^2), retroreflector configuration (torso or W+A), and pedestrian motion (standing or walking in place). Each participant experienced only one of the 12 conditions. Participants were quasi-randomly assigned to a condition. Of the 121 reported participants; there were 10 participants for each condition, except for one condition that had data from 11 participants. Participant response distance was calculated as a product of the speed of the car and the time that separated the participant's response from the moment when the test vehicle reached the test pedestrian.

Materials

The test pedestrians wore a black sweat suit with interchangeable retroreflective markings attached in two different configurations. One configuration placed markings on the pedestrian's torso as shown in Figure 3. The other configuration, Wrists + Ankles (W+A), placed the retroreflective markings on the wrists and ankles. The markings were attached to the sweat suit using Velcro. The torso configuration had three stripes of silver Scotchlite retroreflective material attached to the black sweatshirt. The retroreflective material had a total frontal area of 0.02 m^2. Each stripe was 0.02 m wide; there was one 0.67 m horizontal stripe and two 0.33 m vertical stripes. The W+A configuration had four retroreflectors placed on the body with the total frontal area of retroreflective material being equal to the vest (0.025 m^2). On each wrist area and ankle area there was a 0.07 m by 0.08 m square (see Figure 3). There were a total of 6 sets of retroreflective markings, one for each configuration at the three levels of R_A.

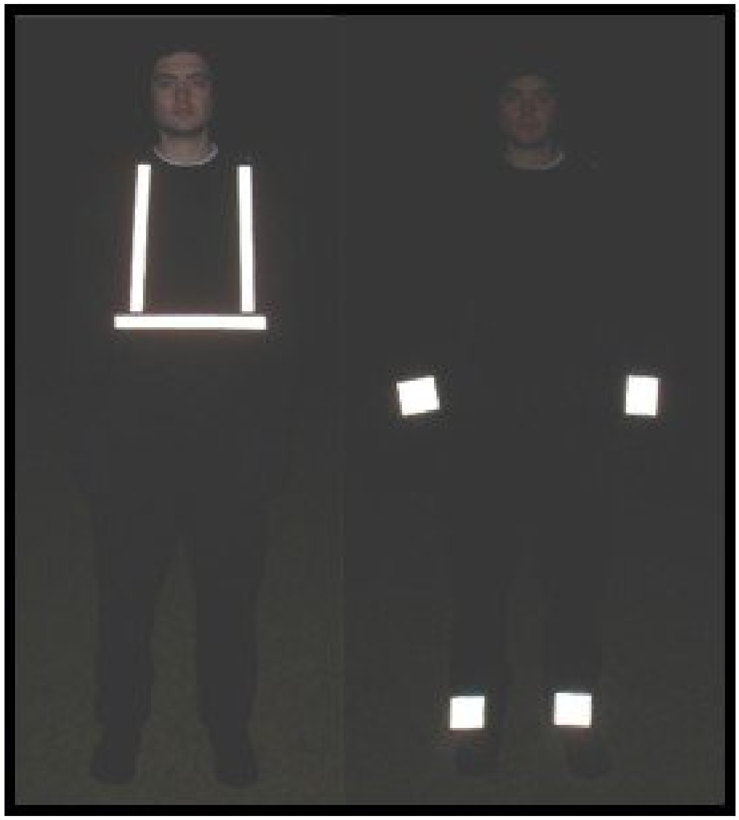

Figure 3. The torso retroreflector configuration and the W+A retroreflector configuration.

The test pedestrian was positioned on the left shoulder of an unilluminated (~0.01 lux) two-lane roadway (Old Stadium Road in Clemson, SC). The maximum sight distance, as measured at night, to the pedestrian on this roadway was 294 meters. Participants were passengers in the test vehicle and driven along the route specified in Figure 4. Participants were provided a button to press to indicate their awareness that a pedestrian was present. The button was interfaced with a laptop computer controlled by an experimenter sitting in the rear seat of the test vehicle.

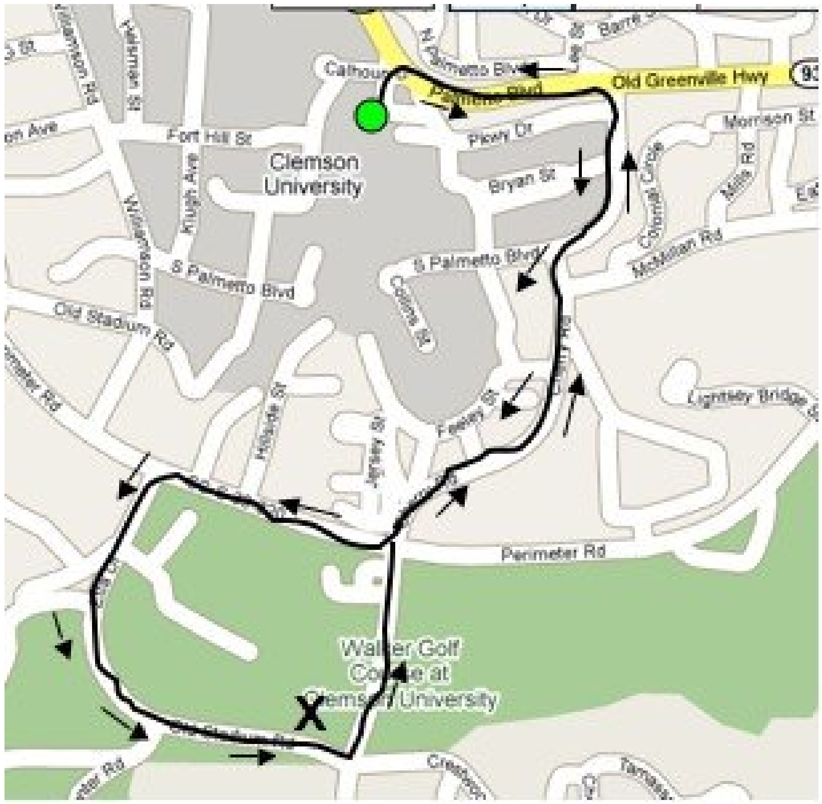

Figure 4. Route around Clemson University in route to Old Stadium Road. The total distance was 5.6 km taking approximately 10 minutes to travel. The “X" indicates the approximate position of the pedestrian. The arrows indicate the direction of travel and the green circle indicates the participant pick-up and drop-off location.

Procedure

Data were collected on nights free from precipitation, fog, or wet road surfaces. Two people participated in each trial. One participant sat in the front passenger seat of the test vehicle and the other sat in the back right seat. Participants seated in the back were asked to lean towards the center of the car to provide them an unobstructed view through the windshield. In order to attain a similar number of participants seated in the front seat and the back seat, seating position was balanced for trials with one participant.

Participants were met in Brackett Hall where informed consent was obtained, visual acuity was tested, and the experimenter said the following instructions:

> "You are going to be taken on a short drive around campus. Your task during this drive will be to press a button every time you see a pedestrian. Please only press the button when you are confident that a pedestrian is present. An experimenter will tell you when to begin looking for pedestrians. While the car is in motion please refrain from talking to the driver. Also, once the experimenter tells you to begin the task please refrain from talking until you are told the study is complete."

