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16. Abstract

A nighttime field study was conducted to assess how several attributes of personal safety garments affect pedestrian conspicuity. Three types of ANSI/ISEA 107-1999 compliant Class 2 and Class 3 garments, like those frequently worn by road construction workers, were examined. Participants drove an instrumented research vehicle on a closed track, through simulated construction zones with naturalistic sight distances, and indicated when they first detected a pedestrian wearing one of the garments. The independent variables included trim intensity (R_A), ANSI/ISEA garment classification/configuration, color of the trim, location of the pedestrian within the work zone, driver age, and driver gender. The distance at which each garment could first be detected served as the measure of garment conspicuity.

The results show that garment classification/configuration, trim color, location of the pedestrian, and driver age all had significant effects on the distance at which garments could be detected. Over the ranges examined, neither the intensity nor the amount of trim material affected conspicuity. However, placement of the trim had a significant effect on conspicuity. Specifically, placing retroreflective trim on the arms of a Class 3 jacket, when compared with a Class 3 vest, significantly increased conspicuity of a pedestrian in motion. Nevertheless, any amount of retroreflective trim—regardless of its placement on the garment, color, or intensity—improved detection distance by as much as a factor of 7.8 when compared with a darkly clad pedestrian.

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CONTENTS

INTRODUCTION

Problem: Pedestrian Fatalities in Work Zones

A review of Census of Fatal Occupational Injuries (CFOI) data performed by the Bureau of Labor Statistics identified 220 reports of worker fatalities in which a pedestrian-worker was struck by a vehicle at a road construction site between the years 1995 and 2001 (S. Pegula, personal communication, August 18, 2003). These incidents included construction, maintenance, or utility work being performed on a road, street, or highway. A detailed review of these reports revealed that in more than half (118) of these fatalities the striking vehicle was part of general traffic not associated with the construction (i.e., traffic passing through the work zone). For individual years, the number of this type of occupational fatality has ranged from 10 to 26. This annual fatality rate is consistent with the trend reported by Pratt, Fosbroke, and Marsh (2001), which also utilized CFOI data for the years 1992 to 1996. The analyses performed by Pratt et al. found that the preponderance of fatal incidents (139 out of 152) involved traffic vehicles penetrating the work zone, as opposed, for example, to a worker being struck while crossing traffic.

The times of day at which the 1995 to 2001 fatalities occurred, when available, is shown in Table 1. The majority of these of these fatalities (78%) occurred in what are predominantly daylight hours: 6 a.m. to 6 p.m. (two incident reports do not include time of the accident).

Table 1
Time of day when road workers were struck by traffic passing through work zones (1995-2001).

Times of Day	Fatalities (%)
12:00 AM - 5:59 AM	11
6:00 AM - 8:59 AM	22
9:00 AM - 11:59 AM	23
12:00 PM - 2:59 PM	20
3:00 PM - 5:59 PM	11
6:00 PM - 11:59 PM	11

Retroreflective Garment Properties and Pedestrian Conspicuity

A number of recent studies have shown that wearing retroreflective materials, or active light sources, significantly increases pedestrian conspicuity. At night, the visibility distance of a dark-clad pedestrian's clothing is less than one-third the distance required to stop for a vehicle traveling 55 mph (88 km/h), and approximately one-half the distance required to stop for a vehicle traveling 35 mph (56 km/h) (Leibowitz & Owens, 1986). Therefore, the goal of increasing the conspicuity of pedestrians at night can be achieved, in part, through use of retroreflective materials.

Previous research on improving the conspicuity of pedestrians has shown significant promise and has addressed several factors regarding the choice of retroreflective material (the effects of retroreflective trim intensity, amount of trim, trim location, color of the trim, etc.). In a recent review, Langham and Moberly (2003) address much of the relevant literature, but with an emphasis on methodological considerations more than the potential experimental manipulations of retroreflective pedestrian markings or their associated benefits. Ultimately, the significance of Langham and Moberly's work is to highlight the needs to improve ecological validity and unified experimental approaches in conducting research regarding pedestrian conspicuity.

Sayer, Mefford, Flannagan, and Sivak (1999) reviewed and discussed a series of published studies that examined the effects of retroreflective trim characteristics on conspicuity; and Sayer, Mefford, and Flannagan (2001) more specifically examined the effects of retroreflective trim color on perceived brightness. With regard to the effect of color on conspicuity, the Helmholtz-Kohlrausch effect had been examined in a number of previous studies (Olson, 1988; Zwahlen & Yu, 1991; Schumann, Sivak, Flannagan, Traube, Hashimoto, & Kojima, 1996; Venable & Hale, 1996; Sayer, Mefford, Flannagan, Sivak, Traube, & Kojima, 1998; Marsh & Tyrell, 1998; Sayer, Mefford, Flannagan, & Sivak, 1999). The Helmholtz-Kohlrausch effect was first described in early German literature as *Farbenglut* (color glow) and has also been referred to as *florence* (Wyszecki, 1986), and is defined as "change in brightness of perceived colour produced by increasing the purity of a colour stimulus while keeping its luminance constant within the range of photopic vision" (Commission Internationale de l'Eclairage [CIE], 1988). Previous studies have attempted to photometrically match retroreflective stimuli anticipating that chromatic stimuli would be perceived to be brighter than a photometrically matched achromatic (white) stimulus. The results indicate that brightness ratings generally follow the Helmholtz-Kohlrausch U-shaped function of dominant wavelength. The Helmholtz-Kohlrausch effect is believed to be caused by a contribution of a chromatic component of a stimulus to its perceived lightness (Nayatani, 1997) where the level of contribution is different for differing hues (Nayatani, 1998).

