UMTRI-2007-42 NOVEMBER 2007

SEASONAL VARIATIONS IN CONSPICUITY OF HIGH-VISIBILITY GARMENTS

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Report No. UMTRI-2007-42
November 2007

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2007-42		

4. Title and Subtitle
Seasonal Variations in Conspicuity of High-Visibility Garments

5. Report Date
November 2007

6. Performing Organization Code
302753

7. Author(s)
Buonarosa, M.L. and Sayer, J.R.

8. Performing Organization Report No.
UMTRI-2007-42

9. Performing Organization Name and Address
The University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, Michigan 48109-2150 U.S.A.

10. Work Unit no. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
The University of Michigan
Industry Affiliation Program for
Human Factors in Transportation Safety

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes
The Affiliation Program currently includes Alps Automotive/Alpine Electronics, Autoliv, Bendix, BMW, Bosch, Chrysler, Com-Corp Industries, Decoma Autosystems, Denso, Federal-Mogul, Ford, GE, General Motors, Gentex, Grote Industries, Hella, Honda, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, Magna Donnelly, Muth, Nissan, North American Lighting, Northrop Grumman, OSRAM Sylvania, Philips Lighting, Renault, SABIC Innovative Plastics, Sisecam, SL Corporation, Stanley Electric, Toyota Technical Center USA, Truck-Lite, Valeo, Visteon/ACH, and 3M Personal Safety Products. Information about the Affiliation Program is available at: http://www.umich.edu/~industry/

16. Abstract

A naturalistic, daytime field study was conducted to investigate the effects of garment color, the amount of background material, driver age, and season on the conspicuity of high-visibility safety garments. Subjects drove an instrumented vehicle along a 29-km route once in the summer and again in the fall. Their task was to detect pedestrians wearing high-visibility garments. Distances at which pedestrians were first detected were recorded. All of the challenges normally encountered when driving on public roadways were present, thus providing a more ecologically valid level of workload than provided by test-track or static evaluations.

The results show that the amount of background material and season significantly affected the detection distance of a pedestrian wearing a fluorescent-colored garment. There was no significant interaction of season and garment color. The analyses suggest that color contrast with natural backgrounds might contribute more to the conspicuity of fluorescent red-orange garments than the corresponding luminance contrast. On the other hand, luminance contrast might contribute more to the conspicuity of fluorescent yellow-green garments than color contrast.

17. Key Words
Daytime, conspicuity, fluorescent, pedestrian, road worker, road worker garments, road worker vests, road worker jackets

18. Distribution Statement
Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	17	

ACKNOWLEDGMENTS

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are:

Alps Automotive/Alpine Electronics
Autoliv
Bendix
BMW
Bosch
Chrysler
Com-Corp Industries
Decoma Autosystems
Denso
Federal-Mogul
Ford
GE
General Motors
Gentex
Grote Industries
Hella
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Nissan
North American Lighting
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Visteon/ACH
3M Personal Safety Products

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INTRODUCTION

In 2005, 64,000 pedestrians were injured and 4,881 pedestrians were killed in traffic crashes in the United States (U.S. DOT, 2005). The potential for harm is even greater for road workers who, like pedestrians, face danger from passing motorists, and who are additionally subject to harm from within the work site from construction vehicles and equipment. Between 1995 and 2002, 844 workers were killed while working at a road construction site. Being struck by a vehicle or mobile equipment accounted for more than half of the fatalities (U.S. DOL, 2005). Increasing the conspicuity of pedestrians and road workers through the use of high-visibility garments has long been advocated to address this problem.

The conspicuity of occupational safety apparel has been studied extensively. The benefit of using fluorescent-colored materials to enhance daytime conspicuity has been recognized for decades (e.g., Michon, Eernst, and Koustall, 1969). Road construction work zones pose additional challenges for making workers conspicuous in that they contain an array of fluorescent orange traffic control devices (e.g., barrels, road signs) that may make road workers less likely to stand out.

