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THE EFFECT OF COLOR CONTRAST ON DAYTIME AND NIGHTTIME CONSPICUITY OF ROADWORKER VESTS

James R. Sayer
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James R. Sayer
Mary Lynn Mefford

The University of Michigan
Transportation Research Institute
Ann Arbor, MI 48109-2150
U.S.A.

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16. Abstract

A static field study was conducted, both during the day and at night, to examine the effect that color contrast within a safety vest has on noticeability. Fluorescent orange and yellow fabrics were matched with orange, yellow, silver, or white retroreflective trim to appear similar to a safety vest. The method of paired comparisons was used to develop a linear scale of how noticeable the various color combinations appeared under cluttered and uncluttered viewing conditions.

The results indicate that color contrast within the safety vest, as well as relative to the environmental surround, affects judgments of noticeability. However, in the nighttime condition color contrast was not an identifiable attribute, as all the retroreflective materials used appeared white when illuminated. In the nighttime condition, the luminance of the retroreflective trim accounted for almost all of the variance in the noticeability judgments.

The results of this study suggest that a design for safety apparel that includes a combination of fluorescent yellow and fluorescent orange fabrics (providing color contrast for the daytime) with silver/white micro-prismatic retroreflective trim (proving high luminance for nighttime) is likely to be the most noticeable combination in both daytime and nighttime conditions.

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CONTENTS

INTRODUCTION

Background

Each year in the United States between 120 to 130 roadway workers die in road construction activities, with approximately 23% of these fatalities being pedestrian road workers struck by traffic and 19% being pedestrian roadworkers struck by construction vehicles (Laborer's Health and Safety Fund of North America, 1998). Unlike the case of pedestrians and pedalcyclists, federal regulations in the United States govern the safety apparel worn by flaggers and roadworkers exposed to public vehicular traffic. In both instances, workers are expected to be provided with, and wear, warning garments. For flaggers, these garments must be reflectorized when used at night (29 CFR 1926.201). For road construction workers, the warning garments may either be reflectorized or made of high-visibility materials (29 CFR 1926.651). Frequently the safety garment of choice is a fluorescent orange vest with white/retroreflective trim.

There have been a number of studies in recent years to show that wearing retroreflective materials, or luminaries, significantly increases the distance at which pedestrians and pedalcyclists are detected by drivers (Blomberg, Leaf, and Jacobs, 1980; Shinar, 1984; Shinar, 1985; Blomberg, Hale and Preusser, 1986; and Luoma, Schumann, and Traube, 1996). Additional research has been performed on the effect of retroreflective marking placement (Owens, Antonoff and Francis, 1994; Jenssen, Moen, and Brekke, 1999), and the effect of retroreflector color on detection (Schumann, Sivak, Flannagan, Traube, Hasimoto, and Kojima, 1996; Venable and Hale, 1996; Sayer, Mefford, Flannagan, Sivak, Traube, and Kojima, 1998; Sayer, Mefford, Flannagan, and Sivak, 1999, and Jenssen, Moen, and Brekke, 1999).

However, the design of safety apparel for roadworkers offers some unique challenges. For example, an optimal design would be one that works well both during the day and night. Requiring different safety apparel for day and nighttime conditions might not only be cost prohibitive, but would lead to uncertainty in some conditions as to which garment should be worn (such as at dusk). Use of a single garment that is suitable under all lighting conditions would mean that workers would not have to stop working as ambient lighting conditions changed in order that they might retrieve appropriate apparel. Additional challenges associated with the design of safety apparel for roadworkers include providing comfortable materials that are lightweight and do not trap much heat or moisture, garments that permit worker flexibility, and durable materials that stand up to prolonged ultraviolet exposure yet can be easily laundered.

In a survey of state Departments of Transportation, Cottrell (1999) reported that the most common problem with nighttime work zone traffic control was poor visibility, and the most frequently suggested solution to the problem was to improve the visibility of roadworkers. Most work zones in the United States contain a wide variety of fluorescent orange and white makers that delineate the work zone from traffic. These markers can be in the form of cones, barrels, barriers, etc. In addition, road signs identifying the work zone, or reduced speed limits within the zone, and even heavy equipment, are frequently also fluorescent orange. Amidst the "sea" of fluorescent orange and retroreflective white markings associated with a work zone, it is increasingly challenging to make roadworkers not only detectable, but also recognizable.

Only a few studies have been performed that are specific to the design of safety apparel for roadworkers, but there is a fairly general consensus that simply designing apparel that is detectable is not sufficient. The design of the apparel should also be specific so that it is recognizable as being worn by a roadworker. Frequently, these investigations have examined attributes of safety vest design, but have also examined other garments such as jackets, pants, and jumpsuits.

A field study by Turner, Simmons, and Graham (1997) examined the effect that vest fabric color had on detection distances in four simulated work zone settings under 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 of 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 conclude by recommending the use of fluorescent red-orange fabric for safety garments, even in cluttered conditions when objects in the environment may match the color of the vest. They also recommended, on the basis of the 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 be examined under daytime conditions.

The Present Study

Under static viewing conditions, simulating a work zone, the present study addressed the following questions related to roadworker safety vest conspicuity:

1. Are vests more conspicuous when the colors of the trim and fabric match, or when the colors contrast?
2. Is the effect of color contrast the same for both daytime and nighttime viewing conditions?
3. Does scene “clutter” affect conspicuity?

The effect of contrasting verses matching background fabric and trim was investigated because it had been suggested that a large uniform surface area the size of a safety vest might stand out in a work zone more so than the same surface area that is broken up by incorporating trim of a contrasting color. For purposes of this study, it was always the case that vests had retroreflective trim. The trim either matched the background fabric in color or it contrasted the background fabric.

The second question under investigation addressed the possibility of one design being optimal for both daytime and nighttime conditions. It could be the case that contrasting colors are effective under daytime conditions, but that maintaining a uniform color over the entire surface area of a safety vest might be judged to be more conspicuous under nighttime conditions.

The final question concerned the wide variety of environmental conditions in which roadworkers might be viewed. Flaggers, for example may not be surrounded by as much equipment or traffic control/delineating devices, such as barrels, as a person in the center of a work zone. However, this could be either an advantage or a disadvantage for either worker. Work zones that are well marked might also present sufficient “clutter” so as to affect the conspicuity of a safety vest. Under daytime conditions, for example, a fluorescent red-orange vest with white trim might simply blend in with all of the equipment and traffic control devices located in a work zone. Yet, the same vest might be judged very conspicuous when worn by persons on the edges of the same work zone, away from similarly colored and patterned objects.

The background and trim colors examined in this study were selected on the basis of three criteria. First, the materials met ANSI/ISEA 107-1999 Class 2 garment requirements for color, the amount of material (in two dimensions), retroreflective performance, and suggested trim layout and dimensioning (ANSI/ISEA, 1999). Second, the tested colored materials, and color combinations, have previously been recommended on the basis of research (Brackett and Stuart, 1982; Gordon, 1983; Turner, Simmons, and Graham, 1997, and Brich, 1998). Finally, the selected fabrics and retroreflective trims are commonly available either from the material manufacturers or in the form of manufactured safety apparel from a wide variety of vendors.

METHOD

Participant Recruitment and Screening

Twenty licensed drivers were paid $20 each to participate in this study. The duration of their participation was approximately 1 hour under daytime viewing conditions and 1.5 hours under nighttime conditions. Ten participants were older drivers (60-70 years of age, mean = 65.7 years) and ten were younger drivers (20-32 years of age, mean = 24.3 years). All participants were recruited from a list of potentially interested persons maintained at UMTRI. Each participant had visual acuity of 20/40 or better as determined by an Optec® 2000 vision tester. In addition, the color vision of all participants was screened using pseudoisochromatic plates (Ichikawa, Hukami, Tanabe, and Kawakami, 1978) under controlled lighting conditions (Macbeth® Examolite® D7500). All participants were found to be color normal.

Task and Experimental Setup

The task in this experiment was a two-alternative, forced-choice selection in a paired comparison. An indirect psychophysical scaling method, known as Thurstonian scaling, was used. The underlying assumption in this method is that differences that are detected equally often can be considered subjectively equal to one another. Participants were presented with all possible pairs of stimuli, one pair at a time, and asked to pick which of the two stimuli in each pair was more noticeable (conspicuous). They had three seconds during each trial to view a pair of vests. Participants were asked to look down at the ground between trials while the stimuli were being changed. Instructions to the participants were as follows:

> We are concerned with the noticeability or attention-getting properties of road construction worker vests. Your task is to choose which of the two vests shown is more noticeable. Please note that vest A is always on the left and vest B is always on the right. Please use the letter associated with the most noticeable vest when reporting your response on the data sheet provided. You will be asked to begin each trial by looking downward, toward the ground. When instructed, please look up at the vests. You will have three seconds in which to make your assessment. Then, when instructed, please look downward again. Trials will take place in rapid succession. You will be given three practice trials.

Participants were run in four groups of five, with ten individuals participating during the daytime and ten at nighttime. The daytime and nighttime groups were equally divided between the younger and the older participants. All participants viewed the vests under both a cluttered and an uncluttered condition. In the cluttered condition, there were six orange and white barrels and two orange construction signs. Figure 1 provides a diagram illustrating the cluttered condition. In the uncluttered state, neither the barrels nor the signs were present. The order in which the cluttered and uncluttered conditions were presented was balanced. Figure 2 provides a diagram illustrating the placement of the barrels and signs in the cluttered condition.

