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**THE ROLES OF RETROREFLECTIVE
ARM TREATMENTS AND ARM MOTION
IN NIGHTTIME PEDESTRIAN
CONSPICUITY**

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October 2004

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16. Abstract <p>A naturalistic, nighttime field study was conducted to assess the effects of retroreflective arm treatments, pedestrian arm motion, scene complexity, and pedestrian orientation on detection distances for older drivers. Participants drove instrumented vehicles in real traffic, along a fixed 38-km route, in search of pedestrians wearing one of three retroreflective trimmed safety garments. Participants had no prior knowledge of where along the route pedestrians would be located, nor the number of pedestrians positioned along the route. All of the challenges normally encountered when driving at night on public roadways were present during the study (oncoming traffic, traffic entering the flow, and distracters such as traffic signals, lights, signs, pedestrians, and bicyclists), imposing an ecologically valid level of workload on participants.</p> <p>The results show that both arm motion and scene complexity significantly affected the distances at which pedestrians were detected at night. Pedestrians with their arms in motion were detected on average 32% farther away than those who stood motionless. Pedestrians located in the low complexity environments were on average detected at distances that were 30% farther than the medium complexity conditions. Yet, there were no main effects of either the type of retroreflective arm treatment or the way the pedestrian was oriented relative to the flow of traffic. Interactions involving arm motion and pedestrian orientation as well as scene complexity and arm motion were found.</p> <p>Overall, the results of this study continue to support the benefits to pedestrians from wearing retroreflective safety garments when in the vicinity of traffic at night. However, further study is needed to better understand the role of reflective markings in combination with garment background materials on pedestrian conspicuity in daytime conditions and in higher complexity nighttime scenes.</p>					
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INTRODUCTION

The visual system limitations associated with nighttime driving are generally not well understood by the driving population and pedestrians. This is evidenced by the lack of a decrease in nighttime speeds and by the fact that pedestrians – frequently clad in dark clothing – overestimate how well oncoming drivers can see them (Shinar, 1984). The visibility distance of a pedestrian wearing dark clothing is less than one-third of the stopping distance for a vehicle traveling 88 km/h and approximately one-half the distance required to stop a vehicle traveling 56 km/h (Leibowitz and Owens, 1986). While pedestrian deaths have decreased by 16% since 1993, still 4,749 pedestrians were killed in traffic crashes in the United States in 2003. Of these deaths, 65% occurred at night (U.S. DOT, 2004).

Rumar (1990) suggests that the most effective and inexpensive way to improve detection of pedestrians at night is to make them more conspicuous through the 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.). A number of recent studies have shown that wearing retroreflective materials, or active light sources, significantly increases pedestrian conspicuity.

Recently, a nighttime field study was conducted by Sayer and Mefford (2003) 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 pedestrians were always in motion, walking in place with arms swinging.

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, even a small amount of retroreflective trim improves detection distance by as much as a factor of 8 when compared with a darkly clad pedestrian (Sayer and Mefford, 2003).

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 indication 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, let alone pants with retroreflective markings, and the importance of conveying the benefits of perceived motion to pedestrians and garment manufacturers alike should be a priority.

Previous Research on Retroreflective Trim Placement and Pedestrian Conspicuity

Johansson (1973) was the first to demonstrate that certain human behaviors (walking, running, etc.) are comprised of a series of pendular motions which form patterns that can readily be identified as a human in motion when main joints of the human body are represented. These patterns were termed biological motion by

Johansson. While a number of research studies had demonstrated the general effectiveness of retroreflective markings and garments (see Langham and Moberly (2003) for a review), Owens, Antonoff, and Francis (1994) were the first to examine Johansson's theory by applying retroreflective markings to the major joints of a pedestrian to determine the effects on the conspicuity of a pedestrian at night. Bloomberg, Hale, and Preusser (1986) performed a test-track experiment examining the placement of retroreflective markings, along with some luminary devices before Owens et al., but did not examine Johansson's theory.

