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# **CONSPICUITY OF HIGH-VISIBILITY SAFETY APPAREL DURING CIVIL TWILIGHT**

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16. Abstract <p>This naturalistic field study examined the effects of garment color (fluorescent yellow-green or fluorescent red-orange), the amount of background material (vest or jacket), pedestrian arm motion (moving or stationary), and driver age (younger or older) on the conspicuity of high-visibility safety garments during civil twilight. Distances at which drivers detected pedestrians wearing high-visibility garments were recorded. All of the challenges normally encountered when driving on public roadways were present, imposing a realistic level of driver workload.</p> <p>The results indicate that only driver age produced a significant main effect on the conspicuity of pedestrians wearing high-visibility garments during twilight. The remaining findings were similar to the results of previous studies conducted during the day and at night.</p> <p>The findings from the current study, in combination with several previous naturalistic studies, suggest that, for the levels of the variables examined, 1) color does not affect conspicuity of high-visibility garments in daylight or twilight, 2) the amount of background material does not affect conspicuity in daylight, twilight or at night, 3) pedestrian's arm motion does not affect conspicuity in daylight or twilight, 4) arm motion is significant at night, and 5) older drivers need to be significantly closer to detect a pedestrian at twilight or nighttime.</p>					
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## INTRODUCTION

In 2004, 4,641 pedestrians were killed in traffic crashes in the United States. On average, a pedestrian is killed in a traffic crash every 113 minutes and another is injured in a traffic crash every 8 minutes, with a total of 68,000 pedestrians injured in 2004. Most pedestrian fatalities in 2004 occurred in urban areas (72%), at nonintersection locations (79%), in normal weather conditions (89%), and at night (66%) (U.S. DOT, 2005).

During the 1995 to 2002 period, 844 persons were killed while working at a road construction site in the U.S. More than half of these fatalities were attributable to a worker being struck by a vehicle or mobile equipment. Workplace fatalities that occur at a road construction site typically account for 1.5% to 2.0% of all workplace fatalities in the United States annually. In 2004, there were 21 highway maintenance worker fatalities, in 11 of which the worker was struck by a vehicle (U.S. DOL, 2005).

The design of occupational safety apparel for highway maintenance workers offers some unique challenges. For example, an optimal design would work regardless of ambient illumination (dawn, daytime, dusk, or nighttime). Requiring workers to wear different safety apparel during different lighting conditions would be both cost-prohibitive and unrealistic. Instead, the use of a single garment that is suitable under all lighting conditions means that workers would not have to change garments as ambient lighting conditions change in order to stay safe. Additional challenges associated with the design of occupational safety apparel include providing comfortable, light-weight materials that do not trap heat or moisture, permit worker flexibility, stand up to prolonged ultraviolet exposure, and can be easily laundered.

The benefit of using fluorescent-colored materials in high-visibility safety garments has been recognized for many years (e.g., Michon, Ernst, and Koutstall, 1969), and numerous naturalistic studies have been performed. However, with the exception of one study (Isler, Kirk, Bradford, and Parker, 1997), all previous research has only examined the role of high-visibility garments on conspicuity either during the day or at night, and none has systematically examined the conspicuity of high-visibility garments during twilight. Nonetheless, road construction and maintenance workers, as well as

people in a number of other occupations, are frequently, if only briefly, exposed to moving traffic during dawn and dusk, and therefore the question of safety garment conspicuity during periods of civil twilight is important to address.

Isler, Kirk, Bradford, and Parker (1997) report the findings of a laboratory study in which participants performed a tracking task while attempting to detect the presence of forestry workers, wearing white or high-visibility garments in the periphery. All stimuli were presented in slides of images of garments taken in an actual forest, and the luminance of the image was systematically varied to simulate various levels of ambient illumination associated with daylight and twilight. The authors reported that a fluorescent lime-yellow garment was most readily detected in the search task during twilight and daytime periods when presented against a green, pine forest background.