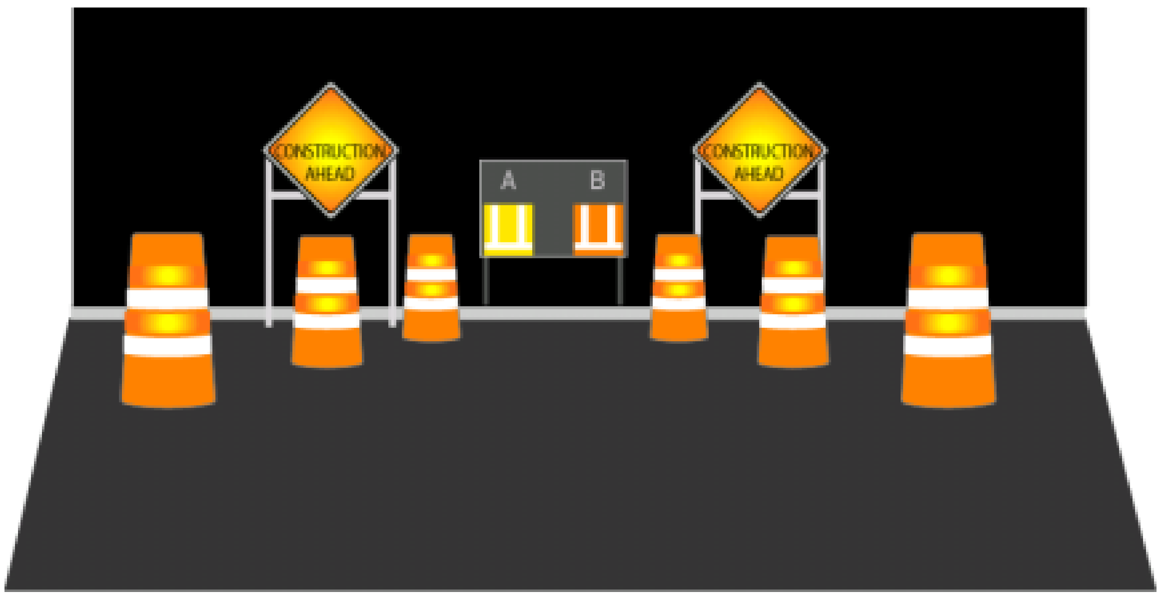

Figure 1. A diagram of the cluttered condition. The retroreflective material on the signs was orange, while the barrels had orange and white retroreflective material. The retroreflective areas are depicted as non-uniform in color in order to distinguish them from the non-retroreflective areas. In reality, the retroreflective areas were uniform in color and matched the non-retroreflective areas.

The experiment was conducted in a parking lot at UMTRI. Participants sat in chairs 75 m from the stimuli, which were mounted against a black background. The stimuli were 84 cm from the ground (to the bottom edge). The stimuli were separated from one another by 50 cm, edge to edge. The background behind the mounting board included a row of large, long-needle conifers.

For the nighttime sessions, a fixture with two properly aimed, low-beam tungsten-halogen headlamps was placed 2 m in front of the participants. All nighttime testing was performed with the stimuli illuminated by these headlamps. There was no other source of illumination in the vicinity. Figure 3 provides an overhead illustration of the location of the participants and the headlamps relative to the stimuli.

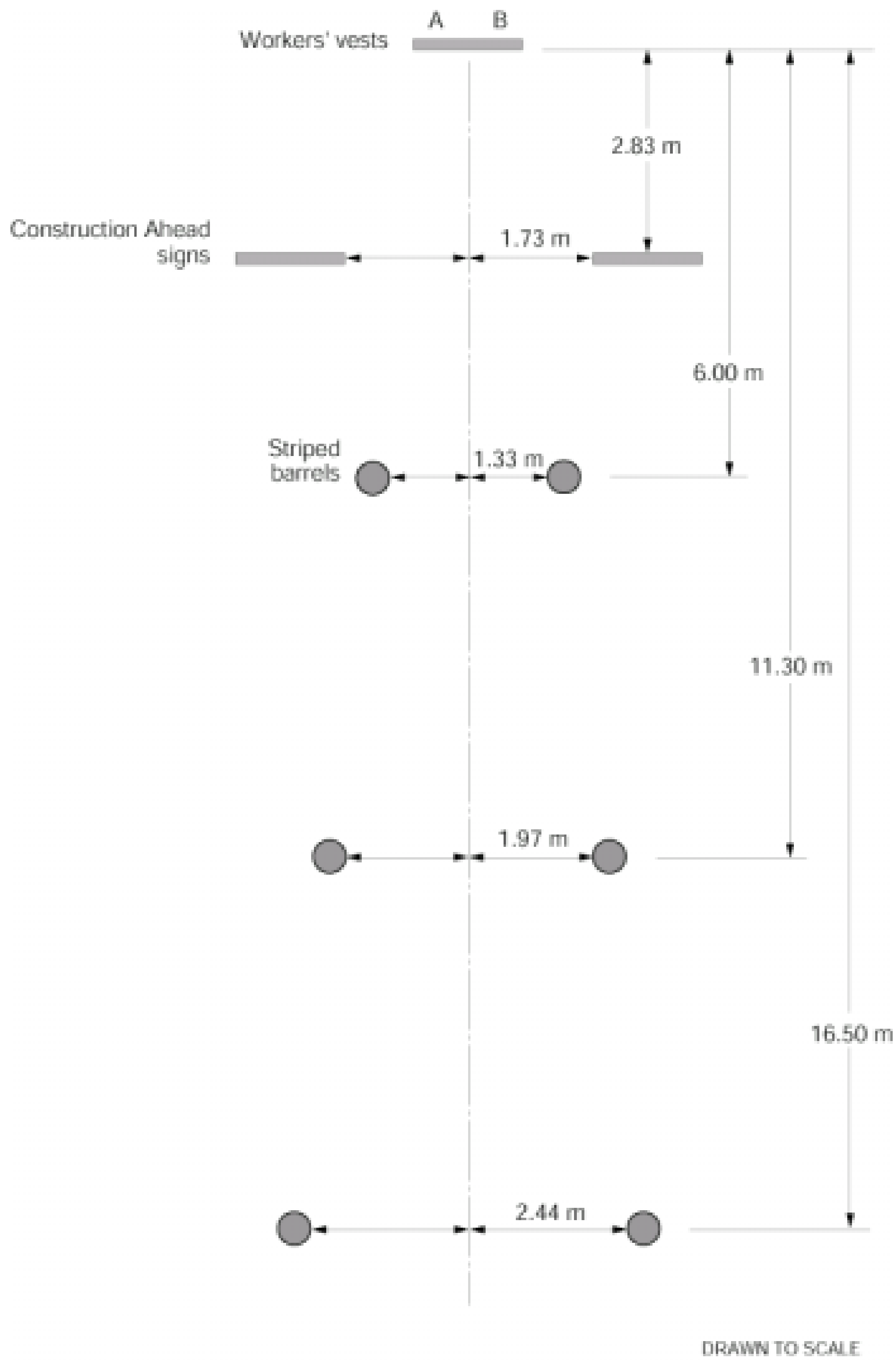

Figure 2. A diagram illustrating the placement of the barrels and signs in the cluttered condition.

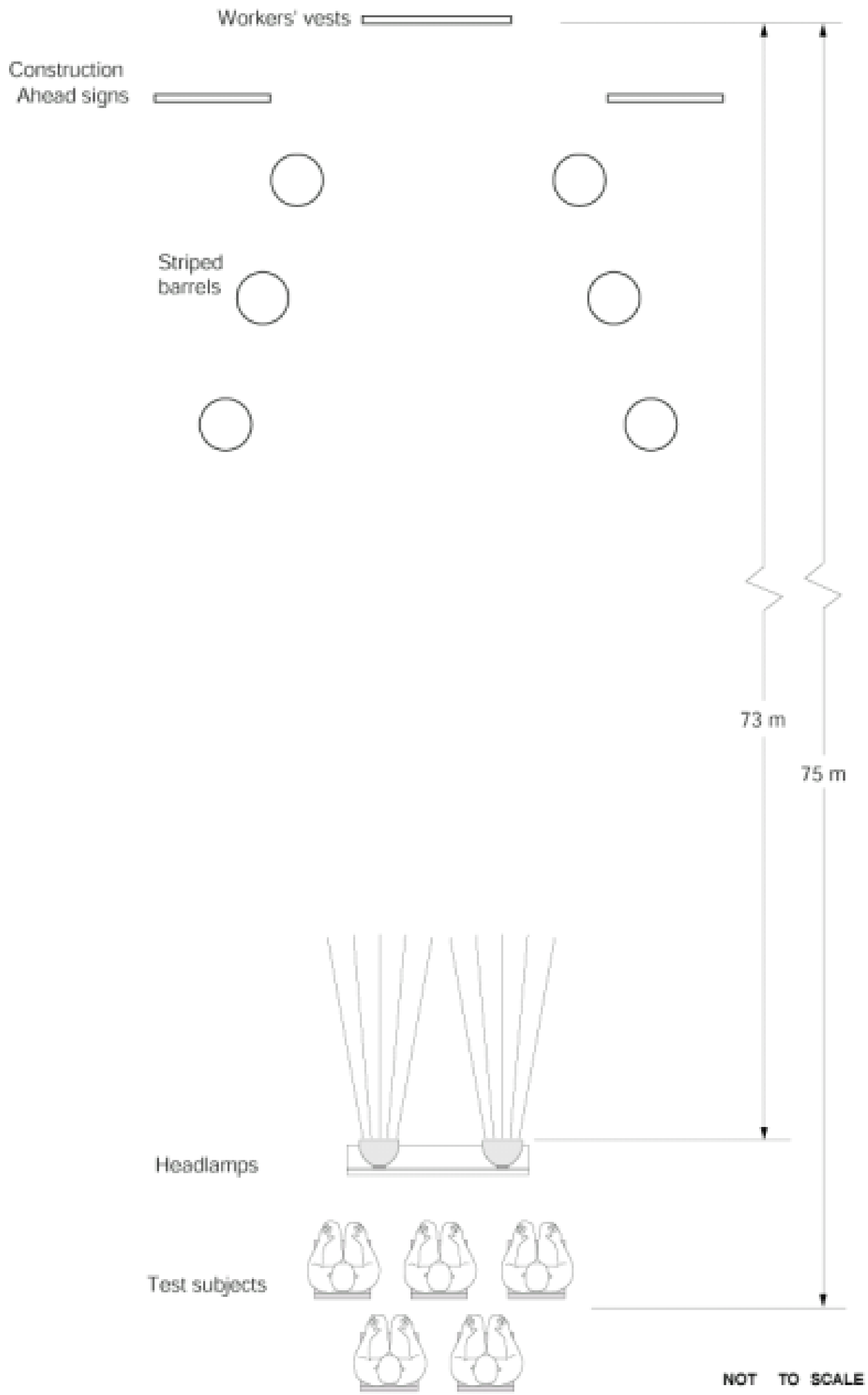

Figure 3. A diagram of the experimental setup.