The Bloomberg et al. (1986) test track study involved pedestrians, bicyclists, and some distracters. The authors reported that every treatment condition they examined resulted in significantly longer detection distances relative to a pedestrian wearing only blue jeans and a white tee shirt. However, recognition distances were not significantly improved by the application of retroreflective dangle tags (small retroreflective disks attached to a pedestrian via a string and located near the waist). While the authors strongly advised the use of active light sources, such as a flashlight, because they resulted in significantly longer detection distances, they also acknowledged that the placement of retroreflective markings on a pedestrian may also be beneficial in that they can serve as conspicuity enhancers by conveying the human form.

Owens et al. (1994) conducted two laboratory experiments. The first entailed trials in which participants watched video sequences filmed by the researchers in several roadway environments where the task was to identify the presence of a jogger who was facing oncoming traffic and who wore a variety of apparel that both included and excluded retroreflective markings. Four types of retroreflective trim placement were examined: no retroreflectors (dark control); a vest with a single diagonal stripe; a suit that included retroreflective trim around the wrists, ankles, and torso (stripes); and a suit that included retroreflective trim at all major joints (biomotion condition). Participants watched the filmed sequences and were instructed to press a floor pedal as soon as they recognized the presence of a jogger in the video. The authors reported that, overall, the retroreflective treatments resulted in significantly earlier detections relative to the dark control, and that the trials in which retroreflectors were present on the major joints were detected significantly earlier than when the vest was presented. However, there was an

interaction between the retroreflective treatments and the roadway environment such that on a road with fixed illumination, both the vest and stripes conditions resulted in significantly earlier detections than the biomotion condition. Yet the results supported the general prediction that the dynamic visual information provided by the placement of retroreflectors on the pedestrian's limbs improved pedestrian recognition.

In the second experiment, Owens et al. (1994) utilized the same procedure and video segments; however, they also had participants perform a secondary task, a two-dimensional tracking control. The authors report findings similar to the first experiment, specifically that retroreflective treatments resulted in significantly earlier detections relative to the dark control and that overall retroreflectors present on the major joints were detected significantly earlier than with the vest condition. However, unlike the first experiment, there was no interaction between retroreflective treatments and the roadway environment.

Owens et al. (1994) concluded that the results of their studies provide evidence that dynamic visual information in the form of retroreflective markings on a pedestrian's limbs and major joints improves recognition, thus supporting Johansson's theory. Yet they conceded that some evidence of an interaction between the roadway environment and the configuration of retroreflective markings exists, and this warrants further investigation utilizing field studies (avoiding problems inherent to video relative to a natural scene), and possibly varying the position of the pedestrian relative to the flow of traffic.

Luoma, Schumann, and Traube (1995) conducted a field study in which they examined the effects of retroreflector placement on pedestrian conspicuity. The experiment was conducted on an actual roadway, with participants performing a recognition task while seated in a passenger car driven by a researcher at a constant speed. Participants were instructed to press a button on a hand-held device whenever they recognized a pedestrian on or along-side of the road. The authors examined the placement of retroreflectors in three positions (on the shoulders and around the torso, on the wrists and ankles, and stripes placed around major joints) and a no retroreflector, dark clad condition. Pedestrians either walked with the flow of traffic or across the roadway. In addition to signs and other distracters that were naturally present, a number of

retroreflective traffic control devices and encounters with bicyclists were included. While the study was performed on a roadway, it was done in a rural area without fixed lighting or the additional complexity presented by headlights from other vehicles.