After the test vehicle traveled approximately 3 blocks away from the pick-up location participants were told to start searching for pedestrians. Participants were driven around Clemson University en route to Old Stadium Road where the test pedestrian was stationed. The posted speed limit on Old Stadium Road was 56km/h (35mph). The driver maintained driving at the posted speed limit at all times. The test pedestrian either stood or walked in place while he faced the oncoming test vehicle. Participants' responses to extraneous pedestrians were not recorded.

Participants were not told about the test pedestrian and were not informed that retroreflective material may be present on a pedestrian. Each participant observed the test pedestrian one time and upon completion of each trial and they were debriefed on the drive back to Brackett Hall.

RESULTS

Two dependent measures quantified performance, the percent of trials during which participants responded to the pedestrian by pressing their response button (percent seen) and the distance that separated the test vehicle and the pedestrian at the moment the response button was pressed (response distance). Each dependent measure required a different type of analyses. A binary logistic regression was used to analyze the data related to the percentage of participants seeing the pedestrian and an analysis of variance (ANOVA) was used to analyze response distance.

The binary logistic regression used retroreflector configuration, pedestrian behavior and R_A as predictor variables. The outcome variable was coded as either 1 indicating the participant responded to the pedestrian or 0 indicating no response. Seat position (front vs. rear) was included as a predictor variable in an initial regression and was found to be not significant (χ^2 (1, N = 121) = .027, p = .869), thus the regression was repeated without the seat position predictor.

Averaged over retroreflector configuration and R_A, the probability that participants responded to the pedestrian was significantly greater when the pedestrian was walking in place compared to standing (χ^2 (1, N = 121) = 9.9, $p < .01$). Here, the probability that participants responded to the walking pedestrian was .72 and was .46 for the standing pedestrian. Averaged over pedestrian behavior and R_A the probability that participants responded to the pedestrian was significantly greater for the pedestrian wearing the W+A configuration compared to the torso configuration (χ^2 (1, N = 121) =

22.5, $p < .01$). Here, the probability that participants responded to the pedestrian wearing retroreflectors on the wrists and ankles was .80 and was .37 while wearing the torso configuration. Averaged over retroreflector configuration and pedestrian behavior, R_A did not significantly influence the probability that participants responded to the pedestrian (χ^2 (2, N = 61) = 1.3, $p = .53$), while the pedestrian was wearing the low, medium and high R_A retroreflectors the probability that participants responded to the pedestrian was .63, .61, and .53 respectively.

Separate binary logistic regressions were used to evaluate the influence of retroreflector configuration within each of the two pedestrian behaviors. A binary logistic regression on the data from all conditions that the pedestrian walked in place, indicated that the probability that participants responded to the presence of the pedestrian was significantly greater when the walking pedestrian wore the W+A configuration (χ^2 (1, N = 60) = 21.3, $p < .001$). Here, the probability that participants responded to the walking pedestrian wearing the W+A configuration was .97 and the probability that participants responded to the walking pedestrian wearing the torso configuration was .47. The separate binary logistic regression run on the data from all conditions that the pedestrian appeared standing indicated that the probability that participants responded to the pedestrian was significantly greater when the pedestrian wore the W+A configuration (χ^2 (1, N = 61) = 9.0, $p < .01$). Here, the probability that participants responded to the standing pedestrian wearing the W+A configuration was .65 and the probability that participants responded to the standing pedestrian wearing the torso configuration was .27.

Two separate follow-up binary logistic regressions were used to analyze the effect of R_A on the probability of detection within each retroreflector configuration. R_A did not significantly influence the probability that participants responded to the pedestrian wearing the torso configuration (χ^2 (2, N = 60) = 4.3, p = .118). While the pedestrian was wearing the torso configuration at low, medium and high R_A the probability that participants responded to the pedestrian was .55, .30, and .25 respectively. Thus there was a non-significant trend for detection to decrease as R_A increased (see Table 1). While the pedestrian was wearing the W+A configuration R_A also did not significantly influence the probability that participants responded to the pedestrian (χ^2 (2, N = 61) =2.5, p =.283) and at low, medium and high R_A, the probability that participants responded to the pedestrian was .70, .91 and .80, respectively.

Table 1. The percentage of participants that responded indicating the presence of the test pedestrian.

	Low R_A	Medium R_A	High R_A	Mean
		Torso		
Standing	60	20	0	27
Walking	50	40	50	47
Mean	55	30	25	37
		Wrists and Ankles		
Standing	50	82	60	65
Walking	90	100	100	97
Mean	70	91	80	80
		Mean		
Standing	55	51	30	46
Walking	70	70	75	72
Mean	63	60	53	59

The response distances were analyzed using a between-subjects ANOVA. An initial 2 x 2 x 2 x 3 ANOVA that included seat position (front/rear), retroreflector configuration, pedestrian behavior, and R_A as between-subjects factors revealed that the effect of seat position was not significant ($F(1, 97) = .294$, $p = .589$, $\eta_p^2 = .003$) and that there were no significant interactions that involved seat position (all $p > .05$). Thus the ANOVA was repeated excluding the seat position factor; the results of this 2 x 2 x 3 ANOVA are reported below. Summary data are presented in Table 2.

Table 2. Mean (SD) participant response distances as a function of R_A, retroreflector configuration, and motion.

	Low R_A		Medium R_A		High R_A		Mean	
				Torso				
Standing	19.5	(35.5)	7.4	(21)	0	(0)	9	(24.3)
Walking	20.1	(25.8)	21	(47.15)	29.8	(69)	23.6	(48.9)
Mean	19.8	(30.2)	14.2	(36.2)	14.9	(49.8)	16.3	(39)
				Wrists and Ankles				
Standing	22.9	(35.8)	16.4	(13.6)	8.6	(8.6)	16	(22.3)
Walking	74.4	(55.2)	130.1	(80.5)	155	(88.1)	119.8	(80.9)
Mean	48.7	(52.4)	70.5	(80)	81.8	(96.7)	67	(78.4)
				Mean				
Standing	21.2	(34.7)	12.1	(17.7)	4.3	(7.4)	12.5	(23.5)
Walking	47.2	(50.3)	75.6	(85.2)	92.4	(100.2)	71.7	(82.1)
Mean	34.2	(44.7)	43.7	(68.1)	48.4	(83.1)	41.9	(66.9)

The between-subjects ANOVA revealed a significant main effect for retroreflector configuration, ($F(1, 109) = 34.62$, $p < .001$, $\eta_p^2 = .241$), indicating that when averaging across pedestrian behavior and R_A, participants responded to the pedestrian wearing the retroreflectors in the W+A configuration from a significantly greater distance (M = 67.0 m, SD = 78.4 m) compared to the torso configuration (M =

16.3 m, SD = 39.0 m). The main effect for pedestrian behavior was also revealed as significant ($F(1, 109) = 45.64$, $p < .001$, $\eta_p^2 = .295$), indicating that when averaged across R_A and retroreflector configuration, participants responded to the walking pedestrians from significantly greater distance (M = 71.7 m, SD = 82.1 m) compared to when the pedestrian was standing (M = 12.5 m, SD = 23.5 m). The main effect of R_A was revealed as not significant ($F(1, 109) = .896$, $p = .411$, $\eta_p^2 = .016$), indicating that when averaged across retroreflector configuration and pedestrian behavior there was not an overall effect of R_A on participant response distance.