Stimuli

Sixteen stimuli (two identical sets of eight) were constructed from rigid foam, covered in fluorescent fabric, and trimmed with retroreflective tape, to simulate a forward, two-dimensional view of a roadworker vest. Each vest measured 610 mm x 560 mm and was trimmed with retroreflective tape that was 50 mm in width. Figure 4 provides an illustration of the simulated vests and the layout of the retroreflective trim. The stimuli, although simulated, met ANSI/ISEA 107-1999 Class 2 garment requirements for material color, the amount of material (in two dimensions), retroreflective performance, and suggested trim layout and dimensioning (ANSI/ISEA, 1999).

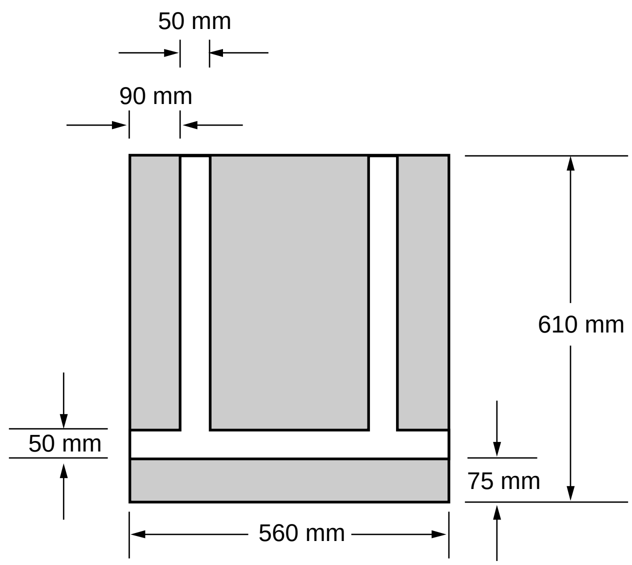

Figure 4. Dimensional illustration of the simulated vests.

Six stimuli were examined in the daytime condition, involving all combinations of two levels of fabric color (Table 1) and three levels of trim color (Table 2). All retroreflective trim materials examined in the daytime condition were glass-bead based. These same six stimuli were examined in the nighttime condition, with the addition of one level of silver micro-prismatic retroreflective trim (referred to in the remainder of the report as high silver). This addition created two new stimuli, one each for the two fabric colors. All trim colors appeared white in the nighttime viewing conditions. A Photo Research® 1980A Spectra Pritchard Photometer equipped with TF-80 Tristimulus filters was used to measure chromaticity coordinates for the vest materials. The measurements were taken from the subjects' point of view under levels of ambient illumination typical for the daytime condition. Nighttime measurements were taken while the fixture with the headlamps that was used during the experimental trials illuminated the materials. Table 3 provides the typical coefficients of retroreflection of the trim materials (R_A) when measured using entrance and observation angles of –4.0° and 0.2°, respectively.

Table 1
Chromaticity coordinates of the fluorescent background material.

	Daytime		*Nighttime*	
Fluorescent Fabric Color	*x*	*y*	*x*	*y*
Red-Orange[1]	0.53	0.35	0.42	0.54
Yellow-Green[2]	0.35	0.50	0.51	0.48

[1] To be referred to as fluorescent Orange.
[2] To be referred to as fluorescent Yellow.

Table 2
Chromaticity coordinates of the fluorescent retroreflective trim materials.

	Daytime		*Nighttime*	
Fluorescent Retroreflective Trim Color	*x*	*y*	*x*	*y*
Red-Orange[1]	0.45	0.40	0.50	0.44
Yellow-Green[2]	0.37	0.50	0.53	0.43
Silver	0.37	0.32	0.43	0.40
High Silver	NA	NA	0.45	0.39

[1] To be referred to as fluorescent Orange.
[2] To be referred to as fluorescent Yellow.

Table 3
Coefficient of retroreflection (R_A) and measured luminance (cd/m^2) of the trim materials.

Fluorescent Retroreflective Trim Color	*Typical R_A ($cd/lux/m^2$)*	*Measured Luminance (cd/m^2)*
Orange	175	11.5
Yellow	175	7.65
Silver	500	35.5
High Silver	700	41.6

RESULTS

Scaling Method

Results from the paired comparisons were used to develop linear scales of how noticeable (conspicuous) the trim and base color combinations were under the four conditions examined (daytime cluttered, daytime uncluttered, nighttime cluttered, nighttime uncluttered). The method is based on Thurstone's law of comparative judgment, which postulates that stimulus differences that are detected equally often are subjectively equal. The procedure used (e.g., Engen, 1971) relies on calculating the proportion of times any one stimulus is preferred over another, and *z* scores for these proportions are then determined. Then an arbitrary value of zero is established for the lowest of the scores, producing a linear scale of perceived differences among all stimuli. The mean Thurstonian scale values are show in Figures 5 through 8.

Additional analyses performed included examining whether participants were consistent in their judgments of vest noticeability. To do that, the coefficient of consistence (ζ) was calculated independently for each participant. The consistency of participants in their judgments is important in order to detect intransitive relationships between stimuli. (For example, stimulus A might be judged more noticeable than B and B more noticeable than C, and yet C might be judged more noticeable than A.) If intransitive relationships occur frequently, then it is assumed that the task cannot be performed along a single psychological continuum (i.e., there are multiple criteria that are being used in the judgment, and they cannot be combined or they are in conflict with each other). When intransitive relationships occur frequently it is necessary to employ multidimensional scaling methods (David, 1988).

The values of ζ ranged from 0.34 to 1.00, where a value of 1 indicates complete consistency by a participant. All but four ζ values were greater than 0.70 (Table 4). Most participants were largely consistent in their judgments, suggesting that, under the conditions examined, the quality referred to as vest noticeability could be judged along a single psychological continuum.

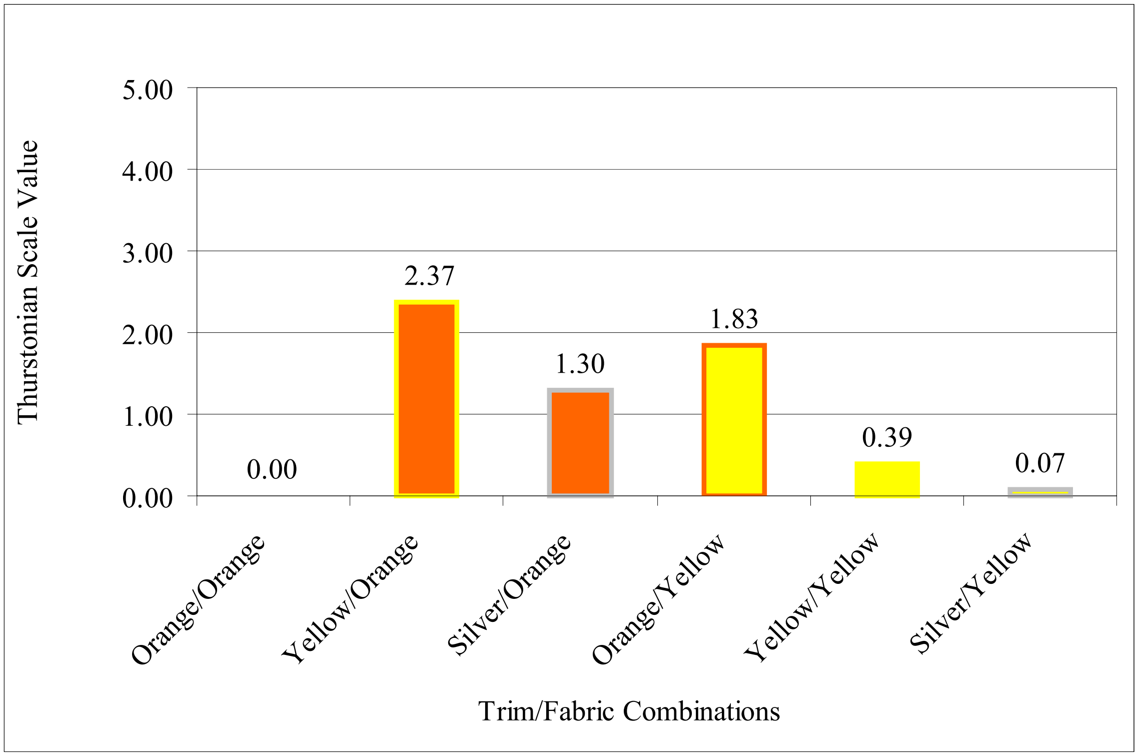

Figure 5. Mean Thurstonian scale values for the daytime cluttered condition, all subjects.