A field study by Turner, Simmons, and Graham (1997) examined the effect that fabric color for vests had on detection distances in four simulated work zone settings in daytime conditions. Eleven fabric colors were examined in both cluttered and uncluttered conditions. None of the vests had retroreflective trim, but one vest was a combination of fluorescent orange and fluorescent yellow fabric. The authors reported that both vest color and work zone conditions had significant effects on detection distance, but that there was not a significant interaction of these two factors. Therefore, collapsing detection distances across work zone conditions, mean detection distances were reported for the ten vest colors and one color combination. The results showed that a fluorescent red-orange vest was detected at the longest distance. The authors concluded by recommending the use of fluorescent red-orange fabric for safety garments, even in cluttered conditions where other objects in the environment may be similar to the color of the vest.

Turner et al. also recommended, based on their results, that fluorescent yellow-green, or the combination of fluorescent red-orange and fluorescent yellow-green, were good alternatives to fluorescent red-orange, but that one color or color combination should be recommended for use as a national standard, and that the effect of combined retroreflective treatment with the vests should be examined under daytime conditions.

Fontaine (n.d.) examined five different fluorescent-colored road worker garments against eight different backgrounds. He measured the field luminance of each garment and background and then calculated luminance contrast ratios (luminance of the foreground object (garment) divided by the luminance of the background). The results are listed in Table 1. The greater the contrast ratio, the more the garment "stood out" from the background. In 75% of the backgrounds examined, the fluorescent yellow-green solid vest had the highest luminance contrast ratios. The fluorescent yellow-green jacket performed best for the two other backgrounds.

Table 1
Road worker vests luminance contrast ratios.

Garment	Lane Closure	Sky	Asphalt	Concrete	Foliage	Work Zone	White Truck	Yellow Loader
Fl orange mesh vest	2.00	0.88	1.54	0.90	1.99	1.14	0.67	2.24
Fl yellow-green mesh vest I	3.21	1.42	2.33	1.68	3.56	1.61	0.28	3.64
Fl yellow-green mesh vest II	1.89	0.83	1.32	0.84	2.16	1.19	0.71	1.94
Fl yellow-green solid vest	4.30	1.90	3.06	2.46	4.76	2.19	1.51	4.75
Fl yellow-green solid jacket	4.61	2.04	2.64	1.97	4.07	1.97	1.41	4.70

Present Study

A naturalistic, daytime field study was conducted to investigate the effects of garment color (fluorescent red-orange or fluorescent yellow-green), the amount of background material (jacket or vest), driver age (young or old), and season (summer or fall) on the conspicuity of high-visibility safety garments. Subjects drove an instrumented vehicle along a prescribed 29-km route once in the summer and again in the fall. Their task was to detect pedestrians wearing high-visibility garments. All of the challenges normally encountered when driving on public roadways were present, thus providing a more ecologically valid level of workload than provided by test-track or static evaluations.

METHOD

Participants

Twenty-four paid drivers, twelve older (ranging from 61 to 89 years of age, mean = 72.3) and twelve younger (ranging from 19 to 30 years of age, mean = 25.2), participated in this study. Each driver was paid for one hour of participation for each season in which he/she participated.

Drivers were recruited from an advertisement placed in a local newspaper. All drivers had color-normal vision, as determined using pseudo-isochromatic plates (Ichikawa, Hukami, Tanabe, and Kawakami, 1978). The average visual acuity was 20/28, with younger drivers averaging better (mean = 20/21) than older drivers (mean = 20/35). 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 (again, a Class 2 vest and a Class 2 jacket). The vests utilized approximately 0.9 m^2 of fluorescent background material while the jackets used approximately 1.1 m^2 of fluorescent background material. All retroreflective trim was white, 50 mm wide, and made of a vinyl-backed, microprismatic material. Each garment contained 0.17 m^2 of retroreflective trim. Figure 1 provides illustrations of the garments.