However, the strength of the Helmholtz-Kohlrausch effect as it relates to pedestrian conspicuity has varied significantly across studies. Sayer et al. (1999) suggested that the differences in the observed magnitude of the effect might be associated with the angular size of the stimulus from the observer's point of view (subtended visual angle). Findings in the basic literature on color vision also suggested that stimulus size, in terms of subtended visual angle, was a critical variable in the perceived brightness of colored stimuli. Specifically, for stimuli that are effectively point sources, the Helmholtz-Kohlrausch effect has been reported to be considerably reduced (Guth, Donley, & Marrocco, 1969; CIE, 1978; Ikeda & Nakano, 1986), whereas the effect is stronger with larger stimuli (Booker, 1981). In addition, there is evidence that the Helmholtz-Kohlrausch effect diminishes when the ambient illumination is low (Ikeda & Ashizawa, 1991; Stalmeier & de Weert, 1994; Schumann et al., 1996; Sayer et al; 1998, 1999, and 2001).

The results of Sayer et al. (2001) indicate that within a given range of photometric values for retroreflective markings (such as one might expect to observe on a pedestrian, pedal-cyclist, or road worker), the distribution of the material, age of the observer, and gender of the observer do not affect subjective assessments of stimulus conspicuity. However, the amount of material (area) examined in the study did have a significant effect on subjective assessments of conspicuity—with more material resulting in a more conspicuous stimulus. The amounts of retroreflective material examined in that study were approximately equal to those specified in ANSI/ISEA 107-1999 for Class 1 and Class 2 garments, suggesting that the additional materials required for a Class 2 garment do in fact improve its conspicuity relative to a Class 1 garment. However, the study relied on subjective assessments of static stimuli viewed at a relatively short distance, and differences between the amounts of retroreflective trim specified between Class 2 and Class 3 garments (which are more common for road construction applications) were not examined.

The Present Study

Under dynamic nighttime viewing conditions, with participants driving instrumented vehicles on a closed track, the present study addressed the following questions related to the conspicuity of retroreflective safety garments for use in road construction work zones:

- Is there an effect of ANSI/ISEA safety garment classification/configuration on conspicuity, where the manipulation is either the amount (area) of the retroreflective trim (Class 2 vest versus Class 3 vest) or how it is distributed on the garment (Class 3 vest versus Class 3 jacket)?
- Is there an effect of the color of the retroreflective trim material on garment conspicuity? Specifically, how strong is the Helmholtz-Kohlrausch effect when the testing conditions have a reasonable level of ecological validity?
- Is there an effect of retroreflective trim intensity (coefficient of retroreflectivity, R_A) on garment conspicuity?

METHOD

Participants

Ten licensed drivers participated in this study. Each participant was paid for taking part in a two-and-a-half hour session. Six participants formed an older group (64-75 years, mean = 69.2 years) and four formed a younger group (21-30 years, mean = 25.0 years).

All participants were recruited from a list of potentially interested persons maintained by UMTRI. Each participant's color vision was screened using pseudoisochromatic plates (Ichikawa, Hukami, Tanabe, & Kawakami, 1978), and each was determined to have color normal vision. All participants were instructed to wear any corrective lenses that they would normally wear when driving at night. Visual acuity was required to be 20/40 or better in order to participate. The average visual acuity scores were 20/23.5 for the younger participants and 20/26.2 for the older participants. Table 2 provides each participant's individual visual acuity score along with their age and gender.

Table 2
Visual acuity scores by participant.

Participant	Age	Gender	Visual Acuity
1	O	F	20/35
2	O	M	20/18
3	Y	M	20/22
4	Y	M	20/22
5	O	F	20/30
6	O	M	20/17
7	Y	M	20/25
8	Y	F	20/25
9	O	F	20/40
10	O	M	20/17

Stimuli

Eighteen new ANSI/ISEA 107-1999 compliant garments served as the basis of the stimuli used. All garments had fluorescent yellow-green background material. All retroreflective trim was 50-mm wide, vinyl-backed, microprismatic material. The eighteen unique stimuli consisted of the orthogonal combinations of three levels of ANSI/ISEA garment classification/configuration (Class 2 vest, Class 3 vest, and Class 3 jacket), retroreflective trim color (white/silver, blaze orange, and fluorescent red) and two levels of retroreflective trim intensity (original, as manufactured, and about 16% of the original R_A value). All garments were size extra large. The Class 2 vests included 0.14 m^2 of retroreflective trim, while the Class 3 garments included 0.23 m^2 of retroreflective trim.

Figure 1 displays the configurations of the retroreflective trim corresponding to the three levels of ANSI/ISEA garment classification/configuration. The lower of the two levels of trim intensity was achieved by applying a single strip of 0.3 neutral density filter (Lee Filters #209) and a single strip of transparent, 0.05 density, film (Lee Filters #269) over the retroreflective trim material, and only minimally covering the background material (garment fabric) for purposes of attaching the film to the garment. The combined filters had the approximate effect of a 0.7 neutral density filter, as light would be attenuated twice (passing towards and departing from the retroreflective trim). The trim intensities that resulted from the filtering ranged from 14% to 19% of the original R_A values.

Table 3 provides the chromaticity coordinates of the garment materials when illuminated by a tungsten-halogen source. Table 4 provides the coefficients of retroreflection (R_A) of the trim materials, as manufactured and after manipulation. The R_A values in Table 3 were derived from an average of six individual measurements of the trim while the trim was applied to the garments. Measurements of coefficients of retroreflection were taken using observation and entrance angles of 0.2° and –4.0° respectively, and otherwise in accordance with ASTM Standard E 1501-99 (ASTM, 1999).