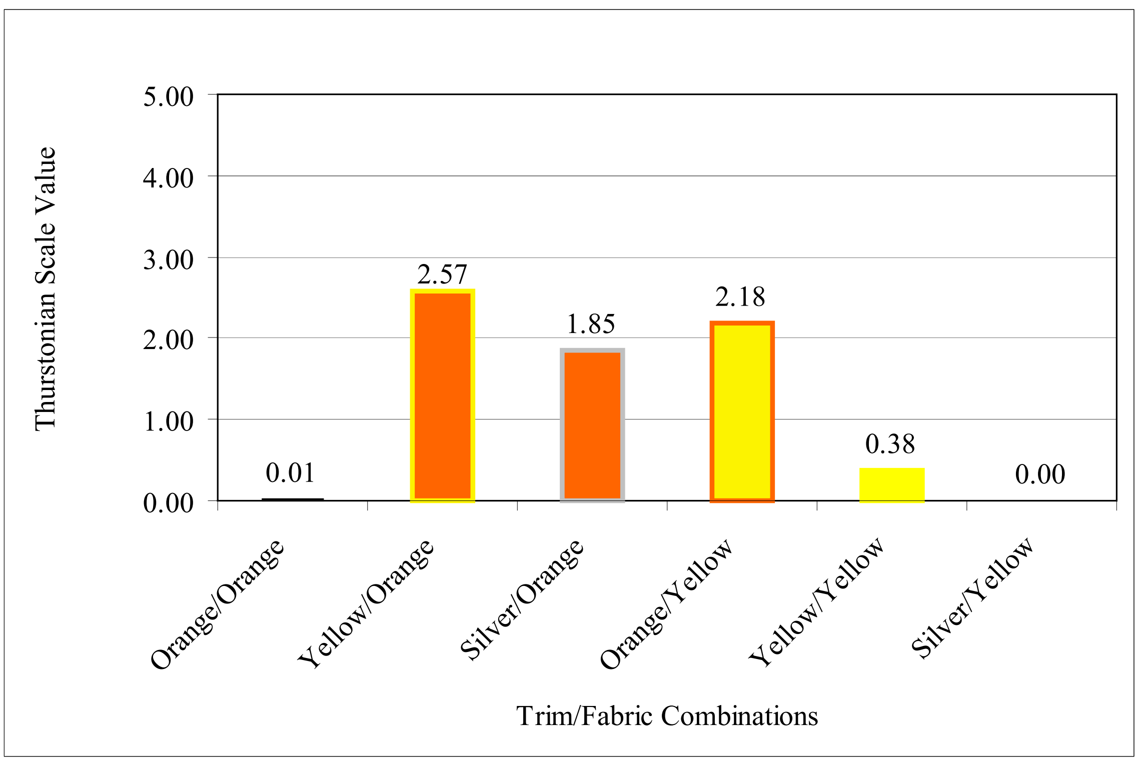

Figure 6. Mean Thurstonian scale values for the daytime uncluttered condition, all subjects.

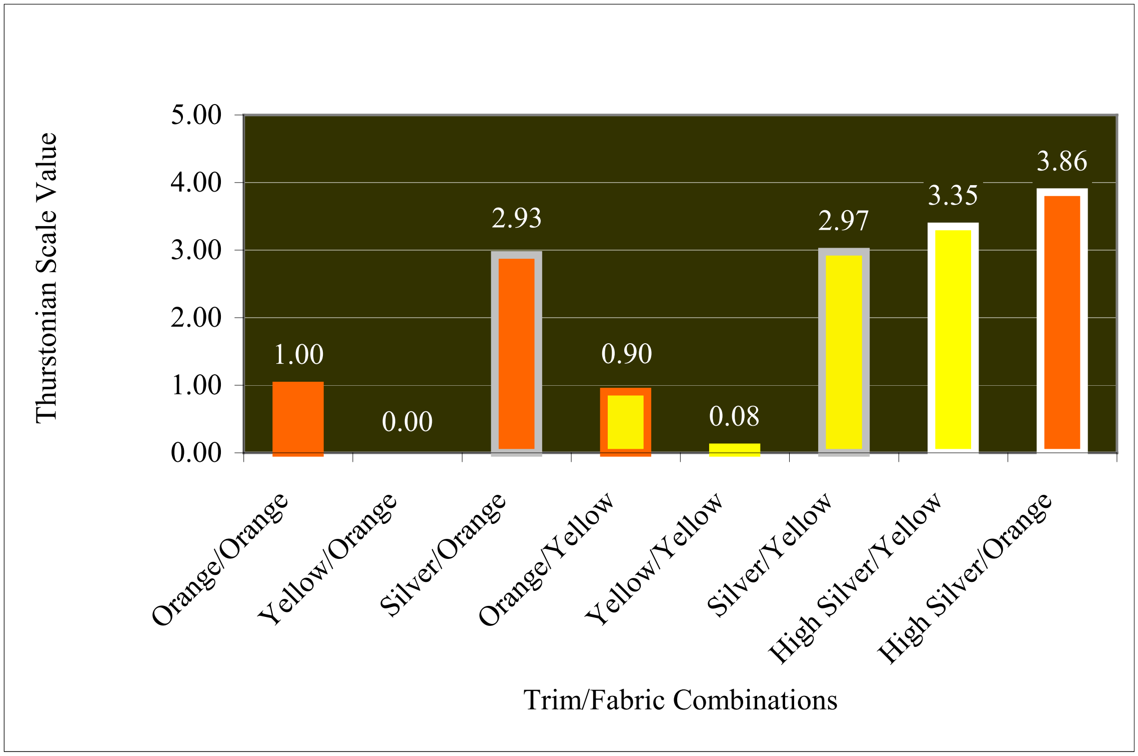

Figure 7. Mean Thurstonian scale values for the nighttime cluttered condition, all subjects.

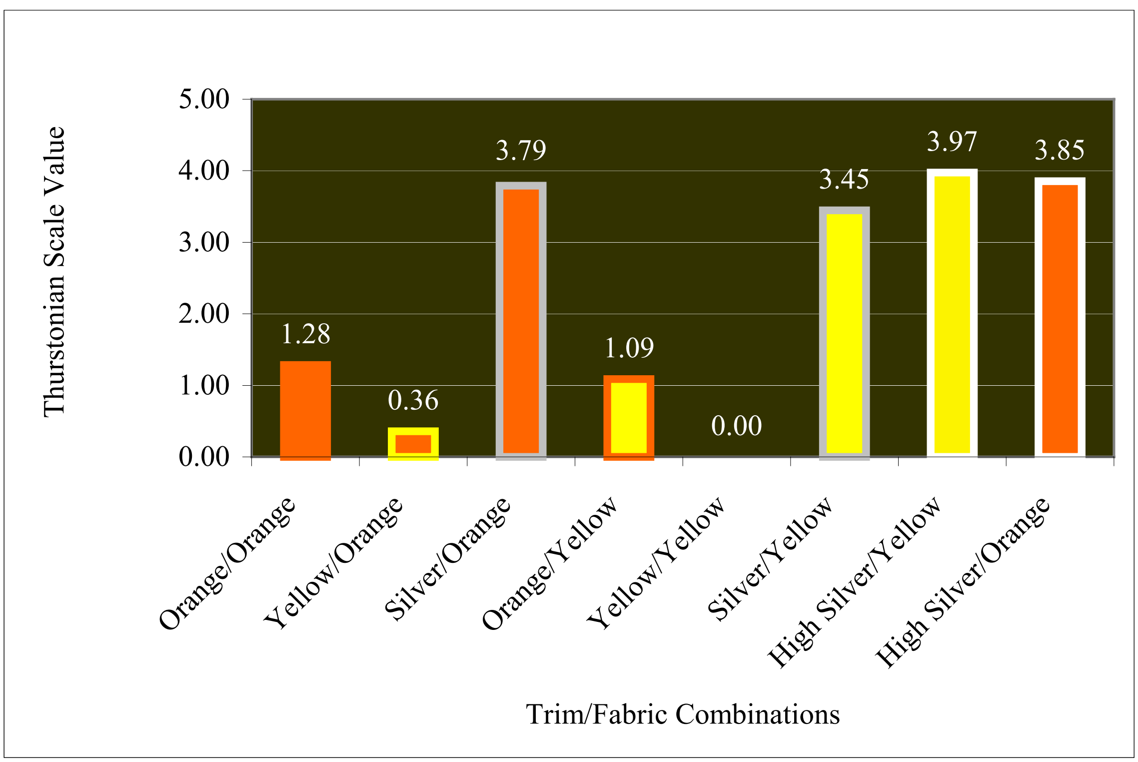

Figure 8. Mean Thurstonian scale values for the nighttime uncluttered condition, all subjects.

Table 4
Coefficients of consistence (ζ) by participant and viewing condition.

Daytime Participant	Age	Gender	ζ Unluttered	ζ Cluttered
1	68	Female	0.95	0.91
2	60	Male	0.98	0.70
3	25	Male	0.84	0.77
4	64	Male	0.81	0.73
5	70	Male	1.00	0.63
6	20	Female	0.95	0.91
7	25	Female	0.81	0.86
8	19	Male	0.87	0.87
9	62	Female	0.41	0.34
10	22	Male	0.92	0.95
		ζ Mean	0.85	0.76
Nighttime				
11	27	Male	0.93	0.47
12	23	Female	0.71	0.96
13	70	Female	0.85	0.87
14	24	Female	0.96	0.96
15	32	Female	0.77	0.97
16	69	Male	0.93	0.96
17	61	Male	0.75	0.78
18	64	Female	0.86	0.86
19	26	Male	0.91	0.94
20	69	Female	0.87	0.87
		ζ Mean	0.85	0.86

Daytime

In both the cluttered and uncluttered daytime conditions, participants judged yellow retroreflective trim on orange fabric to be the most noticeable combination, closely followed by the orange trim on yellow and silver trim on orange combinations. Those stimuli that had little or no color contrast between the trim and fabric (orange on orange, yellow on yellow, and silver on yellow) were consistently judged to be less noticeable than those having greater color contrast. The order in which the stimuli were judged to be noticeable was similar in both the cluttered and uncluttered daytime conditions (see Figures 5 and 6).

Relationship of Daytime Scale Values to Measures of Color Difference

A linear regression was performed that examined the relationship between the daytime Thurstonian scale values and calculated 1976 CIELAB measures for color difference (ΔE) for the retroreflective trims and background fabrics. The variance accounted for by the calculated ΔE values was 26.5% and 28.5%, respectively for the cluttered and uncluttered conditions. The calculated 1976 CIELAB ΔE values for the six stimuli presented in the daytime condition are provided in Table 5. (Comparable calculations were not performed for the nighttime condition as all retroreflective trims appeared white when illuminated, and the color of the background fabric was not readily discernable under the nighttime conditions examined.)

Table 5
Values of 1976 CIELAB color difference (ΔE) for the trim/fabric combinations.