Luoma et al. (1995) report that the placement of the retroreflectors, as well as the direction the pedestrian walked, significantly affected the distance at which pedestrians were recognized. Specifically, recognition distances were greatest when the retroreflective markings were placed on the major joints—closely followed by placement on the wrists and ankles. Furthermore, recognition distances for a pedestrian walking across the flow of traffic and wearing retroreflectors were 42% to 53% longer than when the pedestrian walked with the flow of traffic wearing the same retroreflective markings. The authors report that the primary implication of their findings was that the placement of the retroreflective markings significantly improved pedestrian recognition distances by 60% to 80% relative to an unmarked pedestrian, regardless of whether the pedestrian was walking with or across the flow of traffic.

Lastly, Moberly and Langham (2002) conducted a laboratory experiment, much like that of Owens et al. (1994), by recording scenes from a moving vehicle. The route they choose included naturally occurring distracters, such as reflector posts, but was more or less of a constant complexity. Pedestrians were situated along side of the roadway while filming, and wore either a conventional Class 1 vest or retroreflective markings on their ankles, knees, and elbows (biomotion condition). The amount of material used was held constant between the two conditions at 0.114 m². Pedestrians were filmed in motion, walking in place, or stationary with their arms at their side, facing perpendicular to the flow of traffic (i.e., participants initially saw the pedestrian's arms and legs more so than their torso). The authors used estimated detection distances by determining where in the video sequence the participants first detected the presence of a pedestrian (indicated by pressing a button).

Moberly and Langham (2002) report that there was no significant difference in detection distance between the Class 1 vest and the biomotion condition. However, pedestrians who were moving were detected at significantly longer distances than those who stood stationary for both retroreflector placement conditions, and a moving pedestrian in the biomotion condition was detected at a significantly longer distance than

the one wearing a vest and stationary. The authors go on to cite how real-world driving and the complexity of the surrounding environment, relative to a laboratory study, could effect the results, and suggest that further research is required to examine the potential of biomotion through the placement of retroreflectors in a field study with a variety of scene complexities.

The Present Study

The present study attempts to build upon recommendations from previous research by examining the effects of placing retroreflectors on a pedestrian's arm, in a naturalistic driving environment, while examining the effects of scene complexity, pedestrian motion, and the orientation of the pedestrian relative to traffic. Under dynamic nighttime viewing conditions, with participants driving instrumented vehicles on a prescribed route along public roads, the present study addressed the following specific questions related to the conspicuity of retroreflective safety garments for pedestrians:

- How does the visual complexity of the nighttime environment affect retroreflective garment conspicuity?
- What role does arm motion, simulating biomotion, have on the distance at which pedestrians are detected?
- Is there an effect of ANSI/ISEA safety garment classification on conspicuity, where the manipulation is the amount (area) of the retroreflective trim on the arm of the garment?
- How does a pedestrian's orientation relative to the flow of traffic (facing or perpendicular to) affect the distance at which they are first detected?

METHOD

Participants

Twenty-four older drivers participated in this study. They ranged in age from 60 to 78 years with a mean age of 68.8 years. Each driver was paid for four hours of participation; 1.5 hours during the day and 2.5 hours at night. Based on previous research that was similar in context, longer detection distances are generally observed with younger participants. Consequently, in order to avoid the potential of observing a “ceiling effect,” only older drivers were chosen for this study.

All drivers were recruited from a list of potentially interested persons maintained by UMTRI. The visual acuity of participants ranged from 20/13 to 20/50, with an average visual acuity score of 20/30.6. While participating in the study, all drivers were instructed to wear any corrective lenses that they normally wear when driving.

Stimuli

Three new ANSI/ISEA 107-1999 compliant garments were used as stimuli in this study. Each garment had fluorescent yellow-green background material with silver retroreflective trim. The trim was a 50-mm wide and made up of exposed, wide angle lens. The three garments were a traditional Class 2 vest, a Class 2 vest with the addition of area reflective half-sleeves, and a Class 3 jacket (Figure 1). The Class 2 vests each included 0.19 m² of retroreflective trim, while the Class 3 jacket included 0.28 m² of retroreflective trim. The coefficient of retroreflectivity (R_A) for the trim was 400 cd/lux/m². Area reflective half-sleeves were sewn on to otherwise standard Class 2 vests. The R_A for the area reflective material was 58 cd/lux/m². All of the retroreflective materials appeared white in the nighttime viewing conditions. Figure 1 illustrates the configurations of the retroreflective trim and area reflective half-sleeves.