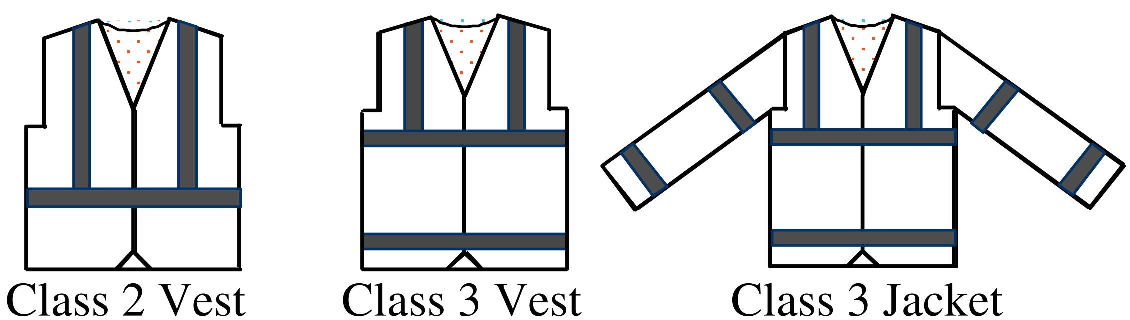

Figure 1. Illustration showing the types of garments used as stimuli in the study, as well as the locations of the retroreflective trim.

Table 3
Coefficient of retroreflection measurements (R_A) for garment trim materials.
Values are the averages of six independent measurements across a garment.

Stimulus No.	Garment Classification	Trim Material	Coefficient of Retroreflection (R_A)*		
			Rotation Angle		Average R_A
			0°	90°	
1	Class 2 Vest	White/Silver	630	567	599
2	Class 2 Vest	White/Silver w/ ND Filter	112	92	102
3	Class 2 Vest	Fl Red	145	156	151
4	Class 2 Vest	Fl Red w/ ND Filter	27	28	28
5	Class 2 Vest	Blaze Orange 1	474	434	454
6	Class 2 Vest	Blaze Orange 1 w/ ND Filter	94	70	82
7	Class 3 Vest	White/Silver	565	536	551
8	Class 3 Vest	White/Silver w/ ND Filter	106	94	100
9	Class 3 Vest	Blaze Orange 2	234	320	277
10	Class 3 Vest	Blaze Orange 2 w/ ND Filter	41	54	48
11	Class 3 Vest	Fl Red	143	160	152
12	Class 3 Vest	Fl Red w/ ND Filter	28	28	28
13	Class 3 Jacket	White/Silver	580	562	571
14	Class 3 Jacket	White/Silver w/ ND Filter	114	105	110
15	Class 3 Jacket	Blaze Orange 2	240	315	278
16	Class 3 Jacket	Blaze Orange 2 w/ ND Filter	55	63	59
17	Class 3 Jacket	Fl Red	150	153	152
18	Class 3 Jacket	Fl Red w/ ND Filter	29	29	29

* Coefficient of retroreflection measurements taken with an observation angle of 0.2° and an entrance angle of -0.4°

Table 4
Chromaticity coordinates (CIE, 1931) of the retroreflective trims and background material.

Material Type and Color	*CIE, 1931* *x*	*y*
Background Material		
Fl Yellow-Green	.46	.50
Retroreflective Trim		
Blaze Orange	.57	.40
Fl Red	.61	.34
White/Silver	.44	.42

Task and Experimental Setup

The task was a forced-choice detection task in which participants drove an instrumented research vehicle on a test track, through simulated work zones, and indicated to an experimenter as they approached a simulated work zone whether they detected a pedestrian on the left or right side of their lane. While the primary task of interest was the detection of the pedestrian located in, or just opposite of, the work zone, the process of driving the research vehicle on the unlit track at night itself required ample effort. Drivers were only allowed to use the low-beam headlamps and were instructed to maintain 56 km/h (35 mph) on the track outside of the work zones, but to observe the 40 km/h (25 mph) posted speed in the work zones. Proper aiming of the vehicles' headlamps was performed just prior to conducting the study, and the headlamp lenses and the windshields were regularly cleaned.

Two participants, in separate research vehicles, took part simultaneously in the experiment by operating vehicles on opposite sides of the track, traveling in the same direction, but generally not in sight of one another. A certain level of continuous pressure to maintain the instructed speeds was provided by the second vehicle operating on the track, along with reminders by the onboard experimenter. Participants were instructed to maintain a ½ track length separation between vehicles. The presence of this second vehicle inhibited a participant from driving either too fast or too slow, as deviations in speed could otherwise result in an encounter with the other vehicle.

Two four-door passenger cars with automatic transmissions served as research vehicles. Each vehicle was equipped with a customized data acquisition system. Each system included a differential global positioning system (DGPS), a computer with a hard disk, and a button used by the experimenter to mark the global positioning data to indicate the location along the track where participants first identified the position of the pedestrian. Vehicle location was recorded in XYZ ECEF (Earth-Centered, Earth-Fixed) coordinates, and the detection distances were calculated by using the following formula:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

where (x1, y1, z1) are the coordinates associated with where the participant saw the pedestrian, and (x2, y2, z2) are the coordinates associated with the actual position of the pedestrian.

The test took place at the Vehicle Dynamics Facility at the Chrysler Proving Grounds in Chelsea, Michigan. The track is a 4.43 km (2.75 mi) oval, with straight-aways that are 1.55 km (0.96 mi) in length. The track surface is asphalt with non-reflective lane delineators on portions of the straight-aways. There is no fixed lighting located on or near the track. The only fixed lighting present was provided by portable light towers placed in the simulated work zones. The track was closed to all other traffic while the experiment was conducted.

