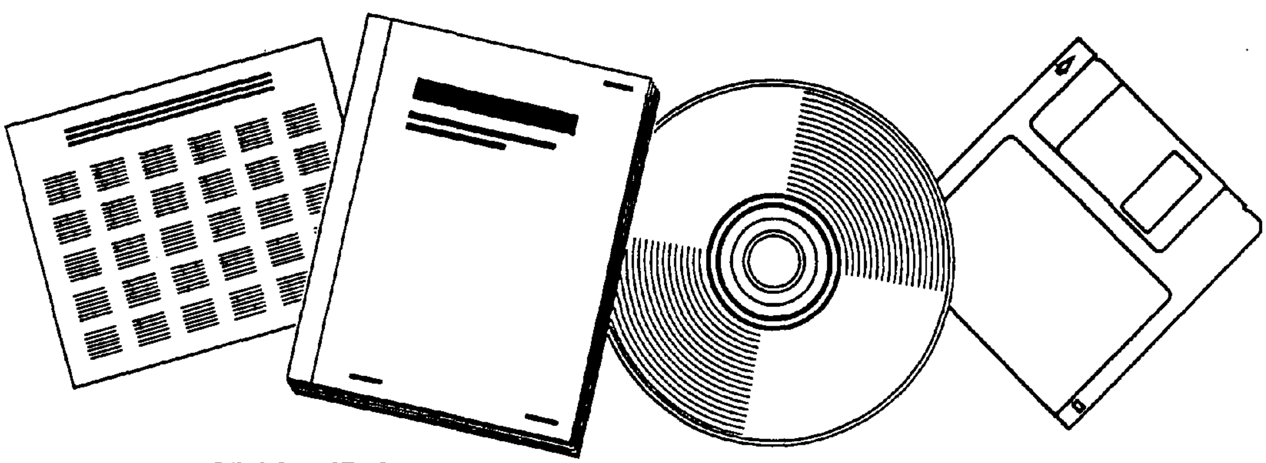
PB97-171615

VISIBILITY AND COMPREHENSION OF PEDESTRIAN TRAFFIC SIGNALS

LAST RESOURCE, INC., BELLEFONTE, PA

MAY 97



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB97-171615

Visibility and Comprehension of Pedestrian Traffic Signals

PUBLICATION NO. FHWA-RD-96-187

MAY 1997

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This report will be of interest to traffic engineers and administrators responsible for pedestrian traffic controls at intersections. There has been some concern that pedestrians do not adequately understand and/or obey pedestrian signals. This research examined the possible use of innovative symbols and red/green pedestrian signals; tested the use of newer, energy-efficient technologies, such as neon, fiber optics, and light-emitting diodes, for pedestrian signals; and developed a performance-based visibility standard for pedestrian signals regardless of the light source.

The researchers reviewed the literature, surveyed current practice, and conducted field studies involving walking speeds of pedestrians, innovative signal displays, and visibility requirements for signal displays.

The study recommendations included using a three-phase (red, yellow, and green) pedestrian signal rather than the orange and white currently in use. The use of a green walking man for "walk," a yellow standing man for "clearance," and a red slash on a man or hand for "do not walk" should be considered for the revised *Manual on Uniform Traffic Control Devices.*

The study on the visibility of the pedestrian signal concluded that the signal luminous intensity of 25 candela (cd) is adequate for all types of pedestrian signal displays.

One copy of this report is being sent to each Region and two copies are being sent to each Division office. One of the copies sent to the Division should be sent to the State highway agency by the Division office.

A. George Ostensen, Director
Office of Safety and Traffic Operations
Research and Development

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

Technical Report Documentation Page

1. Report No. **FHWA-RD-96-187** PB97-171615	3. Recipient's Catalog No.
4. Title and Subtitle **VISIBILITY AND COMPREHENSION OF PEDESTRIAN TRAFFIC SIGNALS**	5. Report Date May 1997 6. Performing Organization Code
7. Author(s) **Sara Pennak, Douglas J. Mace, and Mark Finkle**	8. Performing Organization Report No.
9. Performing Organization Name and Address **The Last Resource, Inc. 309 Armagast Road Bellefonte, PA 16823**	10. Work Unit No. (TRAIS) **3A1b-0142**
12. Sponsoring Agency Name and Address **Office of Safety and Traffic Operations R&D Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296**	11. Contract or Grant No. **DTFH61-92-C-00034** 13. Type of Report and Period Covered **Final Report November 1992 - November 1995** 14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative (COTR): Dr. Carole Simmons, HSR-30

16. Abstract

Two studies were conducted to determine the visibility and comprehension of pedestrian signals. A video questionnaire was developed to study the comprehension of innovative and standard pedestrian crosswalk devices. Results indicated that green and red are interchangeable in meaning with white and orange, respectively. A red "slash man" appears to be a strong alternative to a symbolic orange hand. It was recommended that a three-phase pedestrian signal be considered that would incorporate the strengths of green, yellow, and red with innovative symbols.

The study on the visibility of actual pedestrian signals determined that a minimum signal intensity of 25 cd is adequate for any pedestrian signal regardless of technology, distance, signal size, text, or symbol.

17. Key Words **Visibility, comprehension, pedestrian, innovative traffic control devices.**	18. Distribution Statement **No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.**

19. Security Classif.	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**66**	

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Over the past 50 years, symbolic traffic signal (STS) research has largely consisted of efforts to study the comprehension of symbols. The current research objective was not only to determine performance criteria for acceptable pedestrian signal visibility, but also to study the comprehension of innovative and standard pedestrian signals.