Task and Experimental Setup

The experiment employed a detection task in which participants drove an instrumented research vehicle on two traversals of a 38-km route through the city of Ann Arbor and surrounding communities. Participants were instructed to indicate to an accompanying researcher when they were confident they saw a pedestrian (which was an

Data collection was only performed at night. However, prior to data collection, participants drove the route once during the day in order to familiarize them with the route. All driving was done on major arterials or local roads; there were no highway or freeway segments. Experimenters posing as pedestrians were positioned along the route at twelve different locations (six positions per traversal). They stood on the right side of the road approximately 2 m from the rightmost lane edge. Participants had no advanced knowledge of the locations along the route where the pedestrians would be stationed, and therefore were expected to be ever vigilant in attempting to detect the stimuli.

Experimental Design

The experiment used a mixed design. There were three within-subject variables (garment, arm motion, and scene complexity) and one between-subject variable (pedestrian orientation relative to oncoming traffic). Participant gender was balanced. The dependent measure was detection distance.

In each trial, an experimenter wore one of the three retroreflective garments and was either facing oncoming traffic or was perpendicular to it. The experiment was blocked by pedestrian orientation, with the first twelve participants being presented only with pedestrians standing perpendicular to the flow of traffic, and the remaining twelve with pedestrians facing the flow of traffic. In half of the trials, the pedestrians were stationary (with their arms placed at their side) and in the other half, the pedestrians' arms were in motion (swinging to simulate the type of arm movement which naturally occurs when walking).

Two levels of scene complexity, low and medium, were examined in this study. The low complexity scene was characterized by little/no fixed street lighting, an absence of businesses and their associated lights, and low traffic density, but included naturally occurring distracters such as signs, driveway markers, and roadway delineators (see Figure 2). The medium complexity scenes included fixed lighting found in and around business areas, higher traffic densities, a great number of distracters in the form of signs and traffic control devices, and fixed street lights (see Figure 3).



Figure 2. An example of a low complexity scene. The arrow is pointing to a pedestrian stationed along the roadway.



Figure 3. An example of a medium complexity scene. The arrow is pointing to the pedestrian stationed along the roadway.

The route was such that trials were blocked by scene complexity, where the medium complexity conditions for any traversal were always viewed before the low complexity conditions. The remaining independent variables were controlled for such that each level of garment and arm motion was represented at each level of scene complexity. In both levels of complexity, participants had to contend with light from oncoming traffic in opposing lanes. Because of the amount of naturally occurring pedestrian traffic during testing, it was not feasible to include a baseline measure of detection distance for pedestrians without a retroreflective garment.

RESULTS

Analysis of Variance

A mixed-design repeated-measures analysis of variance (ANOVA) was performed on the data. The within-subject variables were garment (three levels), arm motion (two levels), and scene complexity (two levels). The between-subject variable was pedestrian orientation (two levels). The dependent measure was the distance at which a pedestrian was detected. The analysis included the Greenhouse-Geisser adjustment of the degrees of freedom for within-subject tests.

Missed Trials

Of the 288 trials conducted, there were 33 trials in which 13 different participants missed detecting a pedestrian altogether. Misses were similarly divided between male and female participants, and between the two levels of scene complexity. However, 22 (two-thirds) of the missed trials occurred when the pedestrian stood stationary, and, similarly, in 21 trials where the pedestrian stood perpendicular to the traffic flow. The intersection of the two conditions, stationary and perpendicular to traffic, accounted for more than half (17) of the missed trials. Thus the instance of missed trials is over-represented by the intersection of these two variables since only one-quarter of the trials were conducted with the pedestrian standing stationary and perpendicular to traffic. Zero was used for detection distance on trials in which the subjects failed to detect the pedestrian.