The work zone design employed for this project followed the MMUTCD (Michigan Manual of Uniform Traffic Control Devices) guidelines for a one-lane closure at a spot location for a 48-56 km/h (30-35 mph) posted roadway. The work zone was defined as an intermediate-term stationary location with a working duration of one to three days and/or nighttime work lasting more than one hour. Participants were directed to shift left and thereby change lanes at a reduced speed of 40 kph (25 mph). The entire configuration was 573 m (1880 ft) in length, and it used regulatory and warning signage as well as channeling devices. The work zones were located at the ends of each of the two straight-aways with a single light tower located in the center of the work zone proper, on the right-hand side, 7.3 m (24 ft) from the lane boundary. All traffic control materials used were actual equipment as supplied by a company that specializes in leasing traffic control materials to the road construction industry, and displayed various states of wear/use (Figures 2 and 3).

Men of slight to medium build, ranging in height from 173 to 183 cm, served as pedestrians. On each trial, a pedestrian was located in one of the two positions—in or opposite the work zone. Pedestrians in the work zone were positioned to the driver's right at a distance of 3.7 m from the right-most lane boundary. Pedestrians located opposite the work zone were positioned to the driver's left at a distance of 3.7 m from the left-most lane boundary. Illumination from the portable light towers reaching the track surface where the pedestrians stood was 60 lx at the location within the work zone and 1 lx at the location opposite the work zone. Pedestrians wore either the garments previously described or dark apparel with no retroreflective trim of any kind. Trials in which the pedestrian was darkly clad served as a basis for comparison with trials in which retroreflective trim was worn. During each trial, the pedestrians walked in place, arms and legs in motion, while rotating in order to expose all sides of the garments.

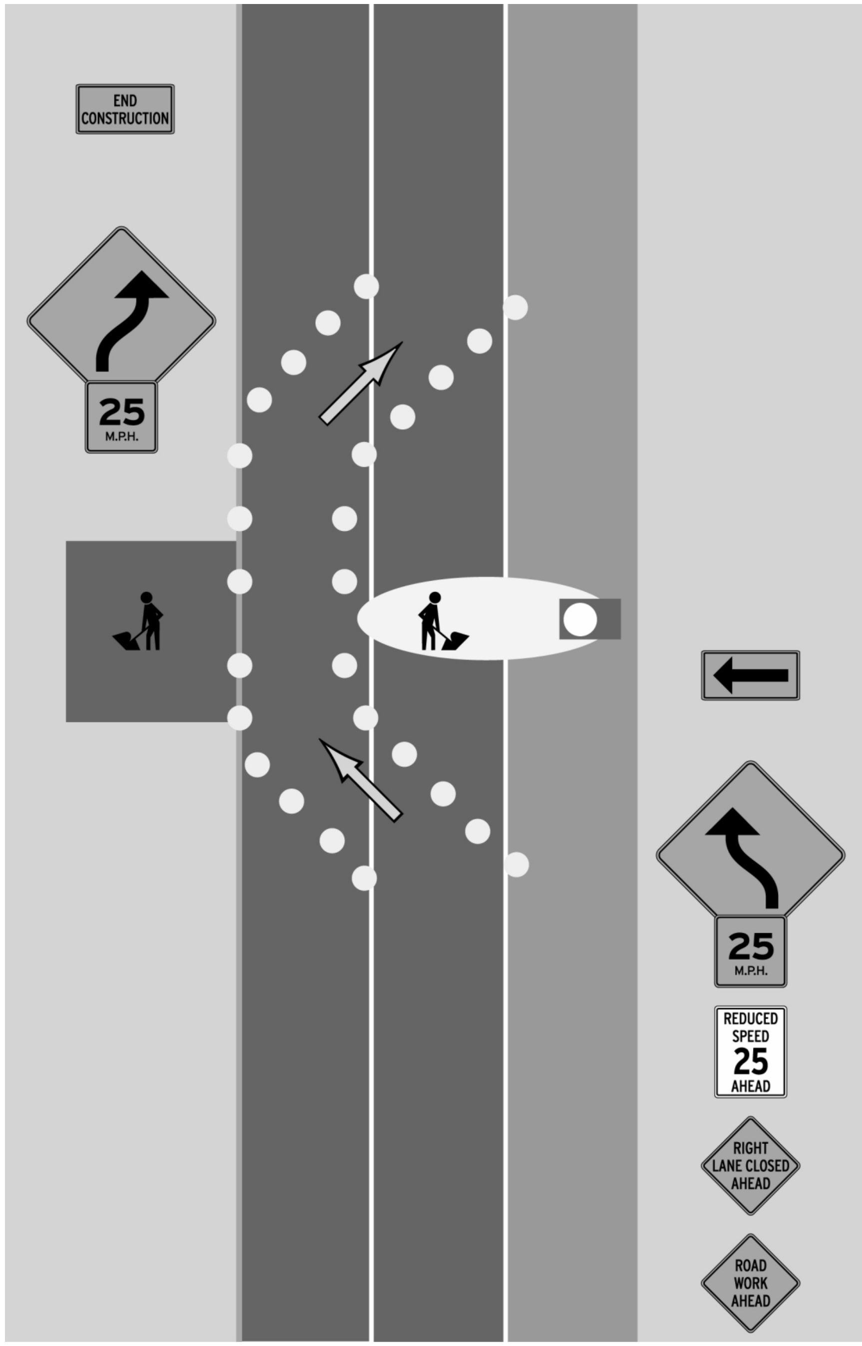

Figure 2. Illustration of the experimental setup, overhead perspective.

Figure 3. Illustration of the simulated work zone from a driver's perspective.