Trim/Fabric Color Combination	1976 CIELAB (ΔE)
Orange/Orange	16.34
Yellow/Orange	24.25
Silver/Orange	16.77
Orange/Yellow	13.25
Yellow/Yellow	2.49
Silver/Yellow	14.64

Nighttime

In both the cluttered and uncluttered nighttime conditions, participants judged stimuli with high silver (micro-prismatic) retroreflective trim on either orange or yellow fabric to be the most noticeable combinations, followed by the silver (glass bead) trim on either yellow or orange fabric. Those stimuli that were consistently judged in the nighttime condition to be least noticeable were those with either the orange or yellow retroreflective trim. The order in which the stimuli were judged to be noticeable was similar in both the cluttered and uncluttered conditions (Figures 7 and 8).

Relationship of Nighttime Scale Values to Measures of Trim Luminance

A linear regression was performed that examined the relationship between the nighttime Thurstonian scale values and measured values of luminance (cd/m^2) for the retroreflective trim materials under the conditions examined. In both the cluttered and uncluttered conditions, the luminance intensity of the retroreflective trim accounted for almost all of the variance (97.6% and 96.8%, respectively for the cluttered and uncluttered conditions). Figures 9 and 10 show the fits and the linear equations associated with the regression analyses.

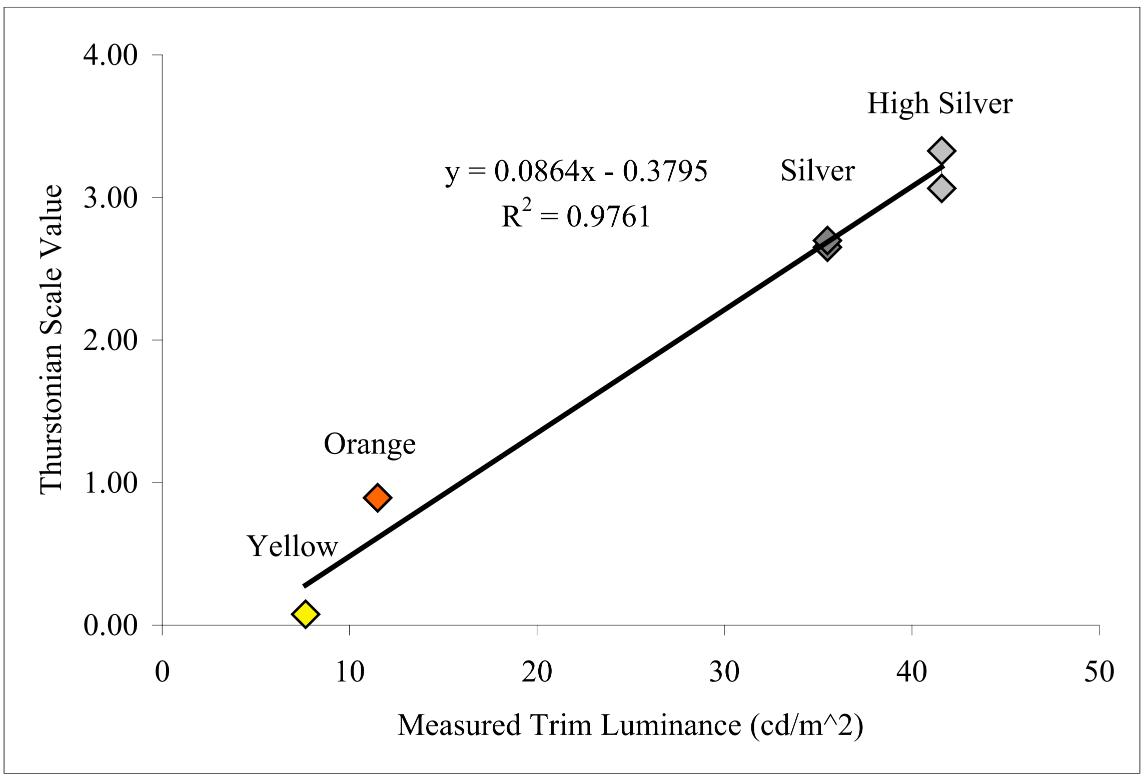

Figure 9. The regression of noticeability on luminance for the nighttime cluttered condition.

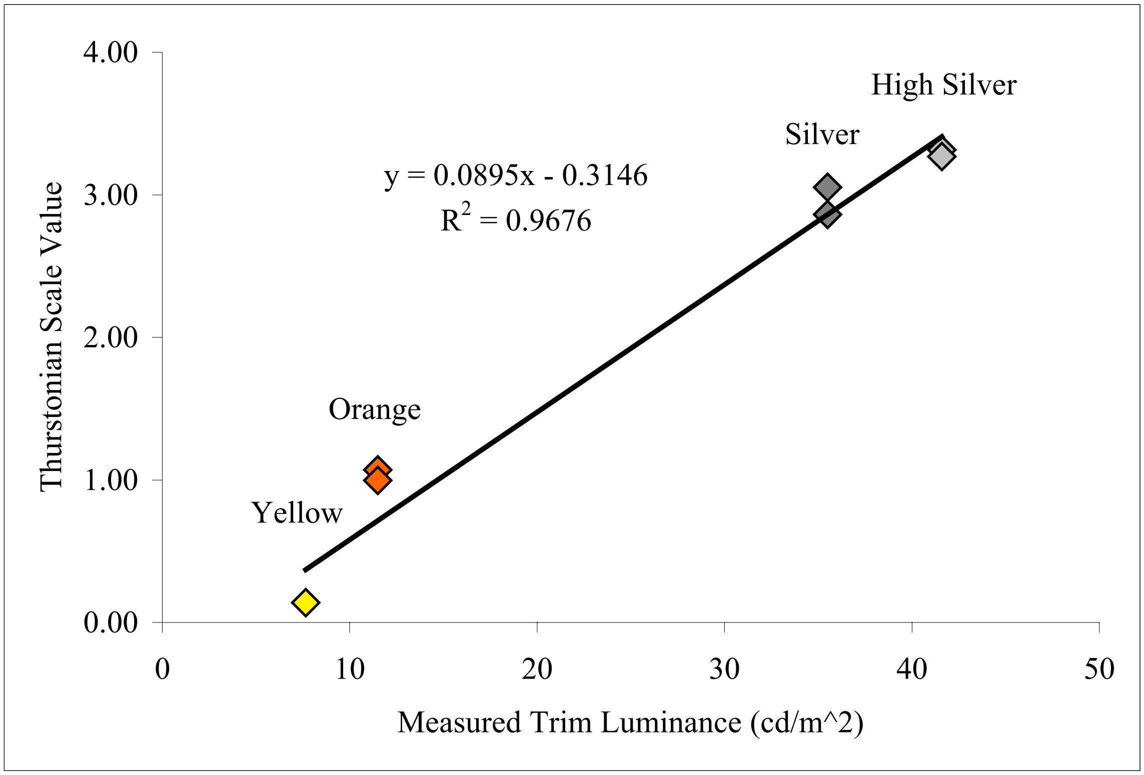

Figure 10. The regression of noticeability on luminance for the nighttime uncluttered condition.

Participant Age

Differences in Thurstonian scale values associated with participant age were minimal. The scale values for both age groups and all four viewing conditions are provided in Appendix A (Figures A1-A8). With one exception, in the nighttime uncluttered condition, where there is a reversal in order of the third and fourth most noticeable combinations, the differences associated with participant age were limited to the fifth through eighth combinations (those judged to be least noticeable).

DISCUSSION

Daytime

It appears there may be two factors contributing to participant judgments under the daytime conditions: color contrast and the presence of fluorescent orange on safety apparel. Under the daytime conditions examined, cluttered and uncluttered, the two stimuli having a color combination of yellow and orange were judged to be more noticeable relative to the four remaining stimuli. In addition, stimuli that lacked apparent color contrast between the trim and base materials (i.e., yellow on yellow, and orange on orange) were consistently judged to be the least noticeable of the combinations presented. However, a linear regression of the calculated color differences on the Thurstonian scale values accounted for no more than 28.5% of the variance observed. This suggests that color contrast may contribute to the judgment of noticeability, but that other attributes are also involved.

The three stimuli that were judged by participants to be most noticeable in both cluttered and uncluttered daytime conditions had two attributes in common: each contained either a fluorescent orange trim or orange base material, and trim and base materials did *not* match. This suggests that not only does color contrast appear to be an important attribute, but so does the use of fluorescent orange.

The apparent benefit of incorporating fluorescent orange in roadworker safety apparel may be influenced by the prior experiences, and therefore expectations, of drivers. Specifically, drivers may have become accustomed to, and may in fact expect, that roadworker safety apparel will contain fluorescent orange material. However, incorporating fluorescent yellow, while retaining some fluorescent orange, may help to make a garment stand out as different from the potential “sea” of orange and white/silver typically observed in construction zones. In the daytime it may therefore be a combination of color contrast not only within the vest, but also some contrast relative to the surroundings, that makes safety apparel most noticeable. The need to incorporate fluorescent orange is consistent with the findings reported by Turner, Simmons, and Graham (1997).

Figure 11 shows an example of how both fluorescent orange and yellow materials could be incorporated into a Class 2 vest, retaining the maximum color contrast effect by keeping the orange and yellow materials adjacent, while using a high powered white or silver micro-prismatic retroreflective trim for nighttime applications (see below). This design assumes that the greatest coefficient of retroreflection can be obtained using white or silver retroreflective trim, relative to any other color, and will thereby provide the best visibility in nighttime conditions. It is important to note, however, that the amount of material necessary such that sufficient color contrast can be perceived has not been empirically determined, and the effect of color contrast may be lost if the area of either fluorescent orange or fluorescent yellow is too small.