Main Effects

Scene Complexity. There was a significant main effect of scene complexity, $F(1, 22) = 7.1, p = .014$. On average, participants detected pedestrians 21 m farther in the low complexity scenes than they did in the medium complexity scenes (Figure 4).

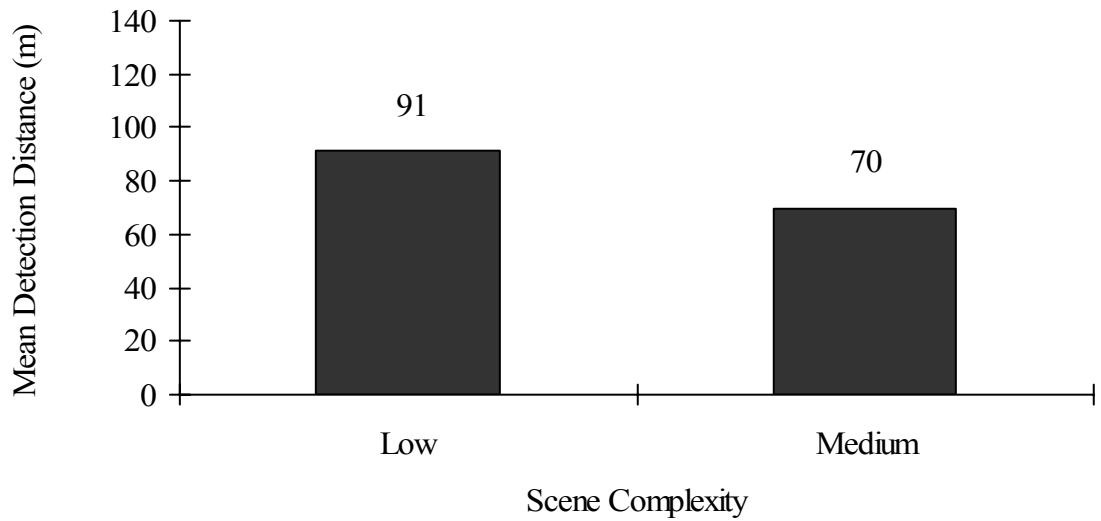


Figure 4. The main effect of scene complexity on detection distance.

Arm Motion. There was a significant main effect of arm motion, $F(1, 22) = 17.5$, $p < .001$. Pedestrians whose arms were in motion were on average detected 22 m farther away than those who were standing stationary (91 m versus 69 m). The results are plotted in Figure 5.