In order to meet our objectives, a review of previous research, pedestrian signal standards, and current practices was undertaken as the first project task. Two field studies and a video questionnaire were then designed and implemented to test the visibility and comprehension of pedestrian signals. The rationale of these studies was threefold: (1) to examine the possible use of innovative symbols and red/green pedestrian signals, (2) to test the use of newer, energy-efficient technologies, and (3) to develop a performance-based visibility standard for pedestrian signals. A fourth study on walking speed was completed to determine whether the current *Manual on Uniform Traffic Control Devices* (MUTCD) standard is adequate for elderly crossing times.

LITERATURE REVIEW AND CURRENT PRACTICES

Our review of pedestrian signals revealed many factors can affect pedestrian crosswalk behavior. The ability of pedestrians to recognize crosswalk signals can be a function of equipment characteristics such as signal size, signal luminance levels, viewing distance, and environmental conditions, including sun position and surrounding complexity. The physical characteristics of pedestrian signals are well specified in the Institute of Transportation Engineers (ITE) and MUTCD standards. However, very little work has been done to delineate the intensity or luminance requirements necessary for adequate pedestrian signal visibility. Legibility of these signals has largely been related to viewing distance and the height of signal letters and symbols.

Pedestrian comprehension of crosswalk signals can depend upon individual differences in cognitive functioning, experience, visual acuity, and the assimilation of surrounding cues, including the actions of vehicular and other pedestrian traffic. Compliance or non-compliance with a signal may or may not indicate signal comprehension since pedestrians use many prompts for determining whether or not to cross a street and signal utilization is not always a factor.

The walking speed of pedestrians is also related to many factors, including street width, vehicle and pedestrian volumes, weather, crosswalk markings, stop lines, traffic conditions, fatigue, intersection type, trip purpose, gait, balance, and the presence of pedestrian signals. According to the 1988 MUTCD, "normal walking speed is assumed to be four feet per second [1.2 m/s]." However, studies conducted by Petzold (1977) found that the average walking speeds of the elderly were slower than this standard as the volume increased. Knoblauch et al. (1993) found that the 15th percentile walking speed for pedestrians more than 65 years of age was 0.94 m/s (Knoblauch et al., 1993). Design walking speeds of 1.0 m/s for midblock crosswalks and for signalized intersections near elderly populations were suggested by Coffin and Morrall (1995).

Currently, incandescent lamps are the most common illumination source for traffic signals. However, this technology is widely believed to be inefficient when compared to other light sources and has higher maintenance and energy costs. Alternatives to incandescent lamps are neon, fiber-optic (FO), and light-emitting diode (LED) technologies. Overall, these technologies are more energy-efficient and purport to produce few, if any, phantom effects.

FIELD STUDIES AND VIDEO QUESTIONNAIRE

Visibility Study

The objective of the visibility study was to test the legibility of 7.6-cm letters and 15.2-cm symbols at distances of 18.3 and 29.3 m at various voltage settings during the day. Specifically, the study was designed to determine which signals were visible to older pedestrians when the signal voltage was set at 100 percent, 75 percent, and 50 percent of full power. Measurements of signal intensity were obtained to better analyze signal performance.

A total of 48 seniors, age 62 and older, participated in this study. Test stimuli included several types (incandescent, fiber optic, and LED) of commercially available pedestrian signals, including 22.9-cm and 30.5-cm rectangular signal housings and two round 29-cm Red-Amber-Green (RAG) signals with symbol masks. Each subject was asked to identify the signal's location in the test stimuli array, to name the signal's display configuration (WALK, DON'T WALK, walking man, or hand), and to assess the signal's brightness on a five-point scale.

Results

The visibility data were analyzed by calculating the percentage of subjects correctly identifying the message of the signal that was energized. Analyses were also conducted on the percentage of responses where signals were identified as "overbright" or where subjects were "uncertain" of the signal message.

- In general, the analysis of recognition, uncertainty, and overbright responses by voltage level suggests that 90 V is a reasonable voltage to operate all of the signals tested. Ninety volts appeared to provide a signal intensity that minimized the frequency of both overbright and uncertain responses regardless of size, technology, or whether the message was symbol or text among the test signals.

- All of the incandescent signals, except the orange DON'T WALK, produced some uncertainty with the signal intensities available at 60 V. As intensity increases, uncertainty decreases.

- All of the signals with intensities of 25 cd or greater resulted in a zero level of uncertainty at 29.3 cm, except for the non-standard white hand at 66 cd and the white WALK at 37 cd that resulted in all correct responses and uncertainty for only one subject. A maximum value of 100 cd would remove many of the overbright signals reported at 29.3 m, while still providing four times the intensity needed for certain recognition by all subjects.

- None of the FO signals was incorrectly identified during the blank trials, indicating the absence of phantom effects for this technology. These results suggest that if FO signals had been tested alone, the minimum intensity requirement would have been set much lower than 25 cd.

Recommendations

The results of the visibility study clearly suggest that a minimum intensity of 25 cd will be adequate for any pedestrian signal regardless of technology, distance, signal size, or text vs. symbol. The data further suggest that 22.9-cm signals provide sufficient visibility with fewer phantom effects than 30.5-cm signals. If FO signals are used, the required minimum intensity will undoubtedly be lower because of the absence of phantom effects. However, another study using only FO signals will be necessary to establish these levels.