As predicted, there was a significant interaction between pedestrian behavior and retroreflector configuration, ($F(1, 109) = 25.86$, $p < .001$, $\eta_p^2 = .192$). As can be seen in Figure 5, this interaction revealed that the increase in response distance that was associated with wearing the W+A configuration was a result of the pedestrian walking. A simple effects test on the effect of pedestrian behavior for the pedestrian wearing the W+A configuration was significant ($t(59) = 6.88$, $p < .001$, $\eta^2 = .445$). The simple effects test indicated that the response distance to the walking pedestrian wearing the W+A configuration (M = 119.8 m, SD = 80.9 m) was significantly greater compared to the standing pedestrian wearing the W+A configuration (M = 16 m, SD = 22.3 m). A simple effects test on the effect of pedestrian behavior for the pedestrian wearing the torso configuration revealed there was not a significant difference between the average response distance for walking and standing for the pedestrian wearing the torso configuration ($t(58) = 1.47$, p =.147).

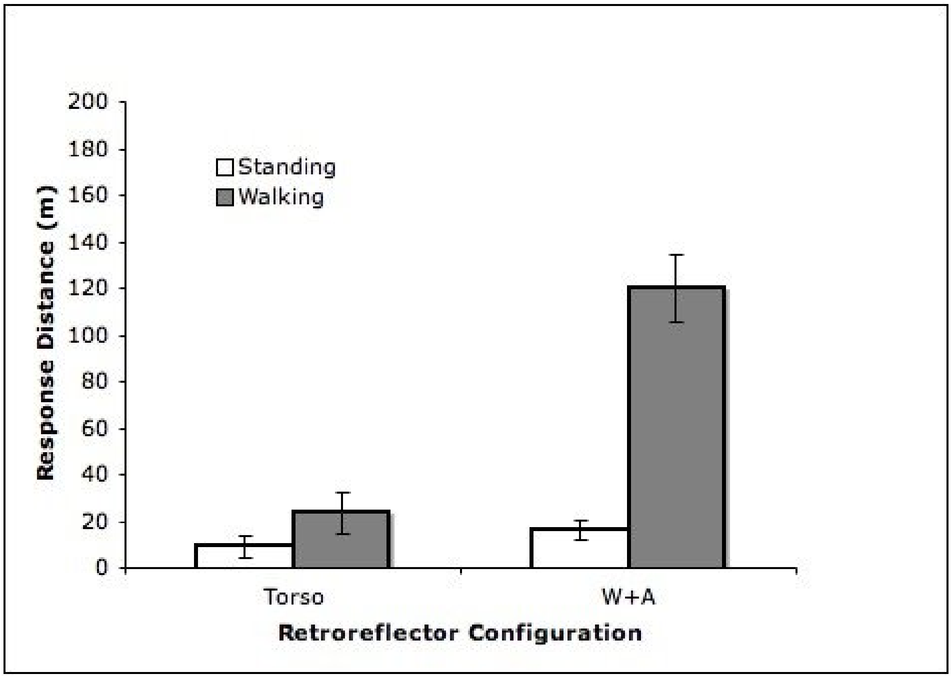

Figure 5. The two-way interaction between retroreflector configuration and pedestrian behavior.

The interaction between R_A and pedestrian behavior was revealed to be significant ($F(2, 109) = 4.2$, $p = .02$, $\eta_p^2 = .072$). As can be seen in Figure 6, the interaction indicates that, averaged over garment configuration, response distances tended to increase as R_A increased when the pedestrian was walking, and response distances tended to decrease as R_A increased when the pedestrian was standing. A simple effects test on the effect of R_A for the standing pedestrian was marginally significant ($F(2, 58) = 2.75$, $p = .073$, $\eta_p^2 = .087$). Tukey HSD follow up tests indicated that there was a marginally significant difference in response distance to the standing pedestrian wearing the low R_A compared to the high R_A ($p = .058$). Participants responded to the standing pedestrian wearing the low R_A from a marginally significant greater distance (M = 21.2

m, SD =34.7 m) than the standing pedestrian wearing the high R_A (M = 4.3 m, SD = 7.4 m). Other comparisons between the R_A levels for the standing pedestrian did not approach significance. A simple effects test of the effect of R_A on the walking pedestrian was not significant ($F(2, 57) = 1.58$, $p = .215$, $\eta_p^2 = .052$). The 3-way interaction between retroreflector configuration, R_A and pedestrian behavior was not significant ($F(2, 109) = 1.26$, $p = .289$, $\eta_p^2 = .023$).

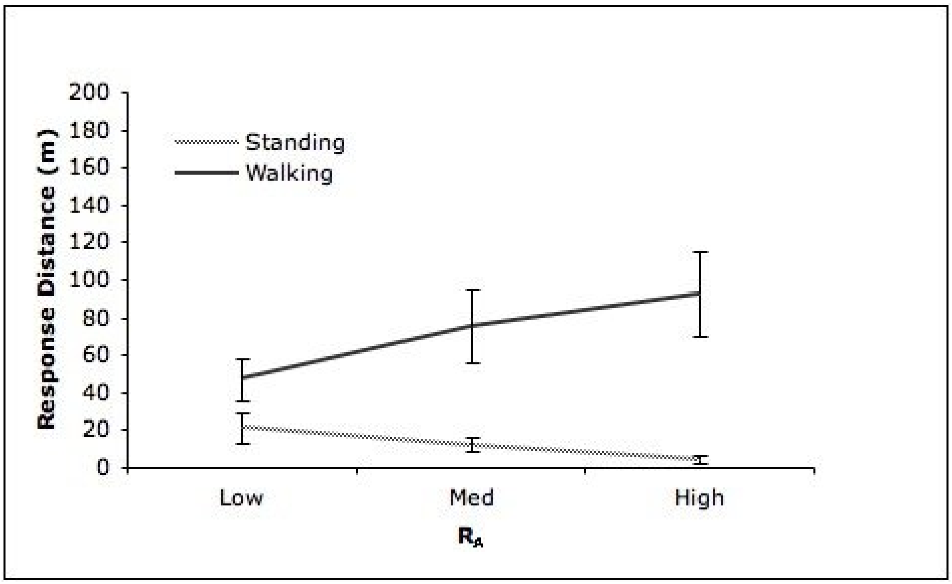

Figure 6. The two way-interaction interaction between R_A and pedestrian behavior

A priori predictions were made about the interaction between R_A and retroreflector configuration within each level of pedestrian behavior. Two separate ANOVAs investigated the effects of R_A and retroreflector configuration. One ANOVA used data from trials that the standing pedestrian was present and a second ANOVA used data from trials that the walking pedestrian was present.