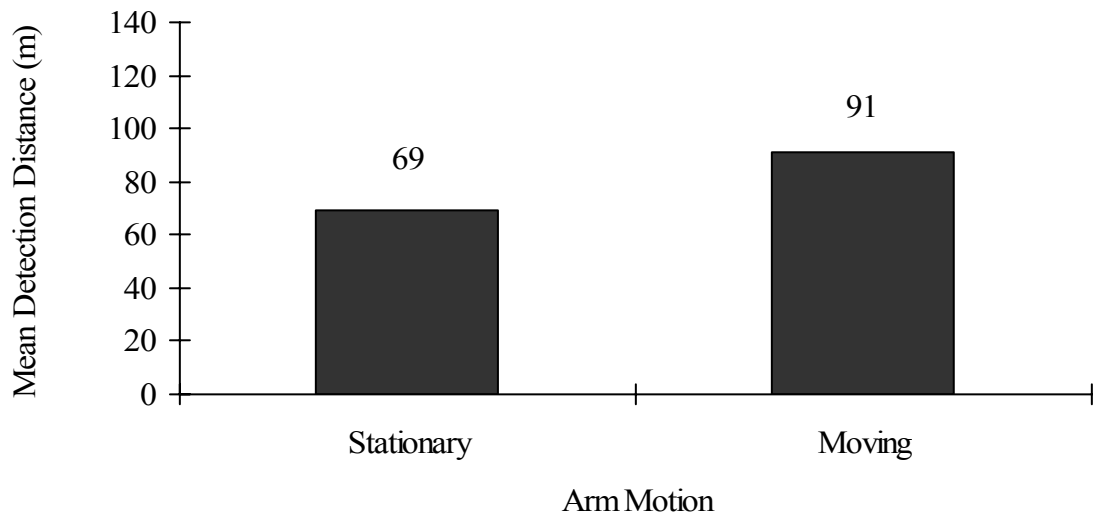


Figure 5. The main effect of arm motion on detection distance.

Garment. The effect of garment was not statistically significant, $F(1.96, 43.05) = 2.3, p = .114$. The non-significant trend was that participants saw the Class 3 jacket at the longest distance (88 m), followed by the standard Class 2 vest (78 m), and the Class 2 vest with the area reflective half-sleeves (74 m).

Orientation. The main effect of pedestrian orientation was not statistically significant, $F(1, 22) = 2.7, p = .116$.

Significant Two-Way Interactions

Arm Motion by Orientation. Although the main effect of orientation was not significant, a significant two-way interaction between arm motion and the orientation of the pedestrian was observed, $F(1, 22) = 16.0, p = .001$. Figure 6 illustrates that while pedestrians who moved their arms were on average detected at similar distances for both the front (90 m) and the side (93 m) orientations, pedestrians who were motionless were detected at substantially longer distances when facing oncoming traffic (89 m) than when standing perpendicular to oncoming traffic (50 m). Stated another way, arm motion significantly increased detection distances, provided the pedestrian was facing perpendicular to the flow of traffic, but arm motion did not affect detection distances when the pedestrian was facing oncoming traffic. The difficulty associated with detecting a motionless pedestrian standing perpendicular to the flow of traffic is further supported by the over-representation of missed trials under these conditions, as reported earlier.

Scene Complexity by Arm Motion. There was a significant interaction of scene complexity and arm motion, $F(1, 22) = 6.1, p = .022$. Figure 7 illustrates that the differences between the mean detection distances for the low and medium complexity scenes were greater when pedestrians moved their arms (109 m versus 73 m) than when the pedestrians' arms were stationary (72 m versus 66 m). In other words, arm motion significantly increased detection distances when the pedestrian was in a low complexity scene, but did not have an effect on detection distance in medium complexity environments.