RESULTS

Analysis of Variance

A mixed-factor repeated-measures analysis of variance (ANOVA) was performed on the data. The within-subject factors were garment classification/configuration (three levels), retroreflective trim color (three levels), retroreflective trim intensity (two levels), and placement of the pedestrian in the work zone (two levels). The between-subjects factors were participant age (two levels) and participant gender (two levels). The dependent measure was distance at which the stimulus, a pedestrian located in or opposite a work zone, was first detected. The analysis included an adjustment of the degrees of freedom using the Greenhouse-Geisser test (Winer, Brown, & Michels, 1991). Trials in which the pedestrian was darkly clad were not included in the ANOVA. However, mean detection distances for a darkly clad pedestrian are provided for the comparison.

Main Effects

Garment Classification/Configuration. There was a significant main effect garment classification/configuration, $F(1.2,7.5) = 9.7$, $p = .013$. Mean detection distances for each of the three garments are plotted in Figure 4, with the Class 3 jacket being most conspicuous (355 m), followed by the Class 3 vest (311 m). A Student-Newman-Keuls test for differences among means revealed that the Class 3 jacket was significantly more conspicuous than either the Class 3 or Class 2 vests (295 m). The difference between the Class 3 or Class 2 vests was not significant. For comparison, the mean detection distance for the darkly clad pedestrian was 94 m.

Retroreflective Trim Color. There was a significant main effect of retroreflective trim color, $F(1.1,6.6) = 6.5$, $p = .039$. Mean detection distances for each of the three trim colors are plotted in Figure 5, with blaze orange being most conspicuous (344 m), followed by white/silver (329 m). A Student-Newman-Keuls test for differences among means revealed that the blaze orange trim was significantly more conspicuous than the fluorescent red trim (288 m), but not significantly different from white/silver. The difference between the white/silver and fluorescent red trim was not significant.

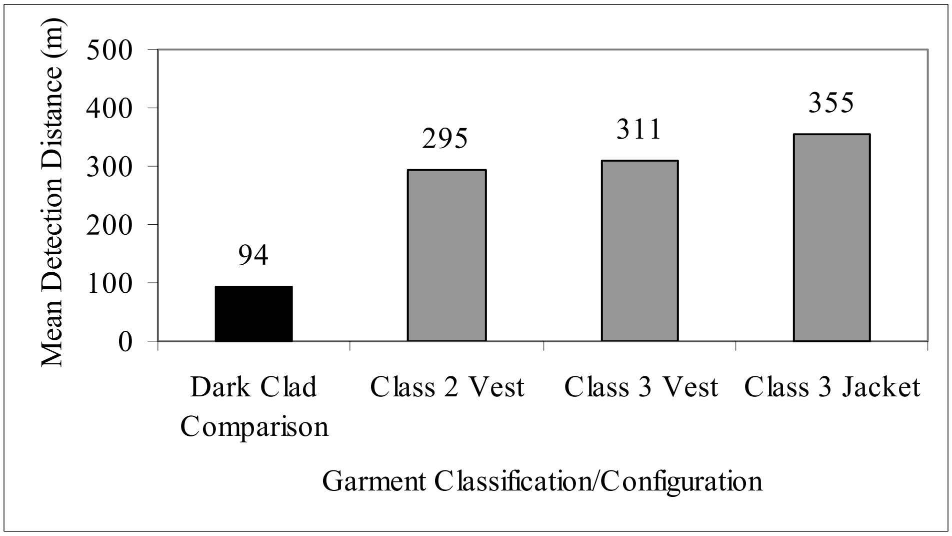

Figure 4. The main effect of garment classification/configuration on conspicuity.

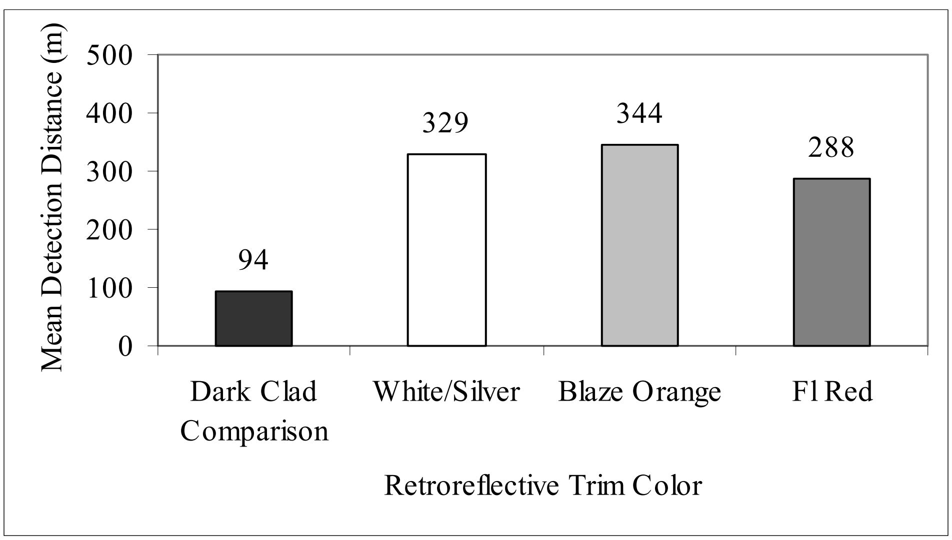

Figure 5. The main effect of garment retroreflective trim color on conspicuity.