In the absence of pedestrian motion, decreasing R_A was predicted to degrade conspicuity. However, as can be seen in Figure 7, the retroreflector configuration does not appear to influence response distance and, as R_A increased participant response distances tended to decrease. According to the ANOVA used on the data from the standing pedestrian, the main effect of retroreflector configuration was not significant ($F(2, 55) = 1.4$, $p = .242$, $\eta_p^2 = .025$) indicating that the standing pedestrian wearing the W+A configuration was not seen from a significantly greater distance compared to the standing pedestrian wearing the torso configuration. There was a marginally significant main effect of R_A ($F(2, 55) = 2.7$, $p =.077$, $\eta_p^2 =.089$) when the pedestrian stood still. Tukey HSD follow-up tests revealed a marginally significant difference between the mean response distance to the standing pedestrian wearing the low R_A material compared to the standing pedestrian wearing the high R_A material ($p = .062$). Other comparisons did not approach significance. When averaged across the two retroreflector configurations, while wearing low R_A, participants responded to the stationary pedestrian at a marginally significant greater distance (M =21.2 m, SD = 34.7 m) compared to the high R_A (M = 4.3 m, SD = 7.4 m) The 2-way interaction between R_A and retroreflector configuration was not significant while the pedestrian was standing ($F(2, 55) = .09$, $p = .911$, $\eta_p^2 = .003$).

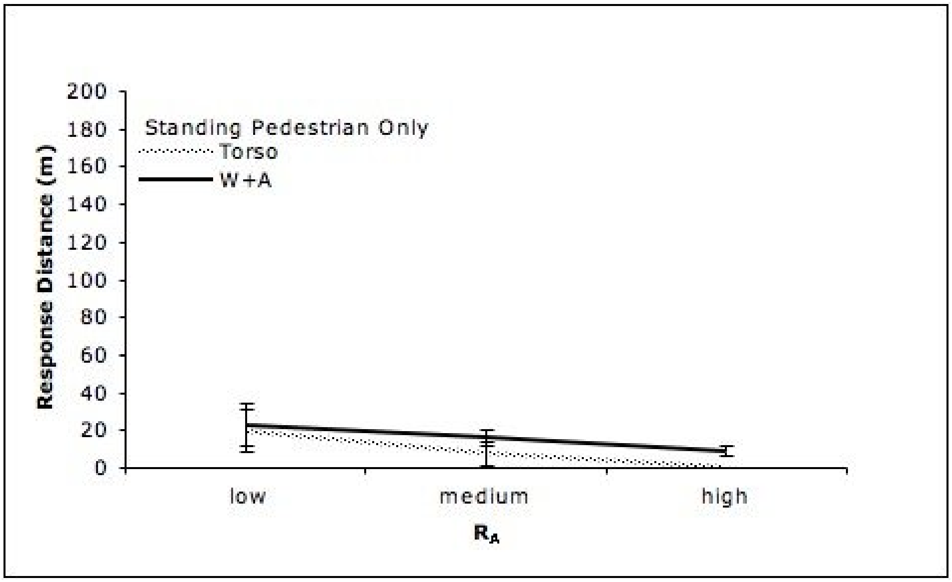

Figure 7. The two-way interaction between R_A and retroreflector configuration for the standing pedestrian

While the pedestrian was walking, it was predicted that the conspicuity of the pedestrian wearing the W+A configuration would be robust to degradations in R_A. In other words, a null main effect of R_A was predicted for walking pedestrians wearing the W+A retroreflector configuration. Response distances to the torso configuration were predicted to vary with R_A. The ANOVA used on the data from the walking pedestrian revealed a main effect of retroreflector configuration ($F(2, 54) = 33.45$, $p < .001$, $\eta_p^2 = .382$). Averaged over the three levels of R_A, the mean response distance to the walking pedestrian wearing the W+A configuration (M = 119.8 m, SD = 80.9 m) was significantly greater compared to the mean response distance to the walking pedestrian wearing the torso configuration (M = 23.6 m, SD = 48.9 m). The main effect for R_A was marginally significant ($F(2,54) = 2.51$, $p = .09$, $\eta_p^2 = .085$) indicating that response distances tended to increase as R_A increased for walking pedestrians. Tukey HSD follow-up tests revealed a marginally significant difference between the average response distance to the walking pedestrian wearing the high R_A material compared to the walking pedestrian wearing the low R_A material (p = .08). Other comparisons did not approach significance. Averaging the response distance across the two retroreflector configurations indicates that participants responded to the walking pedestrian wearing the high R_A retroreflectors at a marginally significant greater distance (M = 92.4 m, SD = 100.2 m) compared to the low R_A retroreflectors (M = 47.2 m, SD = 50.3 m). The 2-way interaction between retroreflector configuration and R_A for the walking pedestrian shown in Figure 8 was not significant ($F(2,54) = 1.66$, $p = .199$, $\eta_p^2 = .058$).

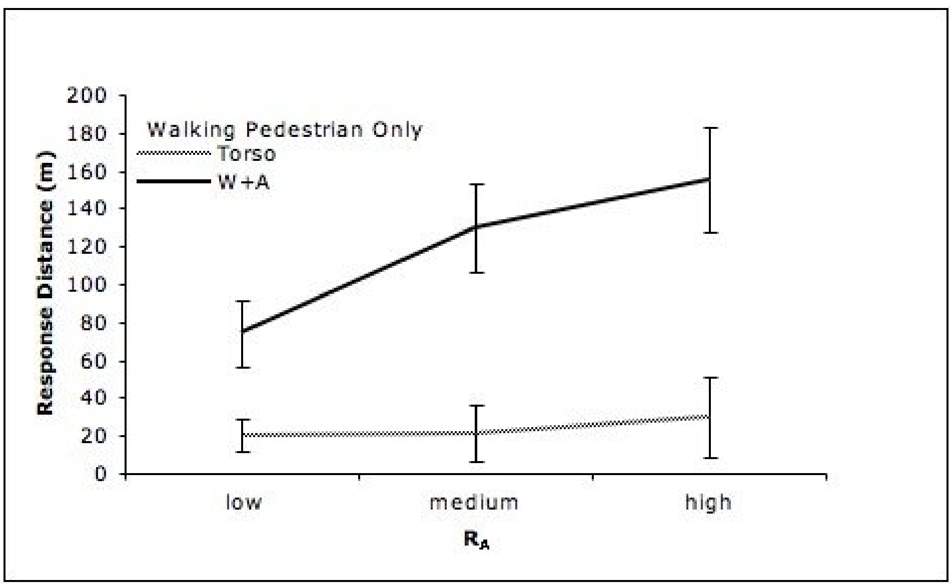

Figure 8. The two-way interaction for the effects of R_A and retroreflector configuration for the walking pedestrian.