### **The Present Study**

A naturalistic field study was conducted to assess the effects of garment color (fluorescent yellow-green or fluorescent red-orange), the amount of background material (vest or jacket), pedestrian arm motion (moving or stationary), and driver age (younger or older) on the conspicuity of high-visibility safety garments during civil twilight. Distances at which drivers of an instrumented research vehicle detected pedestrians outfitted with high-visibility garments were recorded. Drivers had no prior knowledge of where along a fixed 15-km route pedestrians would be located, or how many pedestrians were positioned along the route. All of the challenges normally encountered when driving on public roadways were present (other motor vehicles, traffic signs, pedestrians, and bicyclists), imposing an more ecologically-valid level of workload on the drivers than test-track or static evaluations.

## METHOD

### Participants

Sixteen paid drivers, eight older (ranging from 61 to 80 years of age, mean age = 65.6) and eight younger (ranging from 20 to 30 years of age, mean age = 26.4), participated in this study. Each group was balanced for gender. Each driver was paid for one hour of participation.

All drivers were recruited from a list of potentially interested persons maintained by UMTRI. All drivers had color-normal vision, as determined using pseudo-isochromatic plates (Ichikawa, Hukami, Tanabe, and Kawakami, 1978). The average visual acuity was 20/21, with younger drivers averaging better (mean = 20/15) than older drivers (mean = 20/26). While participating in the study, all drivers were instructed to wear any corrective lenses that they normally wear when driving.

### Stimuli

Four new ANSI/ISEA 107-2004-compliant garments were used in this study. Two of the garments had fluorescent yellow-green background material (a Class 2 vest and a Class 2 jacket) and two had fluorescent red-orange background material (a Class 2 vest and a Class 2 jacket). The vests utilized approximately 0.9 m<sup>2</sup> of fluorescent background material while the jackets used approximately 1.1 m<sup>2</sup> of fluorescent background material. All retroreflective trim was white, 50-mm wide, and a vinyl-backed, microprismatic material. Each garment contained 0.17 m<sup>2</sup> of retroreflective trim. Figure 1 provides illustrations of the garments.

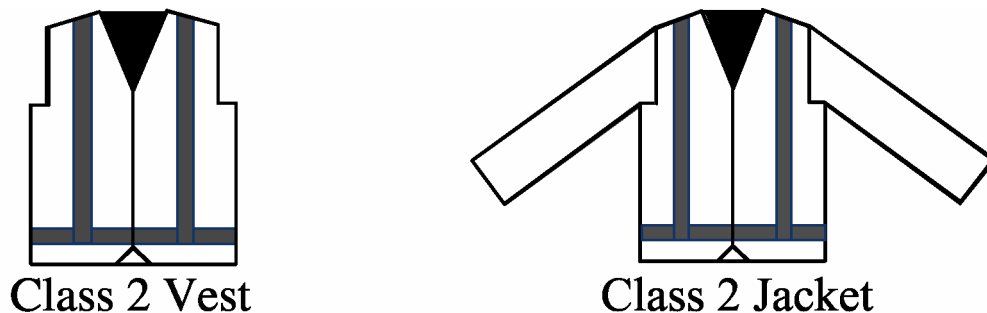


Figure 1. Illustrations showing the types of garments used as stimuli. Light areas represent fluorescent material, dark areas represent retroreflective material.



## **Task and Experimental Setup**

Participants performed a search task while they drove an instrumented research vehicle over a 15-km route in and near Ann Arbor, Michigan. They were asked to indicate to an accompanying researcher when they saw a person wearing a high-visibility garment standing along the side of the road. Drivers had no prior knowledge about the number or location of the workers along the route. Testing was performed in late fall, so there were no leaves present on the trees. The nature of the background—a rural setting—was of low visual complexity, and is a portion of a route previously used in a nighttime conspicuity study (Sayer and Mefford, 2004).