Walking Speed Study

The 48 elderly subjects participating in the pedestrian signal studies were asked to walk 18.3 m along a marked length on an asphalt parking lot near the visibility study test site. Subjects were asked to walk at a "normal street crossing speed" and to imagine they were using a crosswalk at a signalized intersection on a five-lane urban street. Each subject was timed individually with a stopwatch.

Results

- The mean walking speed for this group of subjects was 1.45 m/s, which is well above the MUTCD standard of 1.22 m/s. Only five subjects, or 10 percent, were unable to walk the distance at a rate of 1.22 m/s.

- The 15th percentile walking speed of the older subjects was 1.26 m/s. This result is closer to the average 15th percentile speed for younger pedestrians (1.19 m/s) than to the average 15th percentile speed of older subjects (0.92 m/s) found by Knoblauch et al. (1993).

Recommendations

Although the MUTCD standard appears to be easily met by 90 percent of the elderly subjects tested, these findings may not represent a typical population of seniors. Many of the retirees in the State College, Pennsylvania area are quite active and none appeared to have impairments that would have affected gait or balance. Furthermore, very few of the other factors that typically affect walking speed were present in the test conditions. Based on these results, it is believed that the current MUTCD standard is probably adequate for most elderly pedestrians under optimal conditions. Further recommendations would not be appropriate given the limited testing circumstances.

Video Questionnaire Study and the Comprehension of Pedestrian Signals

The primary objective of the video questionnaire was to test pedestrian comprehension of current in-service and innovative signals. By using a video questionnaire, a variety of innovative stimuli could be tested in a non-risk environment. Most of the innovative signals in the video questionnaire were symbolic and many were presented in non-standard colors such as green, yellow, and red. Standard signals included text and symbolic messages in orange and white.

The 48 elderly subjects who participated in the visibility and walking speed studies also viewed the video questionnaire. In addition, the video questionnaire study included 43 school-age subjects ranging in age from 11 to 15 years. The 45 flashing and steady test stimuli were shown in curb and mid-crossing contexts. Subjects were instructed to provide the *meaning* of the test stimuli by choosing one of four multiple-choice items on a paper-and-pencil answer sheet.

Results

For analysis purposes, subject responses were scored for correctness and non-parametric tests were used to detect any significant differences between signals within a viewing context.

Curb-viewed signals:

- At least 90 percent of the subjects gave the most correct answer of "it's okay to cross" for the six green and white curb-viewed signals shown in the steady mode, with 100 percent comprehension for the white WALK, green WALK, and green walking man symbol.
- There was significant viewer difficulty in the yellow curb signal comprehension. The yellow steady hand was ranked the highest of the seven "wait on the curb" stimuli, with only 65.9 percent correct responses.
- There were no significant differences between the eight orange "wait on the curb" signals. The only orange curb stimuli that did not have at least 90 percent correct responses were the two standard signals—the orange flashing DON'T WALK and the orange flashing hand.
- The four red "wait on the curb" signals shown only in a steady mode performed superbly, with at least 95 percent of the subjects providing the correct response and 100 percent of the young subjects correctly understanding the red hand and the red RAG.
- Between-color analyses showed no significant differences between red and orange "wait" signals within a common symbol and mode. All yellow test stimuli had significantly lower comprehension than either red or orange.
- There were no significant differences between text and symbol for the green/white walk signals and the orange wait signals.

- The innovative standing man was the least successful of the symbols and may contribute to pedestrian confusion when paired with a weakly understood color such as yellow.

- The innovative "slash man" performed well with either red or orange and its comprehension was virtually the same as with the standard hand.

- The innovative DON'T START was ranked the highest in comprehension of the orange wait signals.

- Virtually no differences were found between green and white or between red and orange when only color was varied and other signal characteristics were held constant.

- Although there were no significant differences between flashing and steady modes within a signal type, flashing signals were generally less understandable than steady signals.

Mid-crossing signals:

- Only the green-to-yellow signal transitions had at least 90 percent correct responses for stimuli indicating "it's ok to keep crossing." The standard white WALK to flashing orange DON'T WALK had 89.1 percent correct responses and the standard white man to flashing orange hand had 84.7 percent correct responses.

- At least 10 percent of the subjects thought the white-to-orange transitions meant "turn around and go back."

- When appearing in a mid-crossing transition signal, the innovative DON'T START was ranked the lowest with either a green or white WALK.

- The 10 mid-crossing stimuli changing from a "caution" to a "don't walk" mode presented the greatest amount of difficulty in comprehension. Only one of these signals had 90 percent correct responses—the yellow steady standing man RAG to red steady standing man RAG transition.

- All of the innovative yellow-to-red transitions had a higher percentage of correct responses than the standard or innovative orange-to-orange signals.

Recommendations

The results of this study clearly indicate the strength of red and green as contributing powerful messages to stop and go. Yellow may be too weak to prevent a crossing start, but appears to be useful in preventing the unsafe return to a curb.

Should text continue to be allowed as a pedestrian signal standard, the use of DON'T START needs to be carefully considered. When viewed from the curb, this message is as easily understood as the hand and is ranked above the current DON'T WALK. However, DON'T START performs poorly as a mid-transition signal. It ranked below all symbol and text signals for walk-to-caution transitions, and had fewer than 60 percent correct responses for the caution-to-don't walk modes. Based on these results, it is recommended that text messages remain as WALK and DON'T WALK.