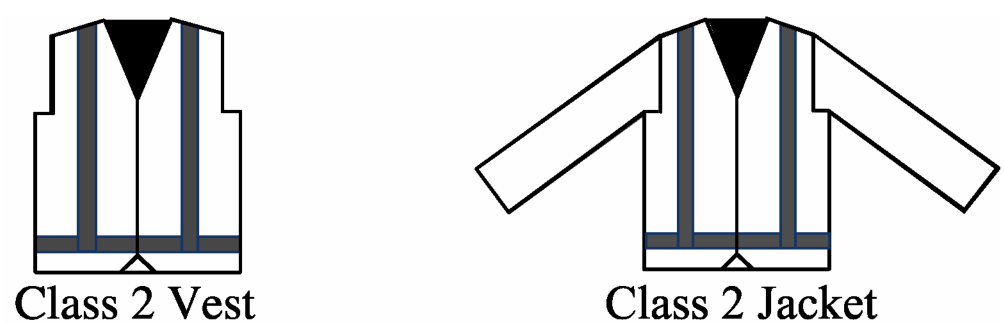

Figure 1. Illustrations showing the types of garments used as stimuli. Light areas represent fluorescent material, dark areas represent retroreflective material

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Procedure

Participants performed a search task while they drove an instrumented research vehicle over a 29-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 pedestrians along the route.

The study was performed during the daytime. A fractional-factorial experimental design, which included Latin-square counterbalancing, was used to control for the order in which the four garments were presented. All subjects participated first in the summer conditions and second in the fall conditions. The two sessions were separated by three months.

Experimenters, who wore high-visibility garments, were positioned along the route at eight possible locations. They stood stationary 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. The unobstructed site distance for each of the eight locations was at least 0.5 km.

Two identical late-model passenger cars, equipped with automatic transmissions and data acquisition systems, served as the research vehicles. 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 two 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 preceding vehicles encountered in the naturally-occurring traffic.

At the beginning of each session, 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 are 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 season (two levels). The between-subjects variable was driver age (two levels). Location of the pedestrians was included in the model as a covariate. The dependent measure was the distance at which a pedestrian was detected. Non-significant two- and three-way interactions were removed from the model, one at a time, until only significant effects remained.

Missed Trials

Of the 240 trials, 11 trials had to be excluded from the analysis because of experimenter error (e.g., not pressing the button in a timely manner) or because the experimenter posing as a pedestrian was obstructed or not in position in time for the trial.

Main Effects

The effect of garment type was statistically significant, $F(1, 9.51) = 20.55$, $p = 0.001$. On average, drivers detected pedestrians 71 m farther when they were wearing jackets as compared to vests (436 m vs. 365 m, Figure 2).

The effect of season was also statistically significant, $F(1, 12.20) = 5.47$, $p = 0.037$. On average, drivers detected pedestrians at farther distances in the fall than they did in the spring (423 m vs. 377 m, Figure 3).

The effects of color and age group were not statistically significant.

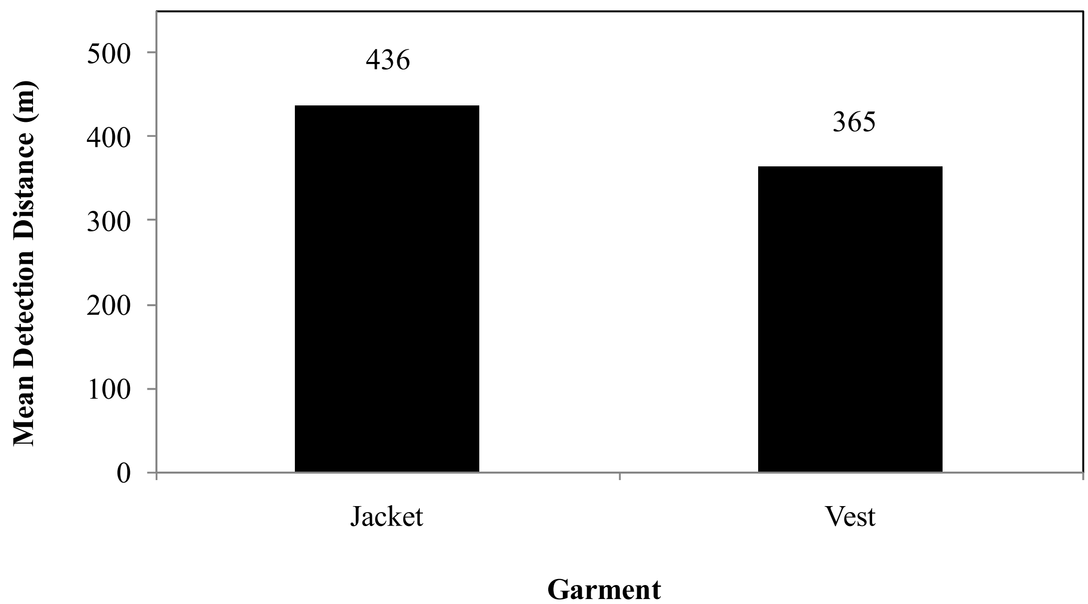

Figure 2. The main effect of garment type on detection distance.