Retroreflective Trim Intensity. There was not a significant main effect of retroreflective trim intensity, $F(1,6) = 0.55$, $p = .488$. Independent of manipulating the intensity, garments employing trims with higher values of R_A were not significantly more conspicuous. The mean detection distance for the low intensity trim (about 16% of the original R_A value) was 314 m, whereas the mean detection distance for the high intensity trim (as manufactured) was only slightly, and non-significantly, longer (325 m).

Pedestrian Placement. There was a significant main effect of where the pedestrian was placed relative to the work zone, $F(1,6) = 9.7$, $p = .021$. Mean detection distances for each of the locations are plotted in Figure 6, with pedestrians being more conspicuous when located to the driver's right—within the illuminated work zone (369 m). The mean detection distance was significantly shorter for pedestrians located on the driver's left—in the dark, opposite the work zone (272 m).

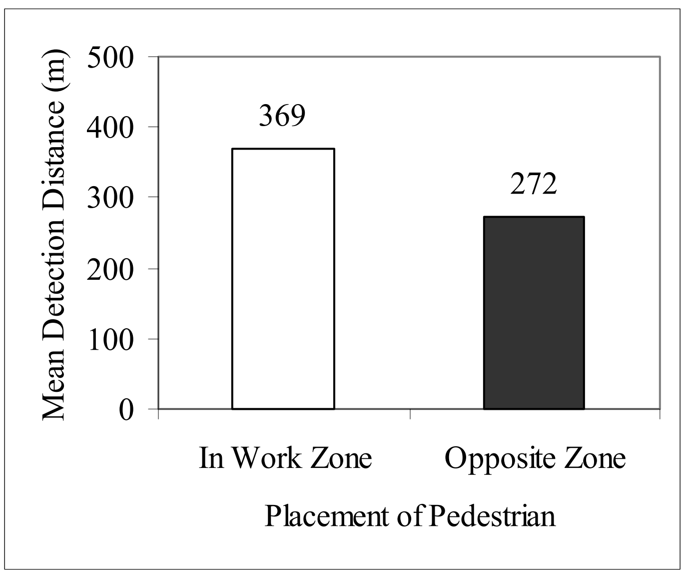

Figure 6. The main effect of pedestrian placement on conspicuity.

Driver Age. There was a significant main effect of driver age, $F(1,6) = 11.7$, $p = .014$. Mean detection distances for both age groups are plotted in Figure 7, with younger drivers having detected pedestrians at significantly longer distances (432 m) than did older drivers (208 m).

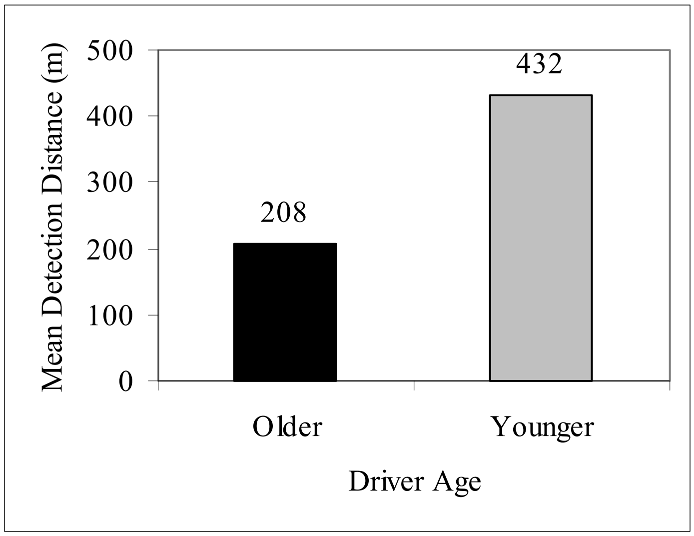

Figure 7. The main effect of driver age on detection distance.

Driver Gender. There was not a significant main effect of driver gender, $F(1,6) = 0.36$, $p = .569$, although the overall mean detection distance for male participants (339 m) was slightly longer than for the female participants (300 m).

Significant Two-Way Interactions

Trim Intensity by Pedestrian Placement. There was a significant two-way interaction of the retroreflective trim intensity and placement of the pedestrian relative to the work zone, $F(1,6) = 14.5$, $p = .009$. Figure 8 illustrates that the low intensity trim presented in the work zone was slightly more conspicuous than the high intensity trim, 383 m versus 355 m. When presented opposite the work zone the reverse was true, specifically high intensity trim was more conspicuous than low intensity trim when placed opposite the work zone (297 m and 246 m, respectively). For comparison, the darkly clad pedestrian was detected at 140 m when in the work zone and only 38 m when opposite the work zone.