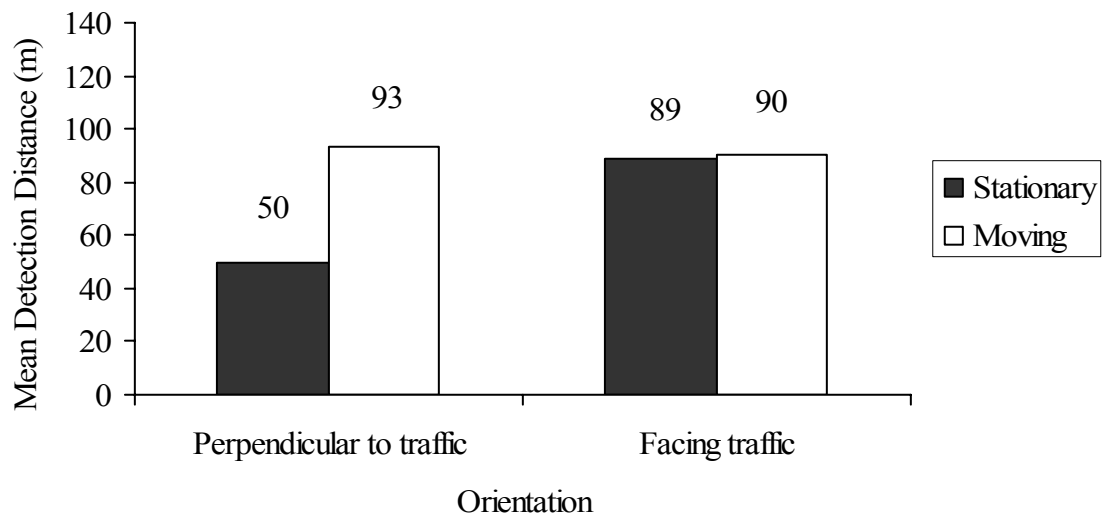


Figure 6. The interaction of orientation and arm motion on detection distance.

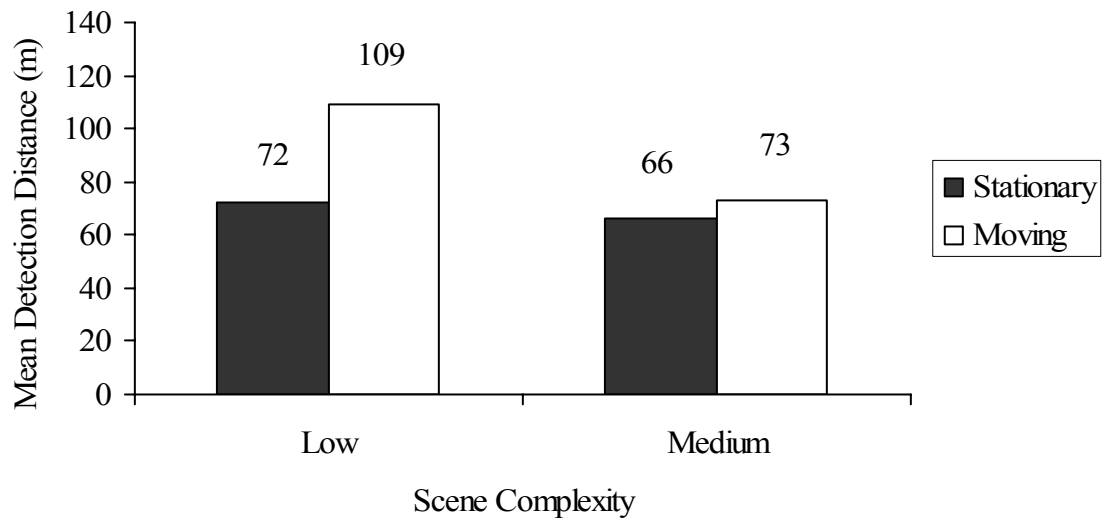


Figure 7. The interaction of complexity and motion on detection distance.

DISCUSSION

The results of this field study indicate that there was no main effect of the three garment types examined on the conspicuity of pedestrians at night. In other words, the addition of retroreflective material to the arms of a safety garment did not significantly improve detection distances. However, the trend that was observed was, at least partially, consistent with what might have been hypothesized *a priori*. Specifically, the Class 3 jacket tended to be detected at the farthest distance on average.

It is not clear why there was not a stronger effect of garment. A possible explanation is that the addition of the half sleeve or full sleeve garments partially obscured the treatment of the torso (when the pedestrian was perpendicular to the flow of traffic), thus partially counterbalancing the benefits of the added retroreflective materials. However, while this might partially account for a lack of improvement of the half-sleeved garment over the vest, it does not explain the lack of a statistically reliable difference between the jacket and the vest. This finding is most similar to those of Moberly and Langham (2002), but not in agreement with the results of studies performed by Owens et al. (1994) and Luoma et al. (1995).