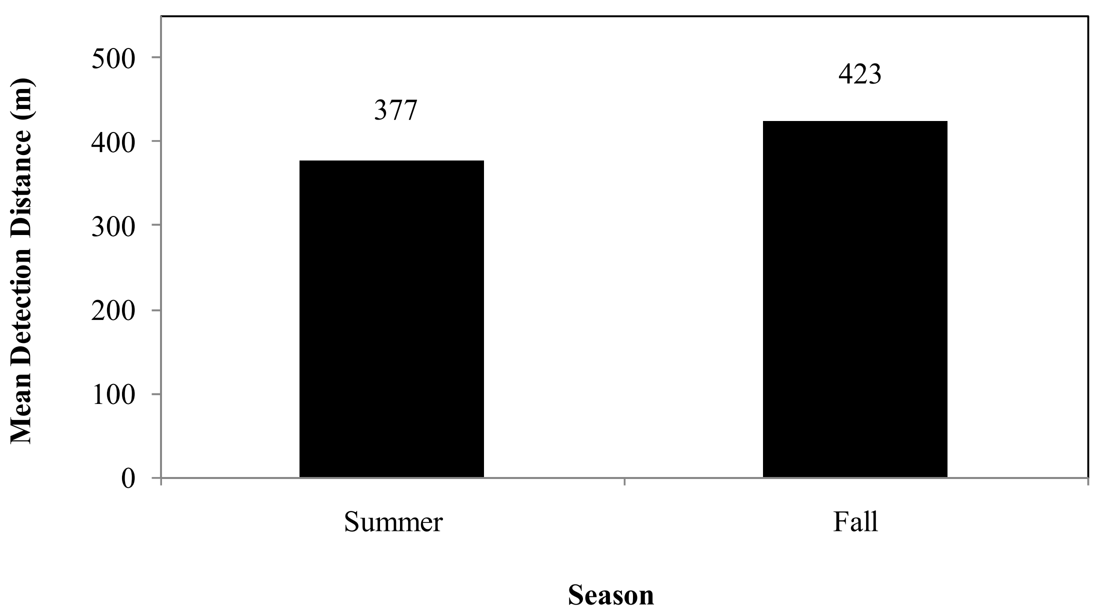

Figure 3. The main effect of season on detection distance.

Two-Way Interactions

The interaction of age group and garment type (see Figure 4) was statistically significant, $F(1, 9.84) = 5.63$, $p = 0.039$. Specifically, while there was little age difference for the jacket condition, younger participants detected the vests at longer distances than did the older participants. The interaction of season and garment color was not statistically significant, $F(1, 130.81) = 1.93$, $p = 0.168$ (see Figure 5).