Observational field studies of these colors and symbols would be needed to determine their effects on pedestrian and motorist behavior. Although the video questionnaire allows a three-dimensional approach to evaluating signals, it also requires the use of the subject's imagination, particularly with the mid-crossing perspective. In addition, these results assumed that the subjects were responding as instructed and were providing their beliefs as to signal meaning and not how they would behave. Previous research has already noted that pedestrian behavior can be influenced by many factors. Thus, the results of the video questionnaire do not provide a complete basis for predicting actual pedestrian behavior with regard to the test signals.

AN OVERVIEW OF PEDESTRIAN SIGNAL LITERATURE AND CURRENT PRACTICES

INTRODUCTION

Over the past 50 years, symbolic traffic signal (STS) research has largely consisted of efforts to study the comprehension of the symbols used with these devices. The current research objective was not only to study the comprehension of pedestrian STS, but also to determine performance criteria for acceptable STS visibility. Although several factors can influence pedestrian crosswalk behavior, this research focused on two primary objectives: (1) to determine the physical characteristics of pedestrian traffic signals that can affect signal legibility, and (2) to assess user understanding of innovative and standard pedestrian signals. A secondary research objective was to study crosswalk length, elderly crossing times, and pedestrian signal standards.

Two studies were designed and implemented to test the comprehension and visibility of pedestrian signals. In particular, the rationale of these studies was to examine the possible use of red/green pedestrian signals and to test the use of newer, energy efficient technologies such as light-emitting diodes (LED's) and fiber optics. A third rationale for this research effort was the development of performance-based visibility standards for pedestrian signals. In order to ensure the legibility of pedestrian signals at varying crosswalk lengths or at maximum intersection widths, experimental tests of actual signals were designed for the current project to measure signal effectiveness at different roadway widths. These tests addressed whether the current 18.3-m distance from the *Manual on Uniform Traffic Control Devices* (MUTCD, 1988) is appropriate and/or sufficient for use as the pedestrian signal standard for determining signal letter and symbol height.

LITERATURE REVIEW AND PEDESTRIAN SIGNAL STANDARDS

Physical Characteristics of Pedestrian Traffic Signals

In 1985, the Institute of Transportation Engineers (ITE) issued a standard defining the acceptable physical characteristics for pedestrian traffic signals. According to their findings, these control devices should be internally illuminated with an operating voltage between 100 and 130 VA at 60 Hz. They recommended that the shape of the signal head be rectangular with the minimum size determined by the length of the crosswalk, but not less than 22.9 cm by 22.9 cm. The signal mask should be flat and cover the entire surface, except where the symbol is cut out. It should be made of a hard, durable material so the heat of the bulb or weather conditions will not cause it to peel or flake. The signal face must be equipped with a screen, visor, or other device that minimizes optical illusion or "phantom effects." Phantom effects can occur when a directed light source on the face of an unlighted signal causes the signal to appear energized.

Although the ITE standards do not specify a source of internal illumination for pedestrian signals, standard colors are given for incandescent or luminous tube sources according to Commission International d'Eclairage (CIE) values. Using the CIE color system, "the chromaticity of a color is expressed in terms of two values identified as x and y." ITE standards for pedestrian signal color are stated in CIE values for the two acceptable signal colors of Portland orange for DON'T WALK indications and white for WALK indications. The 1988 MUTCD similarly states that the WALK indication shall be white and the DON'T WALK indication shall be Portland orange. While internal illumination of pedestrian signals is required by the MUTCD, there are no restrictions placed on technology for the illumination source.

Legibility

The ITE (1985) also recommended that the lighted signal be illuminated over the entire message-bearing surface (MBS) without shadows when viewed from 10 degrees to the left and right on a line perpendicular to the MBS. The message should attract attention and be readable from 3 m to the full length of the crosswalk. There should be four classes of pedestrian crossing signals, with the lowest value intended for the shortest crossings. The signal should be designed so that if the DON'T is burned out, then the WALK does not light either.

In 1990, Janoff conducted a literature review of international traffic signal standards that cited the intensity, luminance, and luminance distribution for symbolic signal standards. According to his review, the following standards (table 1) are applicable to symbolic pedestrian signals:

Table 1. Legibility standards for symbolic pedestrian signals (Janoff, 1990).

	Luminance cd/m^2	**Intensity cd**
CIE	3000[2]	100[1]
Australia	4000[2]	none given
ITE	none given	none given
South America	1000	none given

[1]Without the symbol, but with a colored lens.
[2] On axis.

Prior to the 1990's, very little research had been done on daytime luminance other than studies by Bryant and Smith (1976), and Smith and Weir (1978). In both projects, they found luminance levels had no effect on the recognition of various pedestrian signal shapes. Bryant and Smith (1976) found that adequate daytime luminance can cause excessive glare at night and discovered that 30.5-cm symbols perform better than 20.3-cm signals. Bailey's 1991 pedestrian signal study found that almost 25 percent of the elderly subjects sampled reported difficulty seeing pedestrian signals from the opposite curb, although she notes that the signal displays appear to be sufficient for most users.

The legibility of pedestrian signals based on distance is addressed in the 1988 MUTCD:

> "For crossing where the distance from the near curb to the pedestrian signal indication is 60 ft [18.3 m] or less, the letters, if used, shall be at least 3 in [76.2 mm] high or the symbols, if used, shall be at least 6 in [152.4 mm] high. For

distances over 60 ft [18.3 m], the letters, if used, should be at least 4.5 in [114.3 mm] high and the symbols, if used, shall be at least 9 in [228.6 mm] high."