Zero participants responded to the standing pedestrian wearing the torso configuration at the high level of R_A. Thus the data from this condition violates the

ANOVA assumption of equal variance, as all responses were equivalent. To ensure that the results discussed previously were not an artifact induced by the lack of variability in the high R_A standing torso configuration condition, an additional 2 x 2 x 2 ANOVA was conducted. This ANOVA excluded the data from the four high R_A conditions and the results matched the pattern from the full analysis. That is, significant main effects of retroreflector configuration ($p < .001$) and pedestrian behavior ($p < .001$) remained, as did significant interactions between retroreflector configuration and pedestrian behavior ($p < .001$), and between pedestrian behavior and R_A ($p = .057$). The main effect of R_A remained not significant ($p = .596$). These results suggest that the results from the full analysis were not an artifact caused by the high R_A data.

DISCUSSION

The current experiment examined the effects of R_A, retroreflector configuration and pedestrian motion on the nighttime conspicuity of pedestrians. Presumably, R_A influences pedestrian conspicuity in such a way that greater retroreflective intensity can equate to greater response distance (Cassidy et al., 2005; Flannagan & Devonshire, 2007; Sayer & Mefford, 2004a). Placement of retroreflective markings on the limbs of a moving pedestrian has also been shown to increase pedestrian conspicuity (Balk et al., 2007; Balk et al., in press; Blomberg et al., 1986; Luoma et al., 1995; Owens et al., 1994; Sayer & Mefford, 2004b; Wood et al., 2005) The biological motion information provided by placing retroreflectors on the wrists and ankles of a moving pedestrian was predicted to minimize pedestrian conspicuity problems associated with low R_A. The conspicuity of pedestrians wearing retroreflectors placed on the torso was expected to be more sensitive to fluctuations in R_A to the extent that low R_A would lead to shorter detection distance compared to high R_A.

There are three main results from this experiment that will be discussed. The first is that the W+A configuration exhibited superior conspicuity compared to the torso configuration; this result was expected because previous research has reported similar effects (Balk et al., 2007; Luoma et al., 1995). The percentage of participants that did not respond to the pedestrian wearing the torso configuration (63%) compared to the W+A configuration (20%) implies that pedestrians are more likely to be seen if they are wearing retroreflectors on the extremities. Data from the trials with the walking pedestrian indicated that 53% of participants did not respond to the walking pedestrian wearing the torso configuration and only 3% of participants did not respond to the walking pedestrian wearing the W+A configuration. Here, the result that the W+A configuration doubled the probability that participants responded to the walking pedestrian suggests that drivers are more likely to see pedestrians that wear retroreflectors that present biological motion. The data from trials with the standing pedestrian indicates that 73% of participants did not respond to the standing pedestrian wearing the torso configuration and 36% of participants did not respond to the standing pedestrian wearing the W+A configuration. The difference between the two retroreflector configurations for the standing pedestrian suggests that the W+A configuration may increase a pedestrian's probability of being seen by drivers for reasons other than its ability to present biological motion. This may be because of the human form information provided by the static W+A configuration. Balk et al. (in press) found that, in the absence of motion, pedestrian conspicuity increased when form information was provided by pedestrians that wore retroreflectors that "highlighted" the major joints (waist, wrists, elbows, shoulders, knees, and ankles), on the other hand, retroreflectors worn only on the wrists and ankles did not significantly increase conspicuity unless the pedestrian was moving. The response distance data from current study's results support the suggestion that the W+A configuration leads to superior conspicuity when the pedestrian is walking.

In the current study, averaged across pedestrian behavior and R_A, the average distance that participants responded to the pedestrian wearing the W+A configuration was 4 times the distance of the torso configuration. The difference between the two configurations is mainly because participants responded to the walking pedestrian wearing the W+A configuration from the greatest average distance (119.8 m). Averaged across the 3 levels of R_A, participants responded to the walking pedestrian wearing the W+A configuration at an average distance that was over 7 times greater than the average response distance to all the other conditions combined. Here, regardless of the R_A level, participants responded to the walking pedestrian wearing the W+A configuration at a distance 7.5 times greater than that of the standing pedestrian wearing the W+A configuration, 5 times greater than that of the walking pedestrian wearing the torso configuration and 13 times than that of the standing pedestrian wearing the torso configuration. These results imply that drivers may see and identify pedestrians at the greatest distance when the pedestrian is walking and wearing retroreflective material configured in a way that facilitates the perception of biological motion.

Other on-road studies have reported conspicuity to be much greater for pedestrians wearing a torso configuration similar to that which was used in the current experiment. Luoma et al. (1995) found an average response distance of 96 meters (4 times greater than the current study, see Table 2) for walking pedestrians wearing a retroreflector configuration similar to the torso configuration used in the current study and an average response distance of 241 meters (2 times greater than the current study, see Table 2) for walking pedestrians wearing a retroreflector configuration similar to the W+A configuration used in the current study. Sayer and Mefford (2004a), used a retroreflector configuration similar to the torso configuration used in the current study and found an average response distance of 295 meters (12 times greater than the current study) for walking pedestrians wearing an ANSI class 2 safety vest. The shorter response distances in the present study may be due to the basic experimental design. All manipulations in the current experiment were between-subjects, while both Luoma et al. (1995), and Sayer and Mefford (2004a) used within-subjects designs, which have been suggested to unnaturally "overexpose" participants to pedestrians wearing retroreflective material (Langham & Moberly, 2003). Balk et al. (2007) used a single-stimulus between subjects design and reported response distances similar to the current study for walking pedestrians wearing an ANSI class 2 safety vest. The between-subjects design employed in the current study limited the participants' exposure to seeing only one pedestrian wearing retroreflective material. Such an experimental design may more closely resemble a realistic nighttime encounter with a pedestrian on a rural road.

The second main result of the current study is that R_A had a smaller than expected influence on pedestrian conspicuity. The results of the current study suggest that increasing R_A may have an influence on pedestrian conspicuity only when biological motion is present. These results are at odds with Cassidy et al. (2005) and Flannagan and Devonshire (2007) because the results from both of these studies imply that increasing R_A can significantly increase the conspicuity of stationary pedestrians. Cassidy et al. (2005) reported a significant main effect of retroreflective intensity for participants detecting "… the presence of any retroreflective figure in the road." Their highest level of retroreflective intensity (260 R_I) resulted in a detection distance that was 1.26 times greater than the detection distance to their lowest level (56 R_I) These detection distance results were interpreted as the distance at which their participants first saw retroreflective material, since recognition (such as recognizing that a pedestrian was present) may not have been involved. Participants were subsequently asked to respond when they could "recognize the figure…" and the resulting recognition distances were shorter than the detection distances (there was also a significant effect of R_A on recognition distances). Their results show that the average recognition distance to the high intensity figure was 1.27 times greater compared to the low intensity figure. Flannagan and Devonshire (2007) also found a significant effect of retroreflective intensity because their high intensity material (700 R_A), worn by mannequins, had a response distance that was 2.4 times the distance of their low intensity material (175 R_A). Sayer and Mefford (2004), although the result was not significant they found that under a condition of low ambient illumination, a walking pedestrian wearing high intensity retroreflective material was detected at a distance 1.21 times greater than a walking pedestrian wearing low intensity retroreflective material. These differences are similar to the differences between the response distances to the 3 levels of R_A in the current study.