Performance was examined during civil twilight—the period bounded by sunset and when the sun is  $6^\circ$  below the horizon. Because the civil twilight period only lasted approximately 30 minutes, the complete route was traversed only once by each participant. The route was selected in such a way that four trials (sites with a researcher in a high-visibility garment) occurred on the first half of the route, at which point drivers turned around and headed back, along the same route, but in the opposite direction. Four more trials were presented on the second half of the route. Given that ambient illumination levels at the beginning and end of civil twilight differ, the order in which drivers experienced the two “legs” of the route was balanced across drivers. A fractional-factorial experimental design, which included Latin-square counterbalancing, was used to control for the order in which the four garments were presented.

The experimenters, who wore high-visibility garments, were positioned along the route at the eight possible locations. They stood on the right side of the road approximately 1.8 m outside the edge line. In each trial, an experimenter was wearing one of the four high-visibility garments and was always facing oncoming traffic. In half of the trials the experimenter was stationary, while in the remaining half the experimenter was in motion (swinging his/her arms). The unobstructed site distance for each of the eight locations was at least 0.5 km.

Four identical late-model, passenger cars equipped with automatic transmissions served as the research vehicles. Each vehicle was equipped with a data acquisition system. The data collection systems included a global positioning system (GPS), a computer and hard disk, and a button used by the experimenter to mark the data to

indicate the location along the route where participants first identified the position of an experimenter wearing a high-visibility garment. Because multiple vehicles and participants were run in series, a time interval of approximately two minutes was maintained between vehicles. In addition, participants were instructed to maintain sufficient following distance between them and any proceeding vehicles encountered in the otherwise naturally-occurring traffic.

Prior to the beginning of the study, the research vehicles' headlamps were properly aimed, and the headlamps remained illuminated during the experiment. Throughout the study, the vehicles' windshields were regularly cleaned.

At the beginning of each evening, the following instructions were read to participants:

Thank you for agreeing to participate in our study of conspicuity of road worker garments. You will be accompanied by a researcher while you drive. The researcher will serve as your navigator and will be available to answer questions that you might have about the study, but we ask that you keep any other chatting to a minimum. We would like to have you focus on driving and identifying road workers that you see along the route. Your task is to announce, as quickly as possible, whenever you see a road worker along the side of the road by saying "worker." Here is an example of the vests that the workers will be wearing. (Participants were shown a sample vest.) Once again, please announce "worker" as soon as you see a road worker along the side of the road. Please disregard any other pedestrians or bicyclists.

## RESULTS

### Analysis

The data were analyzed using a mixed linear model. The within-subject variables were garment type (two levels), garment color (two levels), and arm motion (two levels). The between-subject variable was driver age (two levels). Location of the road workers and the order in which the participants drove the route (recall that half of the participants started at the beginning of the route and half of the participants began at the half-way mark) were used as covariates. The dependent measure was the distance at which a road worker was detected. Non-significant two- and three-way interactions were removed from the model, one at a time, until only main effects remained.

### Missed Trials

Of the 128 trials, there was only one trial in which a participant failed to detect a road worker. Additionally, eight other trials had to be excluded from the analysis because of experimenter error (e.g., not being in position) or because the experimenter was obstructed by a leading vehicle.

### Main Effects

The effect of driver age was statistically significant,  $F(1, 104) = 16.77$ ,  $p < 0.0001$ . On average, younger drivers detected road workers 74 m farther than older drivers (Figure 2). Because the other main effects were not statistically significant, the associated mean detection distances are provided below for reference purposes only.

Garment type:

vest = 276 m

jacket = 304 m

Garment background color:

fluorescent yellow-green = 283 m

fluorescent red-orange = 297 m

Arm motion:

stationary = 268 m

moving = 312 m

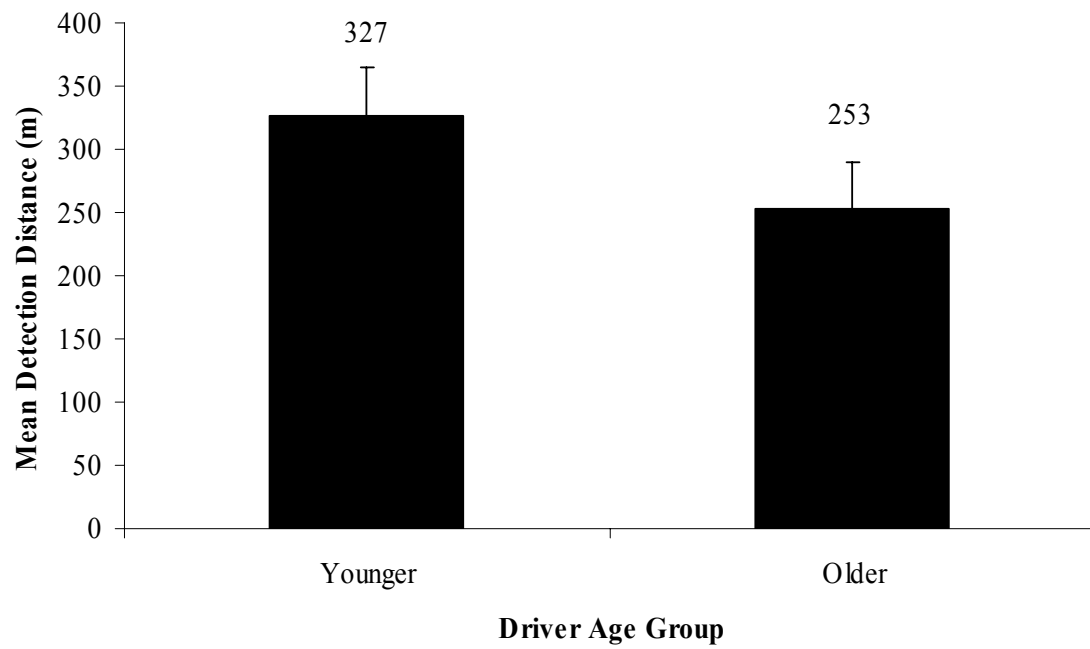


Figure 2. The main effect of driver age on detection distance. Error bars represent standard error of the mean.

## DISCUSSION

The results of this field study indicate that there was no main effect of garment type on the conspicuity of pedestrians during twilight. This is the same pattern reported previously under daytime conditions (Sayer and Mefford, 2005), as well as nighttime conditions (Sayer and Mefford, 2004). So whether under daytime, twilight, or nighttime conditions, the addition of high-visibility fluorescent material in the form of the arms of a jacket did not significantly improve detection distances.

Detection distances for fluorescent yellow-green and fluorescent red-orange garments were not significantly different. Consequently, the finding implies no advantage in conspicuity between fluorescent yellow-green and fluorescent red-orange background materials at twilight. This finding is consistent with that reported by Sayer and Mefford (2005) for a naturalistic daytime study.

Driver age was significant in the current study, with a mean detection distance for younger drivers being 74 m longer than for their older cohorts. In comparison, no age effect was obtained in a previous daytime study (Sayer and Mefford, 2005), but the present finding is consistent with results of a nighttime test-track study using high-visibility garments incorporating retroreflectors (Sayer and Mefford, 2002). Driver age was not an independent variable in the nighttime study by Sayer and Mefford (2004).

In both the current and the previous daytime study (Sayer and Mefford, 2005), arm motion by the pedestrian did not have a statistically significant effect on detection distances. This is in contrast to the findings of a previous nighttime study (Sayer and Mefford, 2004) where arm motion did significantly improve pedestrian detection distances, independent of the type of retroreflective treatment. Sayer and Mefford (2004) theorized that arm motion resulted in a “flashing” appearance of the retroreflectors in the nighttime condition. Because the current study was conducted during twilight, when the retroreflective trim of the garments is less likely to contribute much to a garment’s conspicuity, it is perhaps not surprising that a significant effect of arm motion was not observed. However, it is important to note that the current study, as well as the previous daytime study, only examined one type of orientation—in which the pedestrian faced the oncoming vehicles. In the nighttime study, two levels of orientation were examined, and

an orientation by arm motion interaction was observed. At night, detection distances were shortest when the pedestrian stood motionless and perpendicular to the flow of traffic.