However, the MUTCD does not provide standards for signal intensities or luminance.

Pedestrian Signal Comprehension

The literature review revealed an abundance of research dedicated to the study of pedestrian behavior at signalized crosswalks and pedestrian understanding of crosswalk signals. In an American Automobile Association (AAA) Foundation for Traffic Safety study, researchers at the University of Tennessee found that 52 percent of respondents at the American Association of Retired Person's 55 Alive courses could not correctly identify the meaning of a flashing DON'T WALK (Tidwell, 1993). Only 51 percent of the study's participants at driver's license bureaus answered correctly. Using paper-and-pencil questionnaires, they found that significantly higher proportions of respondents under age 50 comprehended the flashing signal correctly.

Coffin and Morrall's 1995 study on crosswalk behavior of older pedestrians also reported elderly confusion with the WALK and flashing DON'T WALK pedestrian signal indications. Bailey et al. (1991) found that only 31 percent of their elderly subject group knew that a flashing DON'T WALK meant proceed with caution, with the majority thinking the signal meant danger. They reported that "about a third of the respondents indicated they would return to the sidewalk when the signal begins to flash." In terms of understanding the upright hand symbolizing "DON'T WALK," 36 percent of their subjects could not correctly identify its meaning. Bailey notes that a large percentage of the respondents used other cues besides the signals to determine when to cross the street.

This multiple-cue response behavior was also studied by Wagner in 1981. Using photographic records of five high-volume Chicago intersections, he found that "frontliners" on the curb would look either at the signal or at traffic before determining to cross and that "backfielders" looked at the backs of the frontliners, following them across. "Newcomers" rarely looked at the signal or at traffic, but simply gauged the safety of their crossing by noting the presence of others in the crosswalk. Only the lone pedestrian was found to use all cues, alternating his/her gaze at the signal, looking at traffic, and searching for other pedestrians to leave the curb.

Wiener's 1967 study reports a similar phenomenon, particularly with elderly pedestrians who were photographically observed waiting on a corner to convoy with other elderly pedestrians or waiting for a younger pedestrian to act as an "unknowing guide." On-the-street interviews revealed that the elderly were confused by traffic and had little or no understanding of crosswalk signals. Lalani and Baranowski (1993) attempted to reduce public confusion about the use of pedestrian signals by mounting educational signs at signalized intersections. These signs were installed in the city of San Buenaventura, California, and were used to inform pedestrians that a walking man symbol meant "Start Crossing," a flashing hand meant "Don't Start," and a steady hand meant "Don't Cross." Other researchers have also looked into the use of educational signs at crosswalks and have presented similar messages.

Both Zegeer et al. (1985) and Robertson (1977) studied the effects of the steady versus flashing DON'T WALK indication. They found no difference between steady and flashing signals in overall conflicts or violations. However, Zegeer et al. reported a significant improvement in violations and conflicts with a steady DON'T START over the flashing DON'T WALK display. Their test of a three-phase signal included a steady WALK, steady DON'T START, and a steady DON'T WALK, making it comparable to the more easily understood three-phase motorist traffic signal.

In terms of preferences for symbolic pedestrian signals, Robertson (1977) found that pedestrians preferred red and green indication colors, but were more compliant with orange and white. He also noted that the symbolic hand and walking man displays were a "significant improvement over the standard DON'T WALK - WALK display" and that a standing man symbolizing DON'T WALK and a walking man were as effective as their textual counterparts.

Cairney (1988) studied the preferences of elderly and young participants for flashing red and green pedestrian signals. Conducted in Australia, where pedestrian signals change from green to flashing red to steady red, this research also examined the effects of flash rate on signal comprehension. Using an open-ended question format, earlier research by Cairney (1984) had found that 95 percent of the subjects believed that a flashing red pedestrian signal meant do not start walking or meant the signal was about to change to red. When the same group of subjects were presented with a list of three choices for the meaning of the flashing red signal, 71 percent of the respondents gave the correct response of "may complete crossing, but must not begin to cross."

Although Cairney used colored photographs in his 1984 work, video presentations were employed in his 1988 study to represent the test stimuli. The procedures for the comprehension study presented in this report are similar to those of Cairney. Cairney held that the "two groups of most critical importance from the point of view of coping with signals are the elderly and children." A total of 16 adults, approximately 60 years old, and 12 children from the seventh grade participated in his study. His results indicated that there was a highly significant preference for the flashing red signal over the flashing green when the signal message was "You may complete your crossing, but do not begin to cross." Cairney found no clear preference for flash rate, although the slowest rate was judged to be less effective in conveying the signal message.

Crosswalk Lengths and Elderly Crossing Times

While comprehension of pedestrian signals plays an important role in crosswalk behavior, crosswalk length is an additional factor that has an impact on pedestrians, particularly the elderly. Based on interviews with traffic engineering experts, the minimum crosswalk length in urban/suburban areas that would require pedestrian signalization is typically two lane widths, or approximately 7.3 m. The longest intersection crossing would probably be no more than eight lanes wide, or about 29.3 m. This maximum length would typically provide a midpoint pedestrian refuge island if the signal timing was not long enough to accommodate the average walking speed.