Not surprisingly, the complexity of the scene in which pedestrians were viewed had a significant effect on the distances at which they were detected. The medium complexity condition, with its increased number of distracters and competing stimuli, resulted in significantly shorter detection distances, and this finding is in general agreement with the results reported by Owens et al. (1994). Furthermore, as the interaction of scene complexity and arm motion illustrates, arm motion in the medium complexity condition does not generally improve detection distances—unlike in the low complexity condition. Overall, the main effect of arm motion did significantly increase detection distances, consistent with the findings of Moberly and Langham (2002). In addition to the main effect of arm motion, and the interaction with scene complexity, arm motion also interacted with pedestrian orientation. The shortest detection distances were observed when pedestrians stood motionless and perpendicular to the flow of traffic. This result suggests that arm motion can significantly increase the average distance at which such a pedestrian is detected to a point that the detection distance is comparable to

those when the pedestrian is facing the flow of traffic. However, the effect of pedestrian orientation alone was not statistically significant.

There are several important implications associated with the findings from the current study. First, the lack of a significant difference among garments suggests that under the conditions examined, adding arms to a safety garment in order to add retroreflective trim (i.e., turning a Class 2 vest into a Class 3 jacket) does not reliably make the garment more conspicuous. So garment selection alone did not reliably alter the distance at which a pedestrian was detected. The conditions associated with improved detection distances were the low complexity scene, arm motion, and, to some degree, the pedestrian's orientation. While it could be suggested that pedestrians avoid more visually complex environments, try to face the flow of traffic, and keep moving, it is unrealistic to expect that such a suggestion would always be practical (case in point being a surveyor holding a prism pole). Yet in instances where a lot of pedestrians are present or road work is to be conducted at night, the finding that reduced detection distances are associated with the more complex scenes might be used in considering the selection and placement of traffic control devices when work zones are located in higher complexity surrounds. The medium complexity environment, with all of its competing sources of moving and illuminated objects, makes the detection of pedestrians with retroreflective garments more difficult than a less complex environment. These results overall, as they relate to variation in garment conspicuity, might appear to differ from the findings of a previous study (Sayer and Mefford, 2003), in which a Class 3 jacket was detected at significantly longer distances than a Class 2 vest. However, in the previous study the pedestrians were always in motion and the scene was not as complex as the medium complexity condition examined in the current study.

CONCLUSIONS

The current study was conducted under conditions that were generally more ecologically valid than in many previous studies examining similar issues, and the results therefore may be considered to be more representative of actual distances at which pedestrians might expect to be detected at night—at least by older drivers. While there were no sites that included work zones and the associated traffic control devices, conducting the present study on public roads in real traffic provided participants with ample workload while dealing with naturally occurring traffic (oncoming and entering the flow) and distracters (such as traffic signals, signs, pedestrians, and bicyclists) that were naturally present. By way of example, the average detection distance for Class 3 jackets by older drivers in a test track study (Sayer and Mefford, 2003) where pedestrians were moving in or adjacent to a work zone was 230 m. In comparison, the average detection distance for a Class 3 jacket in the current study was only 130 m when the scene complexity was low and the pedestrian's arms were in motion. This suggests, not surprisingly, that the elements of uncertainty and increased complexity of the driving task associated with the more ecologically valid test conditions outside of an immediate work zone environment significantly affects the distance at which retroreflective garments can be detected.

Scene complexity and arm motion, having been demonstrated to be significant main effects in the current study, should warrant serious consideration when designing future studies on the conspicuity of retroreflective or high-visibility safety apparel. While the differences in garments did not reliably affect detection distances in the current study, further examination of garment differences is clearly warranted under a variety of other conditions. Specifically, since testing was only conducted at night, it is not known how the additional background material associated with the different garments might affect daytime conspicuity. In addition, this study included only a limited initial examination of area reflective materials. Clearly additional research is needed to understand how garments incorporating area reflective markings beyond half-sleeves compare to garments with traditional retroreflective trims. In the interim, it is suggested that the safest condition for pedestrians at night is, first and foremost, to wear garments

with retroreflective trim, avoid higher complexity environments when possible, keep moving whenever possible, and face oncoming vehicles when walking in the proximity of traffic.

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