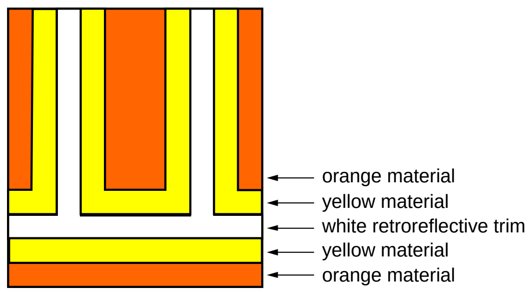

Figure 11. An example of how both fluorescent orange and yellow materials might be incorporated into a Class 2 vest, retaining the maximum color contrast and using a white micro-prismatic retroreflective trim for nighttime applications.

Nighttime

Under nighttime conditions neither color nor color contrast appear to affect the noticeability of roadworker vests; only luminance of the trim material appears to matter—with higher luminance trim (micro-prismatic) material being judged to be most noticeable. However, it is important to restate that all of the retroreflective trim materials examined in this study appeared white when illuminated in the nighttime conditions. Had retroreflective materials that appeared other than white when illuminated been examined, color would likely have affected the judgments of noticeability differently (Schumann, Sivak, Flannagan, Traube, Hashimoto, and Kojima, 1996; Venable and Hale, 1996; Sayer, Mefford, Flannagan, Sivak, Traube, and Kojima, 1998; and Sayer, Mefford, Flannagan, and Sivak, 1999).

Future Research Needs

There remain ample research opportunities regarding the roles of color contrast and retroreflective trim on the conspicuity of roadworker safety apparel. The present study only examined Class 2 type vests, and only looked at a limited, though practical, set of color combinations. Furthermore, all of the retroreflective materials examined appeared white when illuminated in the nighttime condition. Additional research is required to address retroreflective materials that appear other than white when illuminated, the effects of color contrast with mesh base materials, the relationship between the amount of retroreflective material (area) and conspicuity, the placement and patterns of retroreflective trim to aid recognition of pedestrian workers, effects of dirt and wear on conspicuity, and the relationship between additional color-difference metrics (in which luminance is more heavily weighted) and color contrast as a predictive means of assessing the conspicuity of safety apparel.

The vests in this study were constructed using real materials and configurations. Similarly, the tested conditions (cluttered and uncluttered) attempted to simulate two types of real world situations. However, it is likely that even our cluttered conditions were not cluttered enough to simulate some complex real world conditions. All materials used in this study were new and therefore were unaffected by dirt, fading, or wear. In addition, these stimuli were presented in an optimal orientation relative to the observer, straight on as if the roadworker were facing the observer, in the central field of view, such that the maximum amount of material could be seen. Additional testing should be performed which examines whether the use of color contrast remains effective at distances greater than that examined in the present study, and to verify the finding that both color contrast and prior exposure to fluorescent orange contribute to the judgments of noticeability.

CONCLUSIONS

The results of this study demonstrate that color contrast within safety apparel, as well as relative to the surrounding environment, affects noticeability in daytime conditions. In nighttime conditions, assuming that the retroreflective trim appears white when illuminated, only the luminance of the trim affects judgments of noticeability. Color contrast, which cannot be detected under most nighttime conditions with the type of retroreflective materials examined here, has no effect on judgments of noticeability at night. It is proposed that a safety apparel design that might be judged as highly noticeable in both daytime and nighttime conditions would include a combination of fluorescent yellow and fluorescent orange fabrics (providing color contrast for the daytime) with white or silver micro-prismatic retroreflective trim (providing high luminance for nighttime). If this is confirmed by future research, one such vest could then be used during both daytime and nighttime conditions while maximizing conspicuity.

REFERENCES

ANSI/ISEA (1999). *American national standard for high-visibility safety apparel*. (ANSI/ISEA 107-1999), Arlington, Virginia: ISEA-The Safety Equipment Association.

Blomberg, R. D., Hale, A., and Preusser, D. F. (1986). Experimental evaluation of alternative conspicuity-enhancement techniques for pedestrians and bicyclists. *Journal of Safety Research*, *17*, 1-12.

Blomberg, R. D., Leaf, W. A., and Jacobs, H. H. (1980). Detection and recognition of pedestrians at night. *Transportation Research Circular*, *229*, 17-21.

Brich, S. C. (1998). *Development of a safety service patrol uniform standard*. (Report No. VTRC 99-TAR4). Charlottesville, VA: Virginia Transportation Research Council.

Brackett, Q. and Stuart, M. (1982). *High visibility garments for use in work zones*. (No. NTIS PB 84 166826). College Station: The Texas A&M University System.

Cottrell, B. H. (1999). *Improving night work zone traffic control*. (Report VTRC 00-R8). Charlottesville, VA: Virginia Transportation Research Council.

David, H. A. (1988). *The method of paired comparisons*, Second Edition (Stuart, A., Ed). London: Charles Griffin & Company.

Engen, T. (1971). Psychophysics II. Scaling Methods. In *Woodworth & Schlosbergs' Experimental Psychology*, Third Edition (Kling, J. W. and Riggs, L.A., Eds.). New York: Holt, Reinhart and Winston, Inc.

Gordon, D. (1983). *Design of work zone flagger's vest*. (FHWA/RD-83/008). McLean, VA: Federal Highway Administration.

Jenssen, G. D., Moen, T. and Brekke, B. (1999, August). *Nighttime conspicuity of pedestrians in urban environments*. Paper presented at Vision in Vehicles VIII, Boston, MA.

Harrell, W. A. (1994). Effects of pedestrians' visibility and signs on motorists' yielding. *Perceptual and Motor Skills*, 78, 355-362.

Luoma, J., Schumann, J., and Traube, E. C. (1996). Effects of retroreflector positioning on nighttime recognition of pedestrians. *Accident Analysis and Prevention*, *28*, 377-383.

Laborer's Health and Safety Fund of North America (1998). *Fatal Occupational Trauma Among LIUNA Construction Laborers 1988-1989*. Author: Washington, D.C.

Owens, D. A., Antonoff, R. J., and Francis, E. L. (1994). Biological motion and nighttime pedestrian conspicuity. *Human Factors*, 36(4), 718-732.

Sayer, J. R., Mefford, M. L., Flannagan, M. J., Sivak, M., Traube, E. C., and Kojima, S. (1998). *Effects of retroreflective marking color on pedestrian detection distance*. (Report No. UMTRI-98-8). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Sayer, J. R., Mefford, M. L., Flannagan, M. J., Sivak, M. (1999). *Effects of retroreflective marking color on the detection of pedestrians by normal and color deficient drivers*. (Report No. UMTRI-99-6). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Schumann, J., Sivak, M., Flannagan, M., Traube, E. C., Hashimoto, H., and Kojima, S. (1996). *Brightness of colored retroreflective materials* (Report No. UMTRI-96-33). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Shinar, D. (1984). Actual versus estimated night-time pedestrian visibility. *Ergonomics*, 27(8), 863-871.

Shinar, D. (1985). The effects of expectancy, clothing reflectance, and detection criterion on nighttime pedestrian visibility. *Human Factors*, 27(3), 327-333.

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.

Venable, W. H. and Hale, W. N. (1996). Color and nighttime pedestrian safety markings. *Color Research and Application*, 21(4), 305-309.

APPENDIX A

THURSTONIAN SCALES BY AGE GROUP

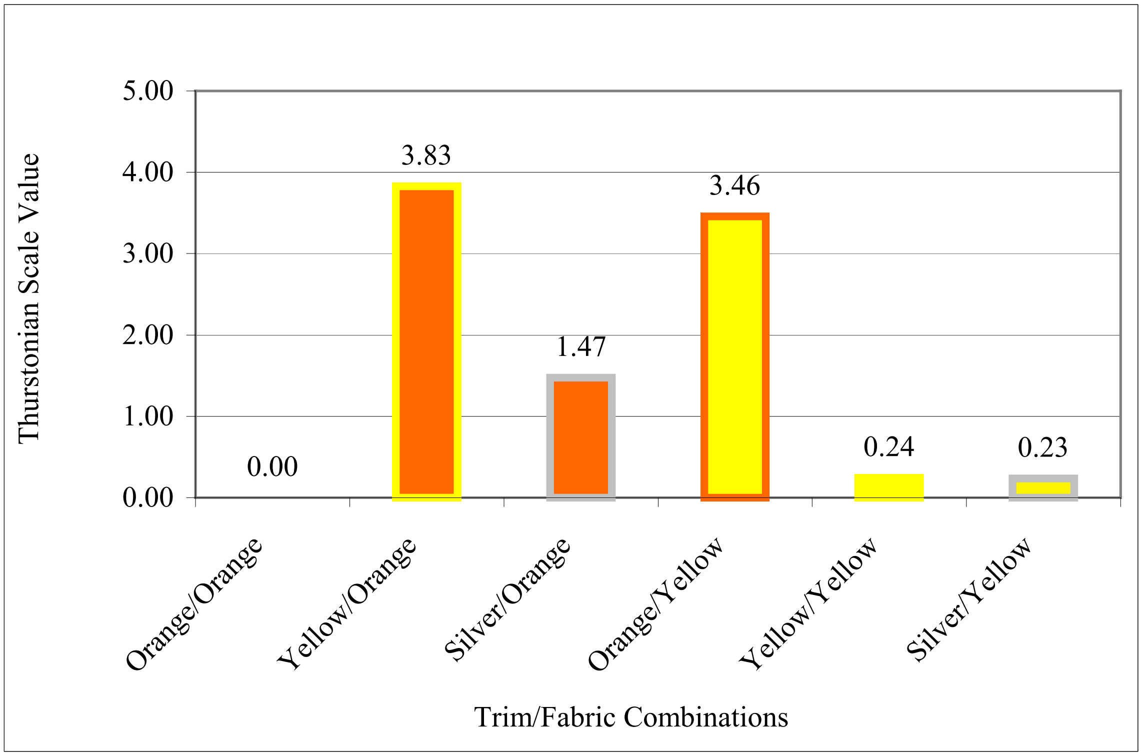

Figure A1. Mean Thurstonian scale values for the daytime cluttered condition, younger subjects.