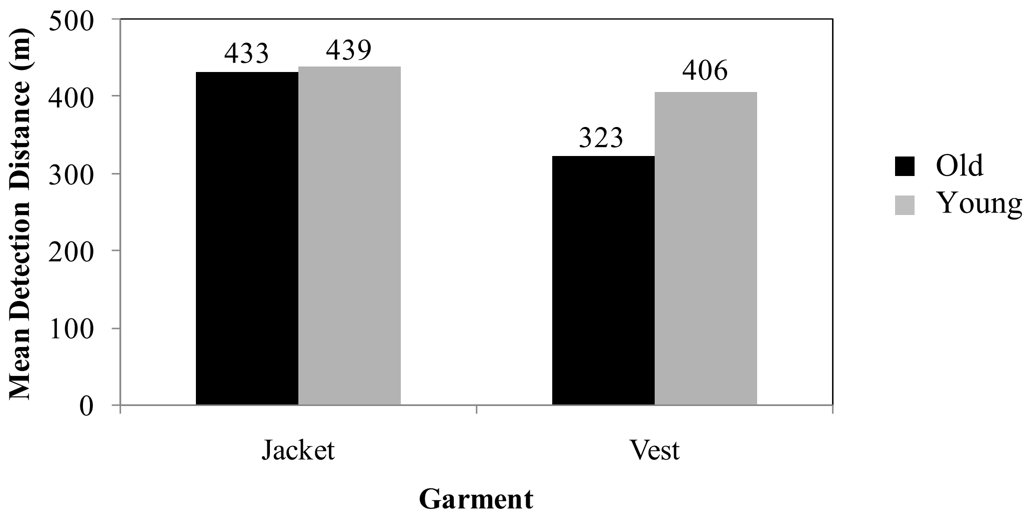

Figure 4. The interaction of garment type and driver age.

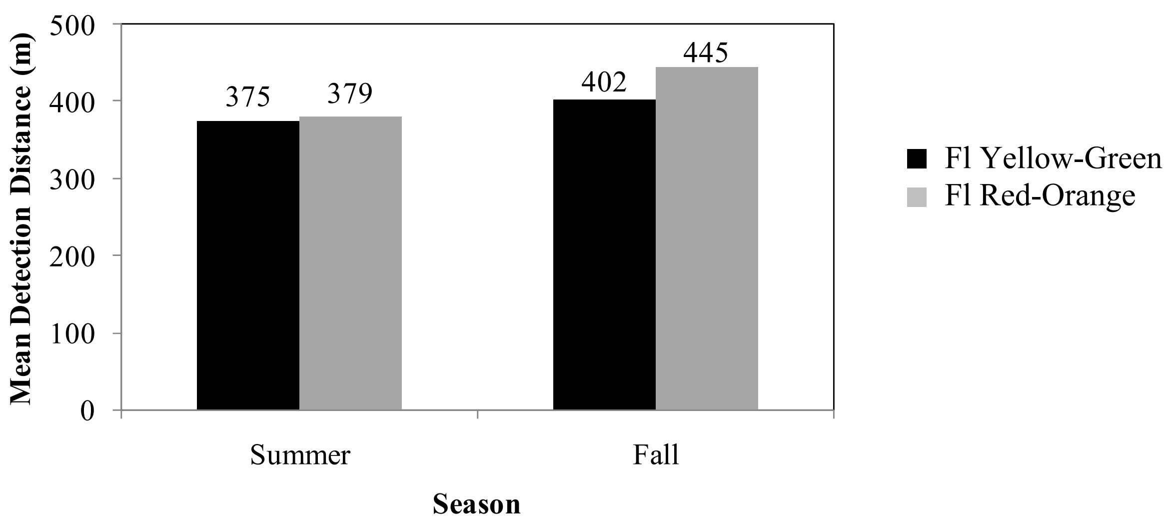

Figure 5. The interaction of season and garment color.

DISCUSSION

The results of this field study indicate that there was a main effect of garment type on the conspicuity of pedestrians with jackets being detected at longer distances than vests. It is logical that additional fluorescent material in the form of sleeves ought to increase the conspicuity of pedestrians, resulting in longer detection distances.

The effect of season was statistically significant. In the fall, drivers detected pedestrians at farther distances than they did in the summer by 46 m (12 %). It is quite possible that this was the result of a learning effect. Even though there was a three-month separation between the subjects' two drives, the route was not complicated. Furthermore, in order to keep the foliage backgrounds comparable, the locations of the pedestrians varied little between the seasons, perhaps resulting in a lack of spatial uncertainty.

Detection distances for fluorescent yellow-green and fluorescent red-orange garments were not significantly different. Additionally, there was no main effect of age. These findings are consistent with those reported by Sayer and Mefford (2005) for a naturalistic daytime study that did not include season as a variable.

In order to be visible at long distances, garments must contrast with their background, preferably with respect to both brightness and color. Because of the color contrast between the fluorescent-colored garments and the background foliage along the route, it was hypothesized that the fluorescent yellow-green garments would be more conspicuous in the fall and the fluorescent red-orange garments in the summer. However, no interaction of season and garment color was found.