Although the average response distances were far shorter in the current study than those found in previous research (Sayer & Mefford, 2004; Cassidy et al. 2005; Flannagan & Devonshire, 2007), regardless of pedestrian motion and retroreflector configuration, the average response distance to the pedestrian wearing high R_A was 1.41 times the average response distance to the pedestrian wearing low R_A. This trend is mostly a result of the conditions in which biological motion was present. The response distance to the walking pedestrian wearing the high R_A retroreflectors in the W+A configuration was 2.08 times greater than the response distance to the walking pedestrian wearing the low

R_A retroreflectors in the W+A configuration.

The experiment conducted by Cassidy et al. (2005) used a within-subjects design and reported highly significant differences between their levels of retroreflective intensity. The benefit to using the within-subjects design is increased statistical power. Thus, although the differences between the levels of R_A for Cassidy et al. (2005) were actually smaller than the differences in the current experiment, the current experiment lacked the statistical power associated with within-subjects manipulations. The benefits to the current study are that the between-subjects design and the use of a real pedestrian closely approximated a driver realistically encountering a pedestrian at night on a dark roadway. The increased ecological validity justified the use of the between subjects design used in the current study. Mainly because of the experimental design, participants were not aware that a pedestrian would appear wearing retroreflectors. This further emphasizes the importance of biological motion because pedestrian conspicuity was the greatest under the conditions that presented biological motion. Furthermore, the trend of responses to the walking pedestrian wearing the W+A configuration with low R_A, medium $R_{A,}$ and high R_A retroreflectors illustrates that increasing R_A can lead to greater conspicuity, but unless a driver is aware that a pedestrian could appear wearing retroreflective material (as may be the case for experiments that have a within-subjects design), pedestrian retroreflectors must facilitate the perception of biological motion for this trend to appear. Otherwise varying the intensity of retroreflective material may influence pedestrian conspicuity in unexpected ways.

The third major result of the current experiment is the surprising finding that increasing R_A tended to decrease the already poor conspicuity of the pedestrian standing on a dark rural roadway. In other words, counter to the expectation that increasing R_A would increase response distance, when the pedestrian was standing there was an "inverse effect" of R_A. Regardless of the retroreflector configuration, the standing pedestrian wearing low R_A retroreflectors was seen from a distance that was 5 times greater than the response distance to the standing pedestrian wearing the high R_A retroreflectors.

Despite the fact that the pedestrian was present during all of the experimental trials, zero participants responded to the standing pedestrian wearing the high R_A torso configuration, only a few participants responded to indicate the presence of the standing pedestrian in the medium R_A torso configuration, and 6 participants responded to indicate the presence of the standing pedestrian in the low R_A torso configuration. The inverse effect of R_A was reinforced by the finding that there were significantly more participants that responded to the pedestrian wearing the W+A configuration with low R_A, medium R_A and high R_A retroreflectors, and the average response distance to the pedestrian wearing the W+A configuration still decreased as R_A increased (see Table 2). This effect was certainly not predicted and its interpretation requires some degree of speculation.

At night, when retroreflective material is activated by the headlights of a car it has high luminance contrast between the retroreflector and its surrounding environment. Luminance contrast is important to drivers at night because, "under night-time lighting levels… it is principally luminance contrast that dominates visual performance" (Plainis & Murray, 2002). Luminance contrast can potentially make an object salient but salience does not necessarily lead to correctly identifying a target if the salient features do not facilitate an observer's ability to identify the target (Nothdruft, 2002; van Zoest & Donk, 2005). Presumably, because of the salience attributed to the high contrast retroreflectors, participants are likely to have detected the retroreflectors before they recognized that there was a pedestrian present. Because the instructions to the participants was not to press the button until they were confident that a pedestrian was present, the results from the current study demonstrate that the salience of the retroreflectors did not always facilitate the participants' ability to identify the pedestrian that was present. Thus, participants' responses to the pedestrian were not dependent on salience but rather their ability to identify pedestrians. In order for the task to depend on salience, in and of itself, the participants' task would have been to respond the instant that "anything" appeared at any particular location, and at anytime without the need to identify what it was that they saw. Presumably the first place that someone looks when first viewing a scene is the location of the most salient feature and if the participants task would have involved responding directly to the salience of the retroreflectors the results might have been substantially different.

The brief amount of time exhibited by participants responding to the walking pedestrian wearing the W+A configuration suggests that less attentional resources were required to identify pedestrians when biological motion was salient. When biological motion was not present, the extended time exhibited by participants identifying the presence of the pedestrian suggests that identification may have required additional resources. Initial fixations are presumably guided by the salient features (e.g. luminance contrast) in a scene (Itti & Koch, 2001; Parkhurst, Law & Nieber, 2002). Over time, fixations become less influenced by salience and eventually become completely driven by contextual cues (van Zoest & Donk, 2005). Contextual cues may have had a more prominent influence on identifying pedestrians that did not present biological motion. Here, the contextual cues that may have influenced where the participants were looking, and their subsequent responses[1], could have been both semantic (e.g. a pedestrian is likely to be associated with a static object positioned on the side of a rural road near a university, alternatively, a guerilla is not likely to be associated with a static object positioned on the side of a rural road near a university) and physical (e.g. retroreflective markings of a reasonable size, located at a reasonable height and position are likely to be associated with a pedestrian, alternatively, a pedestrian would not likely be associated with retroreflectors 10 meters in length that are also positioned horizontally 30 meters in the air). Both semantic and physical contextual cues influence the identification of objects in a scene in such a way that the likelihood of identifying an object increases when the semantic and physical relationship between the contextual cues and the object are strong (Oliva & Torralba, 2007). It is conceivable that when the salient features of the pedestrian did not facilitate the perception of the pedestrian, participants' responses were completely influenced by contextual cues (as may have been the case when biological motion was not salient). Contextual cues could have also lead some participants to assume that the retroreflectors worn by the pedestrian could have been something other

[1] It is appropriate to assume that there is a relationship between the responses that participants made in the current experiment and where the participants were looking because eye movements are tightly linked to visually selecting and identifying an object (Deubel & Schneider, 1996).

than a pedestrian that could appear on the side of the road (e.g. a road sign) and this might explain the null response to the standing pedestrian wearing the high R_A torso configuration.

The results from the current experiment suggest that contextual cues may have had greater influence on participants' responses when biological motion was not present. Here, participant response distances to the standing pedestrian illustrate that there may have been a stronger semantic relationship between low R_A retroreflectors and pedestrians standing on the side of the road because the standing pedestrian wearing the low R_A retroreflectors was seen from a greater distance than the standing pedestrian wearing the high R_A. In other words, from the participants' perspective, the probability that a pedestrian would appear on the side of the road wearing barely detectable retroreflectors is greater than the probability that a pedestrian would appear on the side of the road wearing retroreflectors that appear to be conspicuously bright.