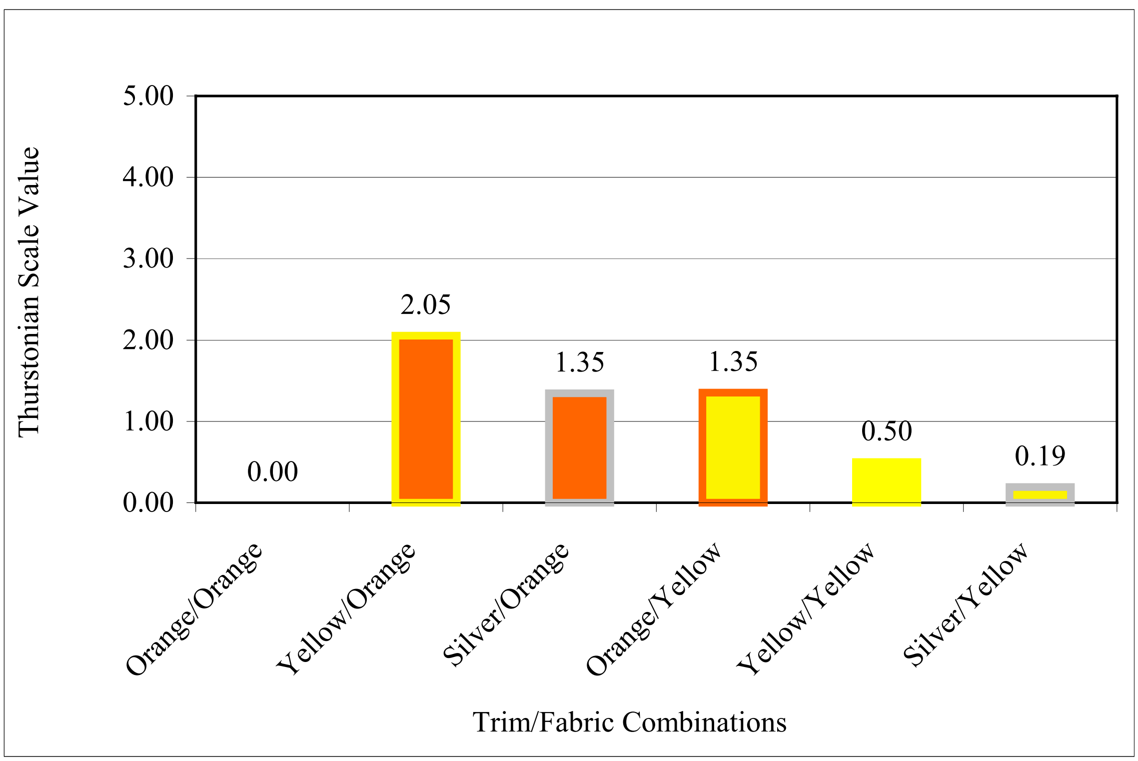

Figure A2. Mean Thurstonian scale values for the daytime cluttered condition, older subjects.

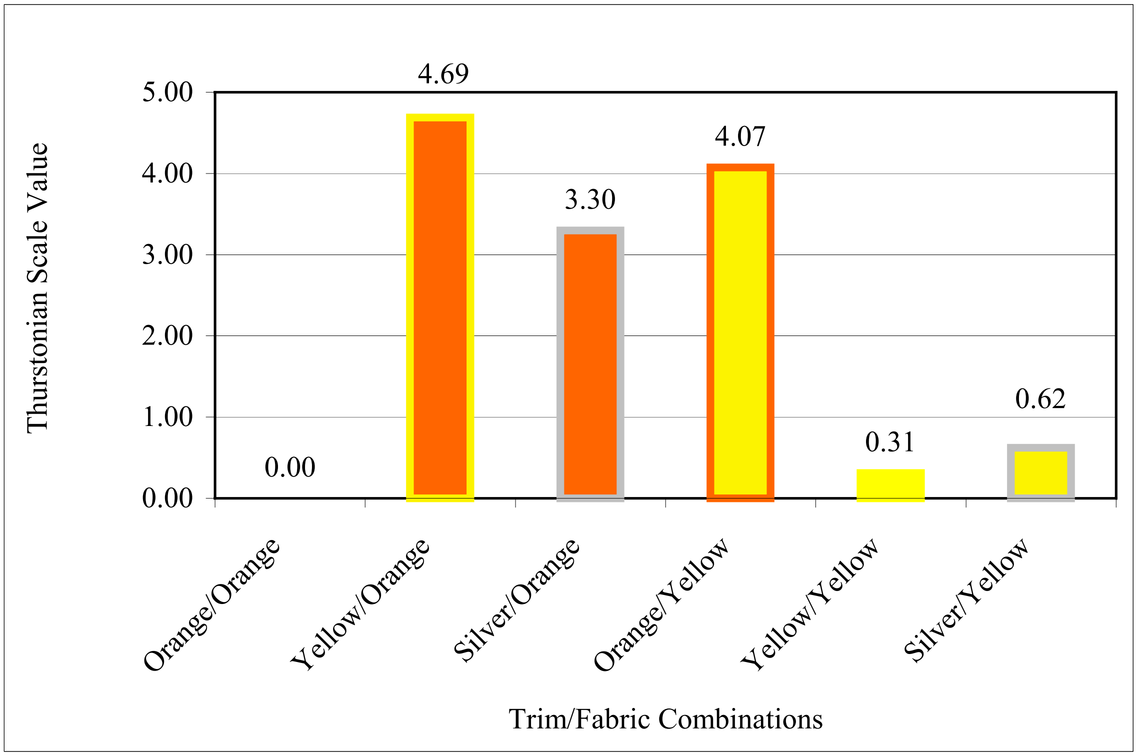

Figure A3. Mean Thurstonian scale values for the daytime uncluttered condition, younger subjects.

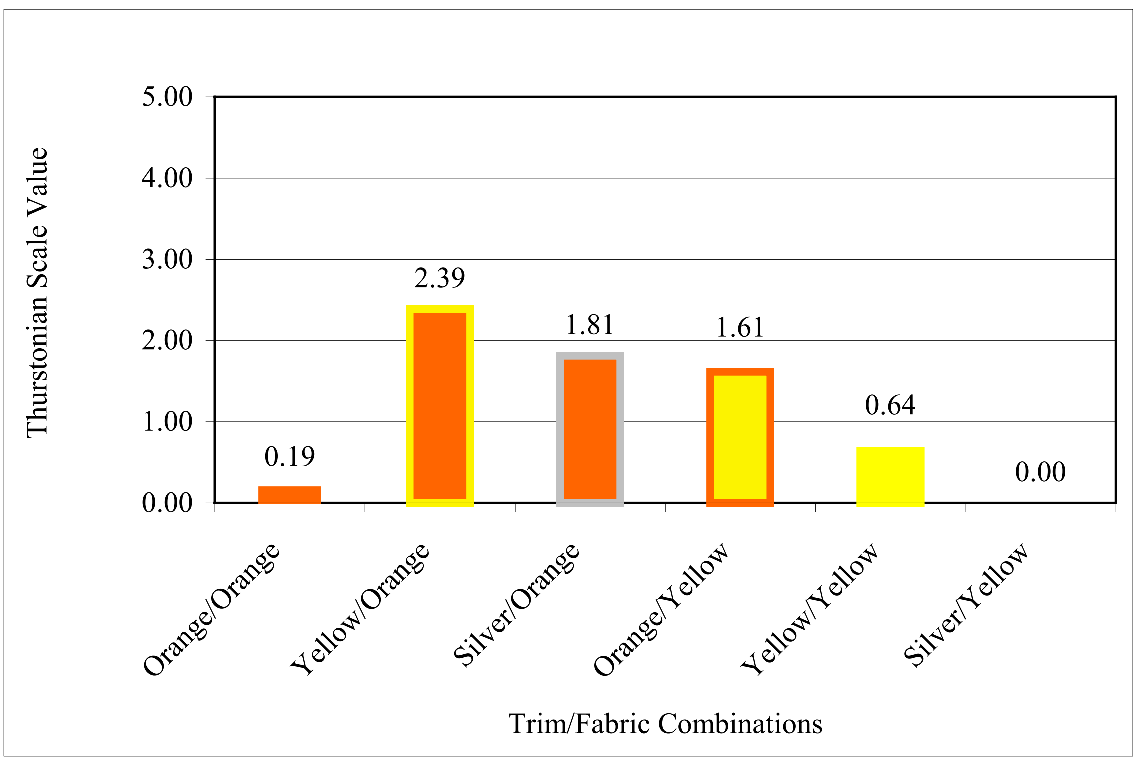

Figure A4. Mean Thurstonian scale values for the daytime uncluttered condition, older subjects.

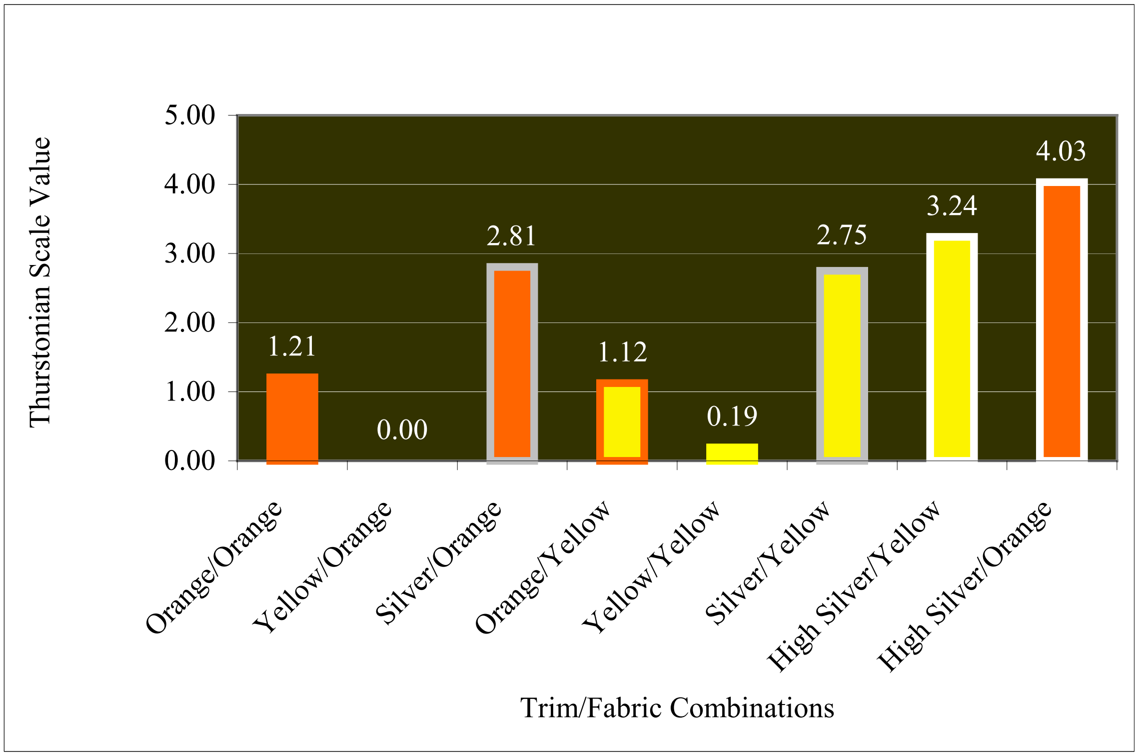

Figure A5. Mean Thurstonian scale values for the nighttime cluttered condition, younger subjects.