Another source consulted for obtaining information on crosswalk lengths was Federal Highway Administration (FHWA) report no. FHWA-RD-93-077, *Older Pedestrian Characteristics for Use in Highway Design* (Knoblauch et al., 1977). Although it did not specifically study crosswalk length distributions, the authors made several recommendations for guidelines related to highway and crosswalk design. Based on the data collected from their field studies, Knoblauch et al. (1993) supported the rewording of American Association of State Highway and Transportation Officials (AASHTO) standards to include the use of "simple [crosswalk] designs that minimize crossing widths and minimize the use of more complex elements such as channelization and separate turning lanes. When these features are necessary, assess alternate designs that will protect elderly pedestrians."

Walking Speed

Literature was also reviewed on crossing times required by pedestrians. According to the 1988 MUTCD, "normal walking speed is assumed to be four feet per second [1.2 m/s]." In their 1991 study, "Issues of Elderly Pedestrians," Bailey et al. conducted a literature review and reported studies in Sweden that indicated that none of the 205 79-year-old subjects were able to achieve a rate of 1.4 m/s when using their preferred rate of walking. Furthermore, "only 32 percent of the women and 72 percent of the males could achieve the 1.4-m/s [Swedish] standard." Bailey also reported that the gait of the elderly is not only affected by the individual's physiological changes, but by road surfaces, curb height, and fear of falling.

Petzold's 1977 report, *Urban Intersection Improvements for Pedestrian Safety*, notes that pedestrian crossing speeds become slower than the 1.2-m/s standard as pedestrian volume increases and "can range well over 50 percent slower on high-volume crosswalks because there are more slower walkers at higher volumes." He also allowed that pedestrian walking speed may be lower if the crosswalk is used heavily by the elderly or handicapped, and recommended that a 1.1-m/s standard be considered if a location warrants it.

The 1993 FHWA report no. FHWA-RD-93-077, *Older Pedestrian Characteristics for Use in Highway Design* (Knoblauch, et al.), stated that mean walking speeds ranged from approximately 1.2 to 1.46 m/s. This average was based on observations of more than 7,000 pedestrians of all ages. The authors also reported that the 15th percentile walking speed for pedestrians older than 65 years of age was 0.94 m/s. For AASHTO design purposes, they further recommended that 0.91 m/s be used for older pedestrians. This report found that walking rates were influenced by more than a dozen factors, including street width, vehicle and pedestrian volumes, weather, crosswalk markings, stop lines, and the use of pedestrian signals.

Two papers presented at the 1995 Transportation Research Board (TRB) Annual Meeting included studies on pedestrian walking speeds. Virkler et al. examined and developed methods to determine appropriate pedestrian crossing times at signalized intersections. Their paper, "High-Volume Pedestrian Crosswalk Time Requirements," included three alternative guidelines for recommended crossing time. These guidelines related walking speed with walking distance, time required for crossing, and delay in stepping off the curb. They also factored in the effects of pedestrian volume and platoon flow. Their conclusions noted that while adequate methods exist for determining low-volume pedestrian crossing times, a "shock-wave" approach is a reliable check in determining adequate crossing times for high pedestrian volumes. This shock-wave approach was delineated by an equation that accommodated two-way platoons with constant headways.

In their 1995 TRB presentation, "Walking Speeds of Elderly Pedestrians at Crosswalks," Coffin and Morrall found a range of walking speeds and mobility levels for people over age 60. Factors that seemed to affect walking speed included traffic conditions, fatigue, intersection type, and trip purpose. They suggested design walking speeds of 1.0 m/s for midblock crosswalks and for signalized intersections near elderly populations. A design walking speed of 1.2 m/s for elderly pedestrians was suggested for other signalized intersections.

CURRENT PRACTICES

The purpose of this review was to determine the types of signals and technologies currently in use.

Commercially Available Pedestrian Signal Equipment

Currently, incandescent lamps are the most common illumination source for traffic signals. However, this technology is widely believed to be inefficient when compared to other light sources and has higher maintenance and energy costs. The output from incandescent lamps also tends to degrade as the lamp ages, making them less bright. Alternatives to incandescent lamps are neon, fiber-optic (FO), and light-emitting diode (LED) technologies.

Given the higher costs associated with incandescent signals, use of energy-efficient LED's was a primary consideration in designing the comprehension and visibility studies. One of the goals of the pedestrian signal study was to examine the viability of using red and green colors as alternatives to the MUTCD and ITE standard orange and white. Recent work by Corbin, Janoff, and Lewin (1995) has examined the ability of LED's to meet current color and intensity standards. Their findings indicated that red and orange signals are currently feasible and that LED orange is within the ITE definition for pedestrian signal Portland orange. Red and orange-red LED's meet ITE standards for red signals, but apparently are outside the orange range acceptable for pedestrian signal standards. Red LED pedestrian signals are currently manufactured and were obtained as test stimuli for the visibility portion of our study.

LED "white" is currently being produced by varying the power to each chip within a packet of 660-nm (red), 555-nm (green), and 470-nm (blue) chips. At the time of this review, the status of white-and-green LED pedestrian signals is unclear. However, Corbin et al. report that several LED manufacturers plan to release a deep green LED that may not meet ITE standards. They note that "mixing these deep green LED's with blue LED's within the same package would most likely result in an acceptable signal green." Similar to the production of white LED's, use of these LED packages could produce an ITE green.