In any case, the data from this experiment underscore the value of biological motion in the context of pedestrian conspicuity. When biological motion was present and the pedestrian was wearing the low R_A retroreflectors, participants responded to the pedestrian from a distance that was 4.6 times greater than the combined average response distance to all of the conditions that biological motion was not present. When biological motion was present and the pedestrian was wearing the high R_A retroreflectors, participants responded to the pedestrian from a distance that was 9.5 times greater than the combined average respond distance to all of the conditions that biological motion was not present. The anomalous inverse effect of R_A on response distance to the standing pedestrian was definitely not an effect inherent of retroreflective material as is evidenced by the characteristic effect of R_A on response distances to the pedestrian when biological motion was present. These results suggest that retroreflector placement can influence conspicuity to a greater extent than R_A alone.

The results from the experiment presented in this paper illustrate that when biological motion is present, such as when the pedestrian was walking and wearing retroreflectors on the wrists and ankles, the value of increasing retroreflective intensity appears to be smaller than the impact of conveying biological motion. In terms of pedestrian conspicuity, these results imply that the range of acceptable retroreflective intensity is quite large when biological motion is present. Considering that the lowest level of R_A used in the current study was much lower than the highest level of R_A this suggests that if biological motion is present that any deleterious effects that may decrease R_A (e.g. large observation angles, retroreflector age, and the accumulation of dirt on the retroreflector) are less problematic to pedestrian conspicuity. When biological motion was present, higher R_A increased pedestrian conspicuity to the greatest extent compared to all other conditions. These results are unique and can be attributed to the experimental design and use of a real pedestrian approximating a realistic on-road encounter with a pedestrian at night. The participants' only responsibility was to look for and respond to pedestrians. Realistically, drivers have to attend to more than pedestrians, thus the participants' having only this one task is somewhat artificial. Limiting the pedestrian behavior to walking in place or standing may also have created some artificiality because pedestrians are likely to move around in a variety of ways that might impact their conspicuity (walking across roadways, bending over, twisting at the waist, etc.). Retroreflective material configured in a way that facilitates the perception of biological motion increases conspicuity for pedestrians that are walking in place and would likely be beneficial for pedestrians moving about in other ways.

APPENDIX

QUANTIFYING RETROREFLECTION

The coefficient of retroreflection (R_A) of retroreflective material will be manipulated in the on-road study. The material will then be worn by a test pedestrian and response distances will be collected from participants driven in a car. Three levels of R_A will be used in the on-road study and these levels were selected from an array of stimuli at different levels of R_A. Ten stimuli were constructed by superimposing different densities of opaque ink on top of a single type of retroreflective material (see Figure 5). A screen-printing method was used to apply various ink treatments to the material. The resulting stimuli can be described by quantifying both R_A and brightness. The variable R_A is a ratio of two physical variables, one is the amount of luminance reflected from the retroreflector at the position of the observer and the other, the amount of illuminance at the retroreflector; R_A can be measured using photometric instruments. On the other hand, brightness is a perceptual variable that can only be measured using human observers and it has been shown that brightness fluctuates relative to changes in luminance (Marks, 1974). A human observer can see the luminance of the retroreflective material. Thus it was important that Both R_A and brightness were quantified to validate that the ink treatment was effective at significantly altering the amount of luminance retroreflected from the stimuli. This Appendix describes a magnitude estimation technique that was used to measure the brightness of the ten stimuli. In addition, the relationship between R_A

and brightness is described, as is the logic underlying the selection of the stimuli that were used in the on-road experiment.

METHODS

Participants

Seventeen Clemson University undergraduate Psychology students participated in this experiment (ages 18 to 21, M=18.8; 9 females) and received extra credit in their psychology course. Participants were recruited via Clemson University's student participation pool. Participants did not know the intention of the study prior to participation. None will participate in the on-road experiment.

Design

The coefficient of retroreflection (R_A) was manipulated within-subjects. There were 30 trials per session where participants gave three brightness estimations for each of the 10 stimuli. A new random order of the 30 trials was used for each set of participants.

Materials

Ten 0.07 m (height) x 0.12 m (width; total area: 0.008m^2) rectangular patches of retroreflective material (3M Scotchlite 8906 Silver Fabric) were used. A screen-printing method was used to reduce the coefficient of retroreflection (R_A) of the Scotchlite material where the following steps were used to apply different ink treatments. First, nine different gradients of solid images were digitally created at the following percentages of black 95%, 85%, 75%, 65%, 50%, 40%, 30%, 20%, and 15%. The highest percentage of black resulted in a relatively dark image tint while lower percentages of black resulted in a series of imagines increasing in lightness. Each image was then set at a 10 line per inch (lpi) line-screen using PackEdge 4.0 (Esko Graphics, 2005). An image setter (Agfa Select Set Avantra 25) was then used to create a film negative of each image on a capillary film using a Fuji (FG 950A) image processor. The film was then adhered to a stretched screen and ultraviolet cured black ink (Nor-Cote International) was injected onto the retroreflective base material through the capillary film using a semi-automated screen-printer (Sias). The final step required that the treated material receive an ultraviolet cure under an ultraviolet source. The result was a uniform pattern of ink that occluded varying areas of the retroreflective material (see Figure 9). After the ink was applied to the material, R_A measurements of each stimulus were made using an ARM Retro-Meter 2 (see Table 3 for results).

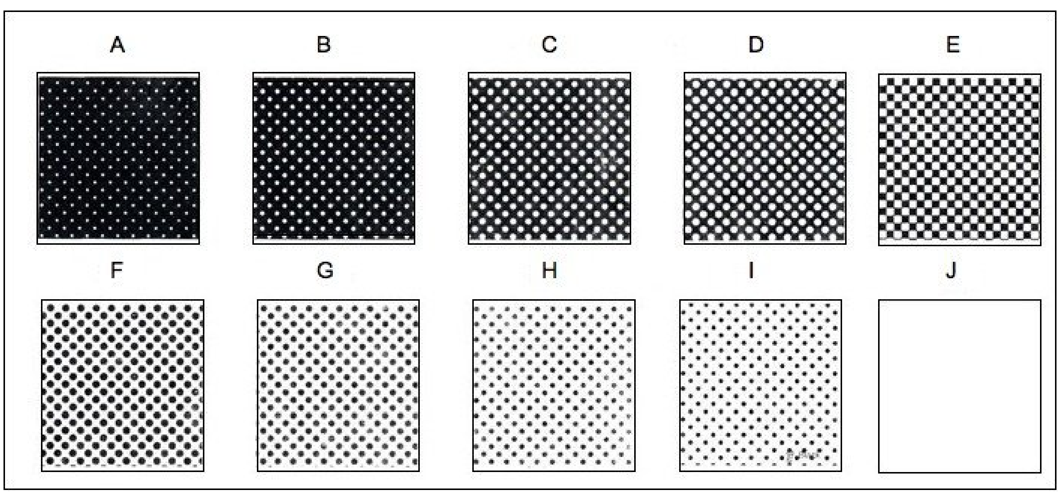

Figure 9. The ten designs used to create the 10 levels of retroreflectivity. Black represents the applied ink and white represents the retroreflective base. The letters A through I correspond to the gradients 95% through 15% respectively while J was not treated with ink.