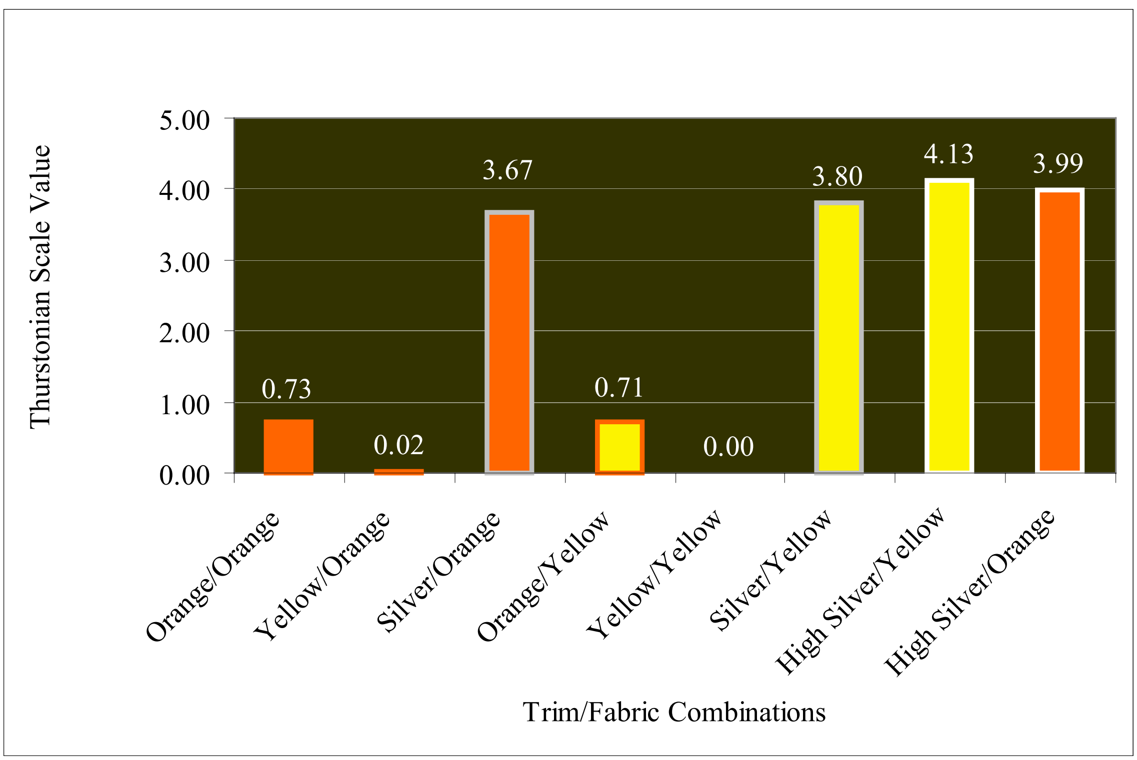

Figure A6. Mean Thurstonian scale values for the nighttime cluttered condition, older subjects.

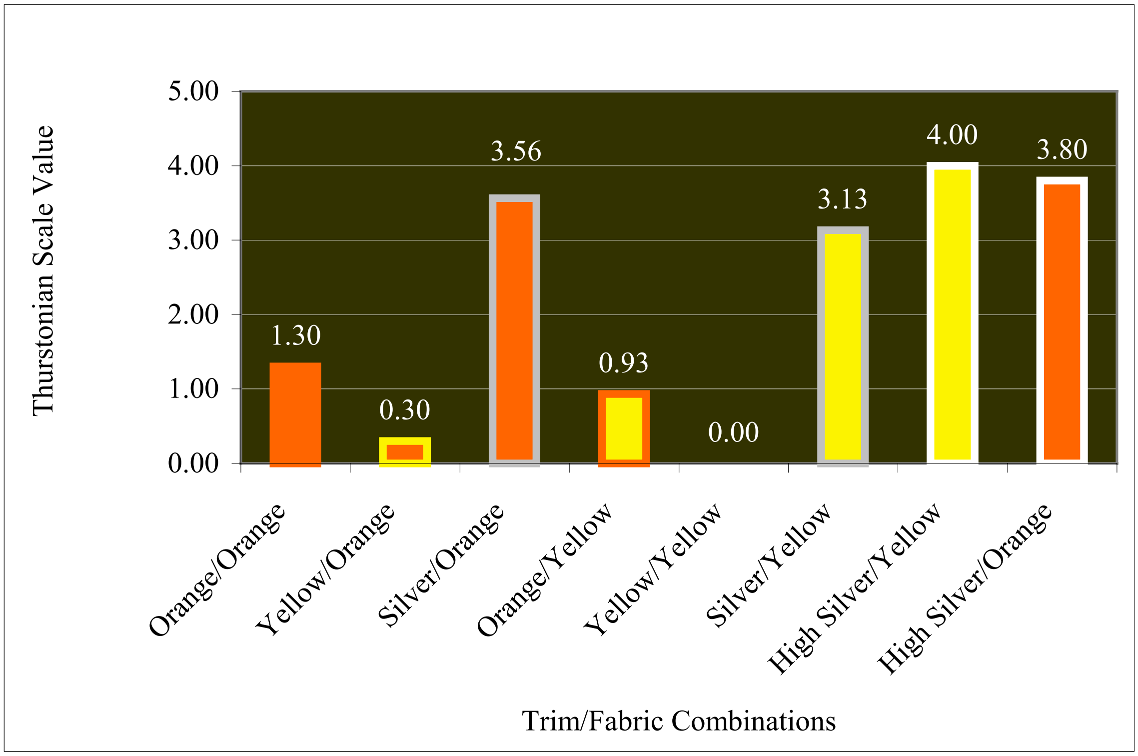

Figure A7. Mean Thurstonian scale values for the nighttime uncluttered condition, Young subjects.

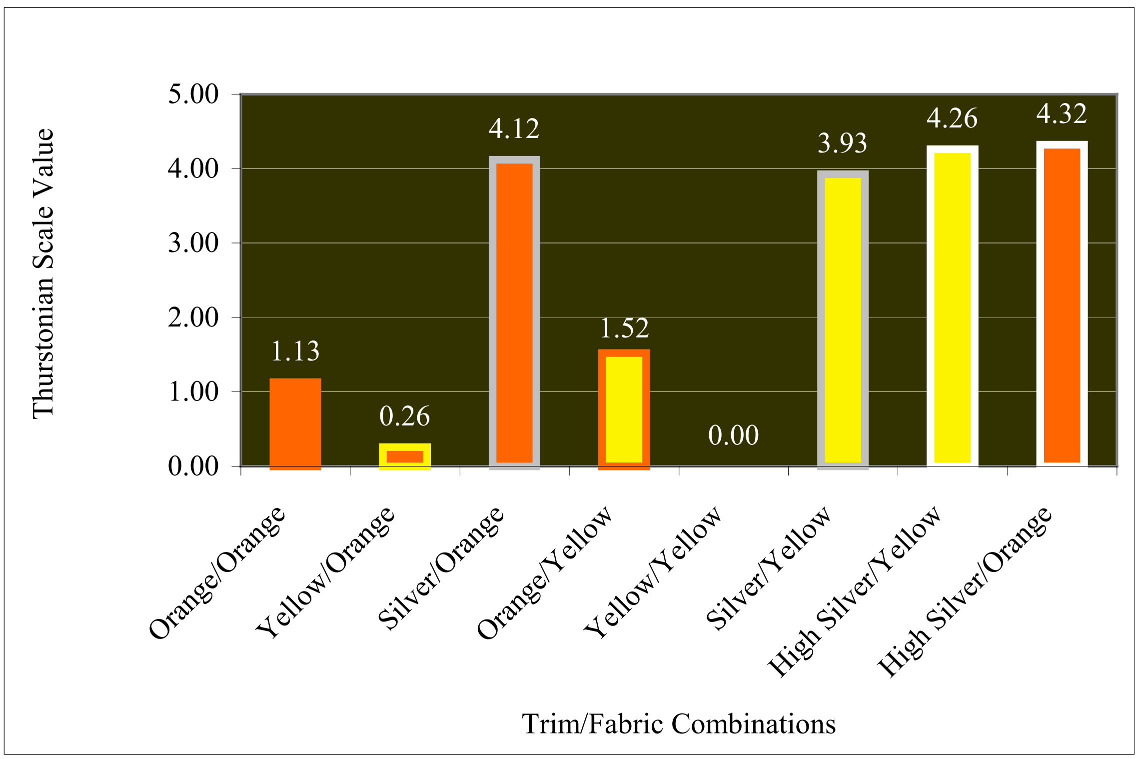

Figure A8. Mean Thurstonian scale values for the nighttime uncluttered condition, Older subjects.