A Nikon D100 digital camera was used to take photographs of a pedestrian wearing a fluorescent yellow-green vest and a fluorescent red-orange vest at each of the eight locations in the summer and in the fall. For one of the locations, the photographs of both vests in each season were analyzed in Adobe Photoshop 7.0.1®. In each photograph, specific areas were analyzed for luminosity and RGB coordinates which were converted to xy chromaticity coordinates. These areas included the fluorescent-colored vests, foliage (green in the summer photographs; red and gold in the fall photographs), grass, asphalt, and a yellow sign. Sample summer and fall photographs are displayed in Figure 6.

Figure 6. Fluorescent-colored vests depicted in summer and fall backgrounds at the same location.

Because these photographs are not designed for actual colorimetry, photometric data were collected for the summer, natural background, and fluorescent-colored vests and then compared with the xy chromaticity coordinates derived from the analysis of the corresponding photographs. Colorimetry data were collected using a PR-650 SpectraColorimeter™. Figure 7 displays the comparison of the Photoshop analysis with the field measurements.

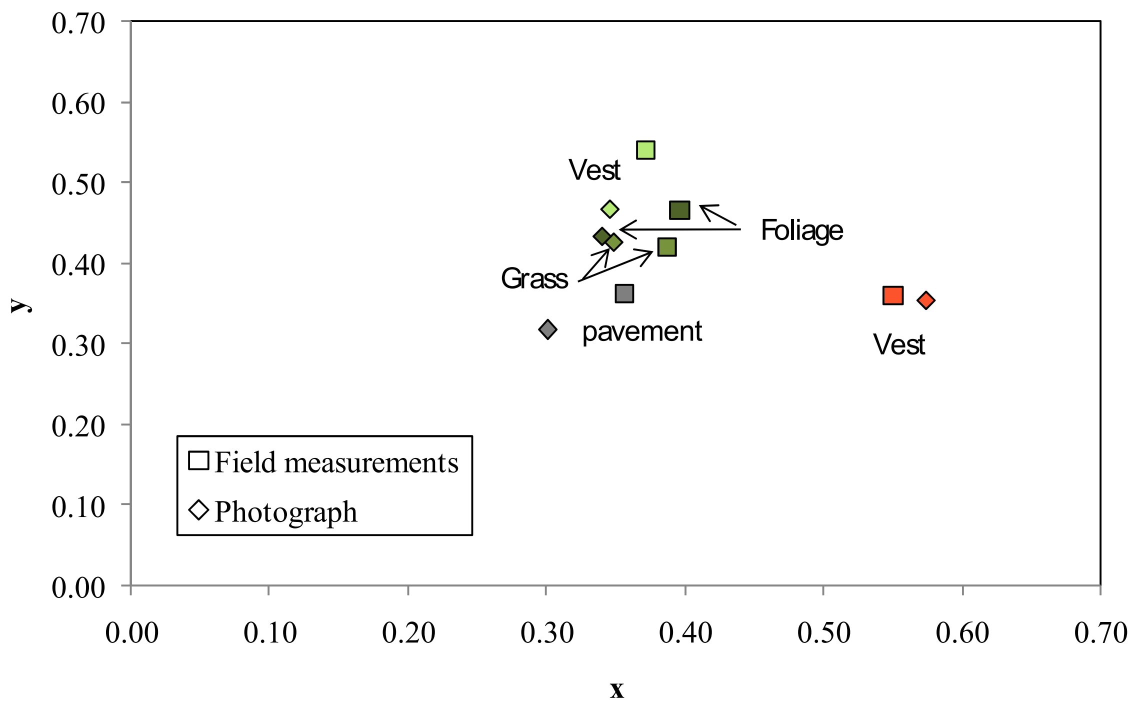

Figure 7. Comparison of the chromaticity coordinates from the field measurements and photographs.

Since the data derived from the photographs align reasonably well with the field measurements, the discussion that follows is based upon the analyses of the photographs. Figures 8 and 9 display chromaticity coordinates for each of the fluorescent-colored vests and the site's background in summer and fall, respectively. Background elements include pavement, green and colored foliage, grass, and a yellow sign. In both seasons, the fluorescent red-orange vest contrasts with its background with respect to color. It is apparent that irrespective of season, the fluorescent red-orange vest is conspicuous because its color is very different from what appears in natural backgrounds. While the fluorescent yellow-green vest's color differs from the natural setting of this study, its contrast is not as great as that of the fluorescent red-orange vest.