Several manufacturers and distributors were contacted to obtain information on the scope of commercially available pedestrian signals. As noted above, current technologies include incandescent lamps, neon, FO, and LED's. With the exception of the LED red, the only colors of commercially available pedestrian signals in North America are orange and white. The Canadian equivalent of the walking man and hand symbols are obtainable from some distributors.

FO and LED signals are typically available in 30.5-cm sizes and can be purchased as retro-fit kits that allow jurisdictions to use their current signal housing. Since LED's are not yet commercially available in white, the orange DON'T WALK message is replaced with the retro-fit kit and the white incandescent WALK is retained.

With its layered message panels, FO signals can also use a single section head, which is reputed to provide cost-efficiency by requiring half the number of heads as incandescent signals. This technology is available in symbolic and text indications and uses only one 42-W lamp per message. Message colors in lunar white and Portland orange are within ITE specifications. FO signals also provide even illumination under all ambient lighting conditions and do not readily produce phantom effects.

Solid-state and transformer neon pedestrian signals are commercially available in 30.5-cm symbolic and text messages. Like LED's, this technology also offers greater energy-efficiency than incandescent lamps and reportedly has lower maintenance costs. According to one manufacturer, neon pedestrian signals produce very few, if any, phantom effects. Another manufacturer provides annual cost data where solid-state neon pedestrian signals are less than half the cost of incandescent signals per signal head.

Audible pedestrian signals are available from at least one manufacturer. According to specification sheets, these signals meet California and Canadian MUTCD standards. Their "messages" are conveyed by the production of widely used bird tones such as "cuckoo" and "peep peep" sounds. Since the primary objective of this study was to examine the visibility of pedestrian signals, audible pedestrian indicators were not tested.

Pedestrian Signal Use

A telephone interview was developed to solicit information regarding in-use signal hardware types, maintenance practices, and any positive or negative experiences that might be addressed by performance criteria. Contacts were made with manufacturers and distributors of traffic signals, and with transportation agencies (table 2).

Table 2. Respondents to current STS use telephone interviews.

Transportation Agencies	Manufacturers and Distributors
Chicago DOT	Econolite
Connecticut DOT	Minnesota Mining and Manufacturing Co. (3M)
D.C. Department of Public Works	Electro Fiber Optics Corp.
Delaware DOT	Tesco
Maryland DOT	Traffic Products Inc.
Virginia DOT	
FHWA Traffic Operations	

From the information gathered from the interview respondents, the following conclusions were drawn about pedestrian signals: (1) the conventional incandescent lamp is the typical installation and (2) several locations have used FO and LED signals. Sources in Connecticut reported greater maintenance efforts with the FO signals. A Chicago representative was pleased with the visual performance of the LED and FO signals because of the absence of the "phantom effect." When the sun was on the signal, only the lighted symbol was visible.

FIELD STUDIES AND VIDEO QUESTIONNAIRE OF PEDESTRIAN SIGNAL VISIBILITY AND COMPREHENSION

INTRODUCTION

Many factors can affect pedestrian crosswalk behavior. The ability of pedestrians to recognize crosswalk signals can be a function of equipment characteristics such as signal size, signal luminance levels, viewing distance, and environmental conditions, including sun position and surrounding complexity. Pedestrian comprehension of crosswalk signals can depend upon individual differences such as cognitive functioning, experience, visual acuity, and the assimilation of surrounding cues, including the actions of vehicular and other pedestrian traffic.

All of these elements can influence pedestrian behavior. While observational studies of pedestrian behavior are interesting, they cannot conclusively determine the recognizability of a signal nor reveal a pedestrian's understanding of its message. Pedestrians use many prompts for determining whether or not to cross a street and signal utilization is not always a factor. Observational data may lead to inferred comprehension when, in fact, a pedestrian may correctly cross a street simply because others are doing so. In addition, compliance or non-compliance with a signal may or may not indicate signal comprehension. Only in situations where pedestrians reverse their direction at a mid-crossing signal change can one suspect pedestrian confusion.

Three studies were conducted to test the legibility and comprehension of pedestrian signals. The first study was a preliminary static field study that tested the visibility of symbolic pedestrian signals using a mock-up apparatus. The second pedestrian signal visibility study was a controlled static field study and required subjects to view an array of actual pedestrian signals at several prescribed distances. The third study was a video questionnaire designed to test pedestrian comprehension using videotaped intersections with various simulated pedestrian signals. Finally, a walking speed study was completed to determine whether the current MUTCD standard is adequate for elderly crossing times.

PRELIMINARY STUDY OF PEDESTRIAN SIGNAL VISIBILITY

During 1994, static field studies were conducted to test the visibility of symbolic traffic signals (STS). Primarily designed to determine the minimum required luminance for the legibility of vehicular STS's, symbolic pedestrian signals were also tested in a preliminary, non-comprehensive study. These tests served as a building block to the more thorough examination of actual pedestrian signals reported in this chapter. A detailed account of the vehicular STS static field studies may be found in the project's final report on *Photometric Requirements for Symbolic Traffic Signals*.

Subjects

A total of 60 subjects participated in the nighttime portion of the preliminary pedestrian signal study and 75 subjects viewed the signals under daylight conditions (table 3). Several performance tests were used to screen each subject's perceptual and cognitive processes to assess acuity, contrast sensitivity, color deficiencies, and cognitive functioning.

Table 3. Subject age statistics.