When comparing mean detection distances for comparable stimuli in studies with differing lighting conditions, an apparent trend appears. Figure 3 presents data from the current and two previous studies conducted by Sayer and Mefford (2004, 2005). For otherwise identical conditions (fluorescent lime-green Class 2 vests viewed by older drivers in low complexity settings), increased ambient illumination is associated with increased mean detection distance. While this is a result that one might anticipate, it is reassuring to see it demonstrated empirically.

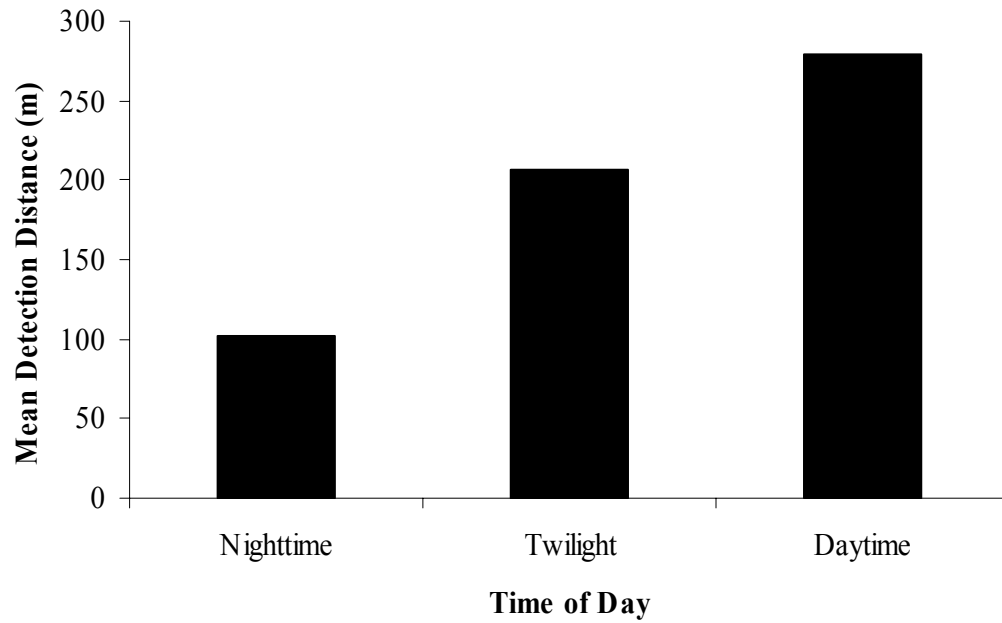


Figure 3. A comparison of mean detection distances for a fluorescent yellow-green Class 2 vest, viewed by older drivers in low complexity settings, for nighttime (Sayer and Mefford, 2004), twilight (present study), and daytime (Sayer and Mefford, 2005) lighting conditions.

## CONCLUSIONS

The current study was performed under conditions that are considered to be more ecologically valid than test-track or static evaluations. Conducting the present study on public roads, in real traffic, provided drivers with ample workload in dealing with naturally occurring traffic and distracters (such as traffic signs, pedestrians, and bicyclists). However, the drivers were actively searching for pedestrians wearing high-visibility garments. Consequently, the detection distances obtained in this study are likely still to be longer than real-world, unalerted detection distances.

Previous research on pedestrian conspicuity has been largely focused on either nighttime or daytime conditions, and has not adequately addressed how to mitigate the risks to pedestrians during civil twilight. Because it is unrealistic to assume that pedestrians will have multiple garments at their disposal, which can be readily switched due to changes in the ambient illumination, the stimuli used in the current study were ANSI/ISEA 107-2004-compliant garments intended to provide high visibility during the daytime, nighttime, and presumably during twilight.

Because it is important to understand how various characteristics of high-visibility garments might individually, as well as collectively, contribute to pedestrian conspicuity under a wide range of ambient illumination conditions, the current study fills a gap in our understanding of the benefits of high-visibility garments. Nevertheless, more remains to be learned about how the various characteristics of a high-visibility garment contribute to its conspicuity. One specific issue of interest is whether these characteristics interact with various colors of background that are associated with seasonal variations in ground cover and foliage.



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