Procedure

Participants were picked up from Brackett Hall and driven to Dyke Road in Clemson, SC. Participants remained seated in the test vehicle during testing. The test vehicle was parked 91.4 m from and facing the retroreflective patches that were mounted 0.914 m above the ground. The stimuli were presented in a stationary device that surrounded the stimuli with black cloth such that the supporting device was not visible from inside the vehicle. The vehicle's engine idled during testing, and headlamps were kept on the low-beam setting. The illuminance measured at the position of the retroreflector was 2.62 lux.

Table 3. Coefficients of Retroreflection and Brightness for the Ten Retroreflective Rectangles (I-J).

Ink Treatment	R_A	Average Brightness
A	10 (4)	3.51 (4)*
B	38 (12)	5.18 (5)
C	97 (16)	8.87 (11)
D	138 (10)	9.23 (10) *
E	227 (37)	12.22 (14)
F	321 (5)	13.86 (17)
G	370 (15)	15.19 (17)
H	421 (26)	15.37 (17)
I	474 (15)	15.58 (15)
J	581 (5)	16.11 (17)*

Note: Coefficient of retroreflection measured at .2° observation angle and -4° entrance angle. Each R_A measurement was an average of six measurements using the ARM Retro-Meter 2 (three measurements for treatment J). Standard deviations are given in parentheses. * Indicates the stimulus levels chosen for the primary experiment.

Two participants were seated in the test vehicle for all but one experiment session. When there was only one participant, that person sat in the front seat. Otherwise, one participant sat in the front passenger seat and the other sat in the middle rear seat. Participants were read the following script (adapted from Marks, 1974, p. 40):

> "We will show you a series of rectangles that will be mounted a few hundred feet in front of the car. For each rectangle, your task will be to judge how bright the rectangle appears to be. We will ask you to assign a number that stands for the rectangle's brightness. For the first rectangle assign whatever number seems to you the most appropriate to represent its brightness. Then, for the rest of the rectangles, assign other numbers in proportion to their brightness. If one rectangle appears to be three times brighter then another, assign a number that is three times higher; if it appears one-fifth as bright, assign a number that is one-fifth as high. Any type of number -- whole number, decimal, or fraction -- may be used as long as the number is greater than zero."

Each trial would begin with the test vehicle headlights being turned on. After the participants wrote down their magnitude estimates the headlamps were turned off and the next stimulus was prepared. Each session lasted approximately 20 minutes. After each session the participants were driven back to Brackett Hall.

RESULTS

Regression analysis was used to determine the extent to which the coefficient of retroreflectivity (R_A) affected brightness. Increases in brightness were linearly related to increases in R_A on a log-log scale (F (1,8) = 687.925, p < .001), where R_A accounted for 98.9% of the variability in brightness. See Figure 6 for results.

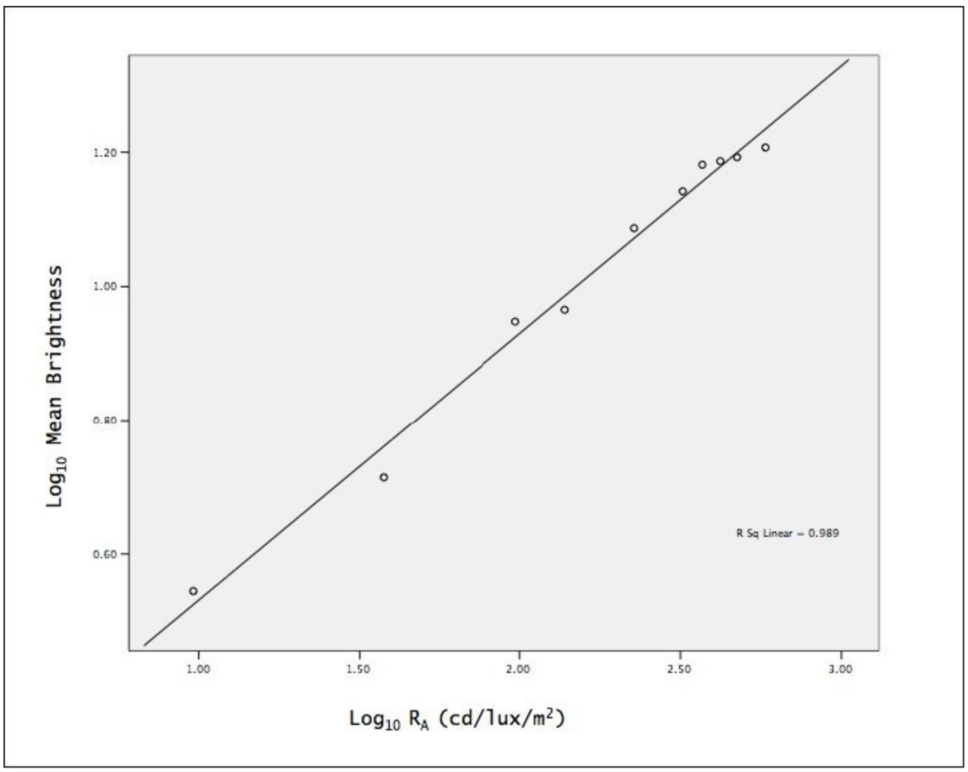

Figure 10. Mean brightness of each of ten different levels of R_A (cd/lux/m^2). A linear relationship between log_{10} of the coefficient of retroreflection and log_{10} of the mean magnitude estimation was significant (p<.001; R^2 = .989). The regression equation is: y =.399(x)+.133.

The regression illustrates that the brightness estimates were tightly coupled to the R_A values. From the ten R_A values, after a log transformation of the brightness data, three were selected to be used in the on-road study: R_A = 10, 138, and 581. These three values represent the least bright sample (R_A = 10), the brightest sample (R_A = 581), and a sample of intermediate brightness that was roughly in the middle of the measured range of (brightness) values (R_A = 138). Within-subject t-tests of log transformed brightness values confirmed that the highest R_A stimulus was rated to be significantly brighter than both the intermediate stimulus (t (16) = 8.88, p<.001) and the lowest R_A stimulus (t (16) = 10.88, p<.001). In addition the lowest R_A stimulus was significantly less bright than the intermediate stimulus (t (16) = 9.631, p<.001).

DISCUSSION

There were ten levels of retroreflectivity (R_A) in this study. Based on the brightness data, three of have were chosen for the primary study on pedestrian visibility at night. Those three levels correspond to 581 R_A, 138 R_A and 10 R_A and are to be considered the brightest, intermediate and dimmest levels of brightness attained with the screen-printing methods previously described. As expected, these three levels were significantly different from each other in brightness.

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