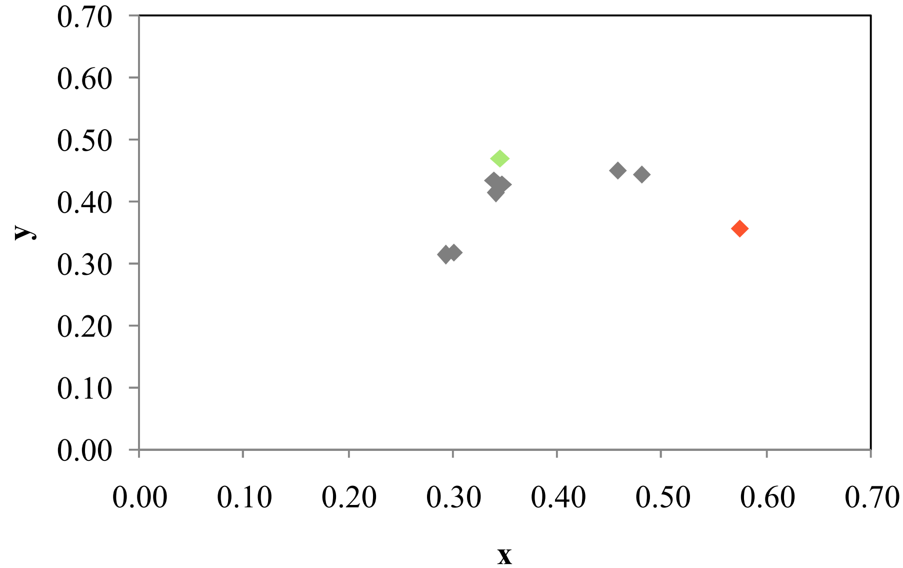

Figure 8. Chromaticity coordinates for the fluorescent-colored vests in the summer setting. Grey diamonds represent the background elements.

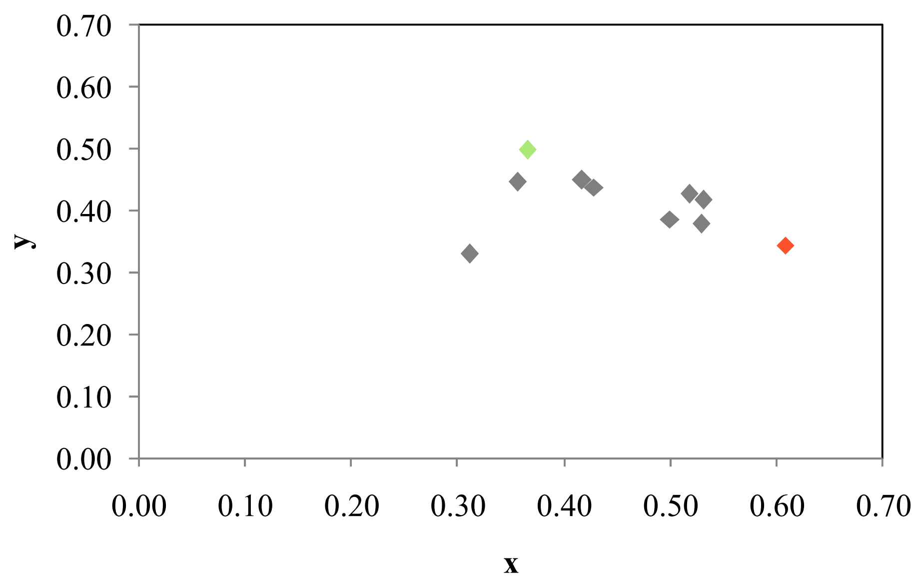

Figure 9. Chromaticity coordinates for the fluorescent-colored vests in the fall setting. Grey diamonds represent the background elements.

Figure 10 displays the mean luminosity data for each of the vests and the background elements. These data indicate that the luminance contrast between the vest and the background is substantially greater for the fluorescent yellow-green material than for the fluorescent red-orange material. Consequently, the luminance contrast might be the primary variable affecting the conspicuity of the fluorescent yellow-green vests in both seasons.