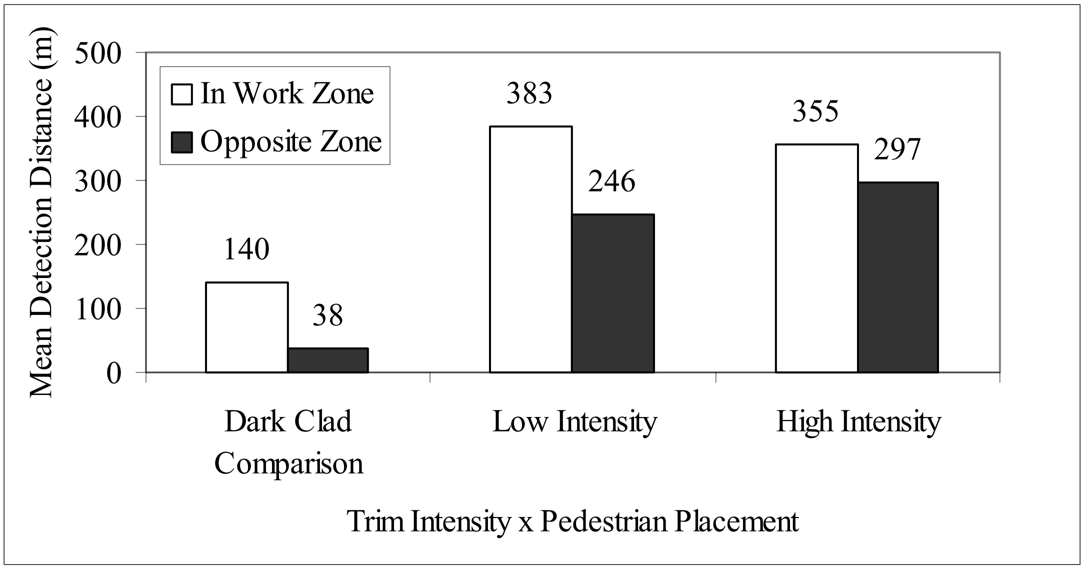

Figure 8. The interaction of trim intensity and pedestrian placement on detection distance.

Driver Age by Driver Gender. There was a significant two-way interaction of driver age and driver gender, $F(1,6) = 7.04$, $p = .038$. Specifically, the differences between younger and older participants were greater for females (499 m versus 102 m) than for males (365 m and 314 m). This interaction is illustrated in Figure 9.

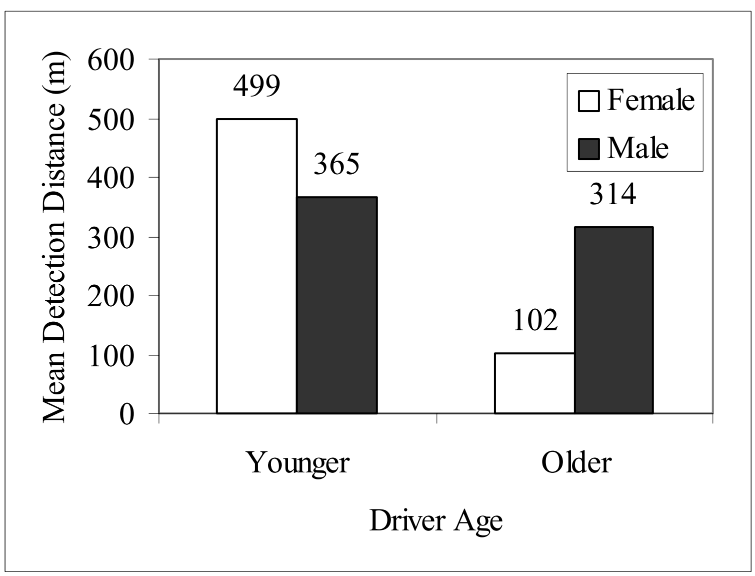

Figure 9. The interaction of driver age and driver gender on detection distance.

Significant Three-Way Interactions

There were three instances of significant three-way interactions. These interactions involved: garment classification/configuration by retroreflective trim color by driver age, $F(2.7,16.3) = 3.19$, $p = .012$; garment classification/configuration by pedestrian placement by driver age, $F(1.2,7.0) = 8.47$, $p = .02$; and garment classification/configuration by pedestrian placement by driver gender, $F(1.2,7.0) = 8.43$, $p = .02$.

DISCUSSION

The results of this study have several important implications for the design of high-visibility safety apparel, or personal protective equipment, for pedestrians in road construction work zones. First, the placement of retroreflective trim on a garment can be at least as important to pedestrian conspicuity as is the amount of the trim—apparently due in part to a biomotion effect. Second, at threshold detection distances, and under conditions of reasonable ecological validity, retroreflective trim color was found to have no effect on pedestrian conspicuity. This lends further support to previous findings (Sayer et al., 1998, 1999, and 2000) that the color correction factors in ASTM E 1501 (1999), and the Helmholtz-Kohlrausch effect, are not valid under all conditions of interest for determining the conspicuity of retroreflective materials. Third, the intensity of a garment's retroreflective trim, even when reduced to less than 20% of its initial value, had no effect on pedestrian conspicuity when presented in a simulated work zone condition. These three findings are discussed in greater detail below.

Retroreflective Trim Area and Trim Placement

The main effect of garment classification/configuration was effectively the result of two variables, trim area and trim placement. The two most direct comparisons were made between the Class 2 and Class 3 vests, in which trim area varied but the placement remained relatively constant, and between the Class 3 vest and the Class 3 jacket, in which trim placement varied but the trim area was constant.

In the comparison of the Class 2 and Class 3 vests, the 0.09 m^2 difference in retroreflective trim (0.14 m^2 versus 0.23 m^2) did not have a significant effect on the conspicuity of pedestrians in the work zone (despite a 16-m improvement in detection distance associated with the additional material). In comparing the Class 3 garments, there was a significant effect, with the Class 3 jacket being more conspicuous than the Class 3 vest. The 44-m difference in detection distance associated with the Class 3 jacket is seemingly attributable only to a difference in how the retroreflective trim was positioned. Overall, the finding of improved conspicuity of the Class 3 jacket in comparison to either of the vests suggests that the placement of the retroreflective trim on the arm/sleeve of the jacket accounted for the significant improvement in conspicuity for this garment. The method employed in presenting the stimuli (pedestrians were in motion) likely contributed to this finding. Therefore, it is not clear how the results might differ if the pedestrians/garments were stationary when presented. Thus, placing retroreflective trim on the arms of the jacket, at least when a pedestrian is in motion, appears to provide a very salient cue for disembedding (detecting and recognizing) pedestrian road workers from surrounding retroreflective stimuli (barrels, signs, etc.) that otherwise may distract a driver or clutter the work zone relative to locating a pedestrian.