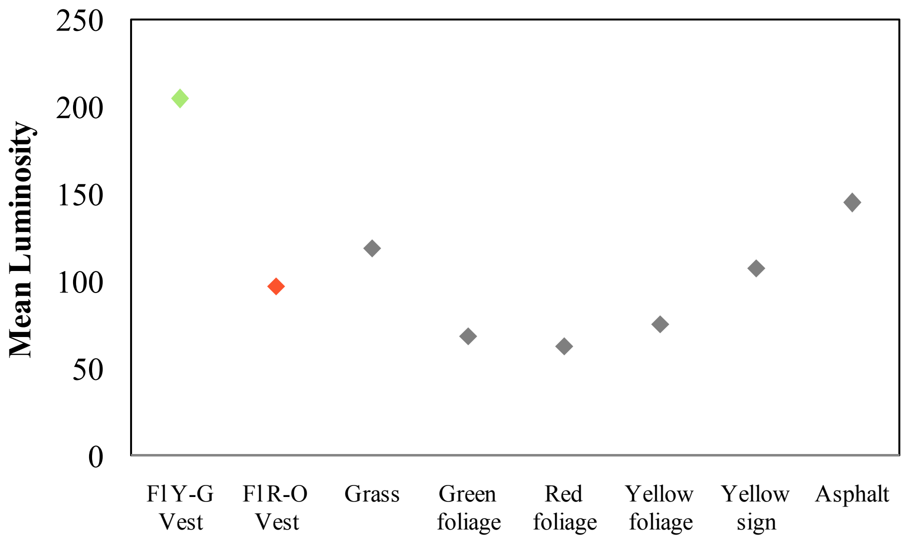

Figure 10. Mean luminosity data for each of the fluorescent vests and background elements.

CONCLUSIONS

The current study was performed under conditions that are probably 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 nonetheless 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 ambient lighting conditions. The results of daytime studies suggest that there is no difference in the conspicuity of pedestrians wearing either fluorescent yellow-green or fluorescent red-orange ANSI 107-compliant Class 2 garments. The current study reinforces this finding. This study also found that different colored foliage associated with seasonal variations presented in natural backgrounds did not affect the distances at which the fluorescent-colored garments were detected. Our analyses suggest that the conspicuity of fluorescent red-orange garments might depend primarily on color contrast, while the conspicuity of fluorescent yellow-green garments might depend primarily on luminance contrast. The current study further supports the recommendation for road workers and pedestrians to wear high-visibility garments, specifically fluorescent yellow-green or red-orange. However, there does not appear to be a preferred color based on seasonal variations in natural backgrounds.

REFERENCES

ANSI/ISEA (2004). *American national standard for high-visibility safety apparel and headwear* (ANSI/ISEA 107-2004). Arlington, VA: ISEA-The Safety Equipment Association.

Fontaine, M. (n.d). Innovative traffic control devices for improving safety at rural short-term maintenance work zones. Retrieved August 15, 2007, from http://ops.fhwa.dot.gov/wz/workshops/accessible/fontaine.htm.

Michon, J. A., Eernst, J. T., and Koutstall, G. A. (1969). Safety clothing for human traffic obstacles. *Ergonomics*, *12*, 61-70.

Michon, J. A., Eernst, J. T., and Koutstall, G. A. (1969). Safety clothing for human traffic obstacles. *Ergonomics*, *12*, 61-70.

Turner, J.D., Simmons, C.J., and Graham, J.R. (1997). High-visibility clothing for daytime use in work zones. In *Safety and Management in Maintenance and Construction Operations, Transportation Research Record No. 1585,* Washington, D.C.: Transportation Research Board, National Research Council.

United States Department of Labor. (2005). *2004 census of fatal occupational injuries*. Retrieved August 15, 2007 from: http://stats.bls.gov/iif/oshwc/cfoi/cftb0201.pdf.

United States Department of Transportation (2005). *Traffic safety facts 2005: A compilation of motor vehicle crash data from the fatality analysis reporting system and the general estimates system* (Report DOT HS 810 631). Washington, D.C.: National Highway Traffic Safety Administration.