Color of Retroreflective Material

The results of this study support the hypothesis that differences in the subtended solid angle of stimuli largely account for the discrepancies in calculated color correction factors (F_c) reported in a variety of previous studies. Therefore, whether color correction factors as specified in ASTM E 1501-1999 should be broadly applied is brought into question. In the findings presented here, in which stimuli could often be considered points sources based upon their size and the distances at which they were detected, the Helmholtz-Kohlrausch effect was not observed. Rather, the most saturated stimuli, fluorescent red trim, were the least conspicuous (i.e., were associated with the shortest detection distances). As has been suggested previously (Sayer et al., 2001), the appropriate use of color correction largely depends on what assumptions are made about the subtended angles of the retroreflective markings at the point at which they are first detected and recognized (sight distance). However, for many applications accurate assumptions about sight distance can be difficult to determine. Relatively large correction factors are potentially applicable—reflecting the expectation of a relatively large Helmholtz-Kohlrausch effect—when the stimuli are saturated and could be expected to be reasonably large in terms of subtended angle when first detected (e.g., the use of color in highway signage). Yet, when the subtended angles are expected to be smaller, the use of color correction factors as currently specified in ASTM E 1501-1999 is not supported in the current findings.

Retroreflective Trim Intensity

The manipulation of trim intensity did not produce a significant difference in garment conspicuity, despite a rather substantial manipulation. Retroreflective trim that was presented as manufactured (i.e., new materials) was not substantially more conspicuous than retroreflective trims having intensities below 20% of the new materials. While the mean detection distances differed in the direction one might expect, the magnitude of the change was extremely small (about 3% collapsed across all other conditions). As illustrated in Figure 10, presented independently by color, the benefits of the very high intensity material in terms of conspicuity appear to be limited within the context of the type of road construction work zone environment examined. This may be due to the presence of numerous other retroreflective stimuli, some of which appeared new (very little wear), and the driver's need to differentiate the pedestrian (target) from the surrounding retroreflectors (distracters). Certainly, at some level of reduced intensity, one would expect that the conspicuity of retroreflective trim would begin to diminish, with detection distances ultimately approaching those observed for the darkly clad pedestrian. However, rather surprisingly, the anticipated trend was not observed over the large range of trim intensities employed. The specific value of trim intensity at which detection distances begin to significantly decease should be the subject of further study. However, it appears, from the result of the present findings, that the value is well below trim intensities of 100 R_A. This finding has particularly important implications for the longevity of a garment, and therefore for what might be expected to provide a pedestrian with adequate protection for a long service life (i.e., a garment that would remain highly conspicuous).

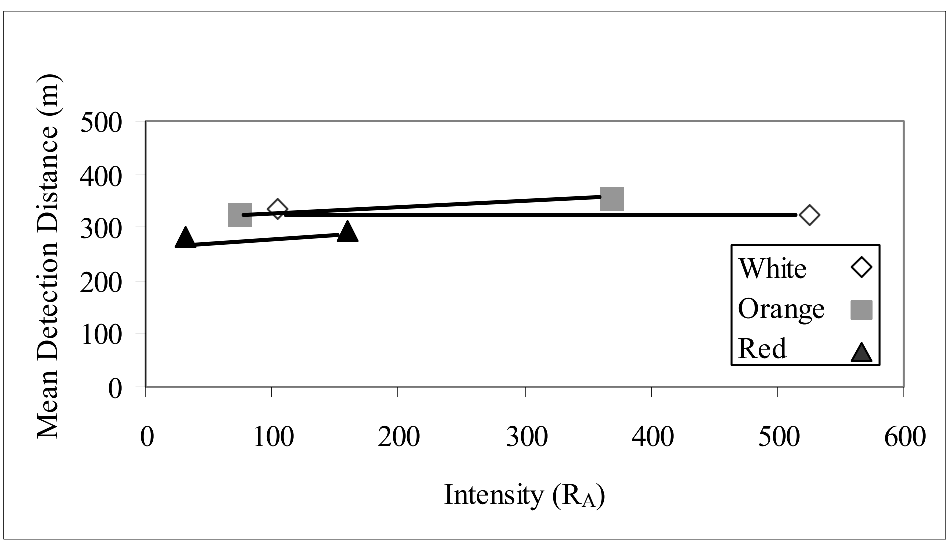

Figure 10. Mean detection distances by retroreflective trim intensity (R_A) and color.

CONCLUSIONS

The results of this study lend added support to the well-established use of retroreflective safety garments at night. Even for one of the worst viewing circumstances (older drivers attempting to locate a low-intensity, red-trimmed garment on a pedestrian located outside of the illuminated work zone), the pedestrian was, on average, detected at a distance more than *six* times that of a darkly clad pedestrian. However, the actual minimum value of retroreflective intensity that can produce sufficient levels of conspicuity remains unknown, and should therefore be the subject of further research. Of equal importance is the finding that including retroreflective trim on the sleeves of a garment significantly improves a pedestrian's conspicuity, at least when the pedestrian is moving. In line with previously reported results on what has been termed the biomotion effect, the idea that drivers can more readily detect a retroreflective garment in motion relative to its stationary surround makes intuitive sense. Nonetheless, it is relatively infrequent that one sees a road or utility worker wearing a long sleeved safety garment, and the importance of conveying the benefits of perceived motion to pedestrians and garment manufacturers alike should be a priority.

Finally, findings from the current study further bring into question the use of color correction factors for specifying retroreflective trim intensity per ASTM E 1501-1999. As has been suggested previously, the use of these color correction factors is not supported for all applications—particularly in the case of pedestrian garments expected to be detected at long sight distances and with the consequent small visual angle subtended by the retroreflective garment.

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