	Age Range	Mean Age	Daytime n =	Nighttime n =
Young	19-40	25	31	41
Old	60-78	70	29	34

Apparatus and Stimuli

Actual size, mock-up STS's were used in this study. Three "light boxes," each containing a set of 12 lamps, housed the light sources and stimuli. The lighting systems within the boxes were interfaced with, and controlled by, a laptop computer that turned the lamps on and off many times per second. The ratio of on-time to off-time controlled the luminous intensity of the lamps. The boxes contained two banks of lamps: (1) a bank of low-intensity lamps, mainly for use at night, and (2) a bank of large high-intensity daytime lamps. The low-intensity nighttime lamps were used in pairs and could be modulated throughout a range of intensities. However, the four daytime lamps were controlled individually and were either fully on or fully off. In order to maintain a uniform luminance across the symbol, it was necessary to also use the daytime lamps in pairs.

Six stimuli were mock-ups of WALK and DON'T WALK in both solid and dot outline forms. These styles were made to represent symbols for incandescent and fiber-optic/light-emitting diode (FO/LED) technologies, respectively. The solid white walking man and orange hand were shown in two sizes: 15 cm and 23 cm. Small dots were used to create an outline of a 15-cm white walking man and a 23-cm orange hand. The 15-cm mock-up signals were viewed at 18.3 m, while the 23-cm signals were presented at a distance of 27.4 m. These viewing distances correspond to the MUTCD standards noted earlier. No other signal colors were tested in the preliminary study.

In order to assess signal visibility, subjects were asked to determine the orientation of the pedestrian signal symbol. For the symbolic man, subjects indicated whether the man was facing left or right. The symbolic hand was shown as either a left or right hand and subjects determined its orientation by noting the location of the thumb.

Results

Our findings indicated that the greatest problem in legibility was for the dot outline signals, especially for older subjects during the day. At a distance of 18.3 m, 33 percent of the older subjects could not distinguish the walking man orientation for dot outline symbols at any luminance level tested. Only 3 percent of the subjects less than age 40 had this difficulty with the same stimulus at the same viewing distance.

At first glance, it may appear that older subjects did not understand the task instructions and were simply confused as to whether the dot outline walking man was facing left or right. However, task comprehension did not appear to be a problem in distinguishing symbol orientation for the continuous walking man. All of the older subjects reached threshold legibility at 27.4 m for the continuous symbol and at least 93 percent were able to distinguish orientation of the continuous walking man at 18.3 m.

It is possible that the difficulty with the dot outline walking man may simply be due to the mock-up nature of the signals. Although the dimensions of the dot outline symbol mask were in accordance with current manufacturing standards, the use of incandescent lamps with this mask, rather than fiber optics or LED's, may have contributed to possible muddiness or insufficient brightness. The maximum luminance tested with the mock-up apparatus was 2200 cd/m^2. Different results may have been obtained with higher luminance from commercially made signal equipment.

For threshold legibility, the photometric results from this preliminary study suggested that the solid symbolic hand required an average of 65 cd/m^2 and the solid symbolic man required about 103 cd/m^2. The equivalent signal intensity to provide these luminances at the longest distance of 27.4 m would be about 1.2 cd based on the formula provided in the project's final report on visibility requirements. These early results showed no difference in the luminance required at the two distances for any of the technologies or symbols, which would be expected since signal size was adjusted to maintain the same size image on the retina.

Because the mock-up apparatus provided no phantom from the signals that were not illuminated, the luminance requirements may well have been underestimated. Additional testing of actual pedestrian signals appeared to be warranted so that realistic phantom effects could be assessed. This testing would also include the effects of signal technology, color, size, and viewing distance.

1995 VISIBILITY FIELD STUDY AND VIDEO QUESTIONNAIRE

Based on the results of the preliminary field study, two studies were conducted a year later to test pedestrian signal visibility and comprehension. The static field study used actual pedestrian signal equipment and tested the visibility of text and symbol indications in three signal technologies at various distances during the day. The video questionnaire study tested the comprehension of current and innovative pedestrian indicators in five colors, using both text and symbols.

Elderly Subjects

Forty-eight seniors, age 62 or older, were recruited for participation in the visibility, comprehension, and walking speed studies. Many of the subjects had participated in previous research projects and had originally been contacted through their volunteer groups, churches, and senior organizations. Elderly subject age statistics are shown in table 4.

Table 4. Older subject age statistics (n = 48).

		Mean	Standard Deviation	Range
Age:		72	4.9	62 - 82
	Male (n=29)	72	4.6	65 - 82
	Female (n=19)	71	5.2	62 - 79

Walking Speed

Each of the elderly subjects participating in the pedestrian signal studies were requested to walk 18.3 m along a marked length on an asphalt parking lot near the visibility study test site. Subjects were requested to walk at a "normal street-crossing speed" and to imagine they were using a crosswalk at a signalized intersection on a five-lane urban street. Each subject was timed individually with a stopwatch.

As shown in table 5, the mean walking speed for this group of subjects was 1.45 m/s, which is well above the MUTCD standard of 1.22 m/s. Only five subjects, or 10 percent, were unable to walk the distance in 1.22 m/s. However, two of these subjects were within one-tenth of the standard. A sixth subject barely met the standard with a time of 1.24 m/s. Confirming results from other studies, men tended to walk faster than women. Interestingly, there were no significant age differences ($df = 2$, $p = 0.94$); walking speeds were widely distributed across the range of ages in the elderly group.

Table 5. Mean and 15th percentile walking speeds for older subjects (in meters per second).

	Mean	Range	15th percentile
Total (n = 48)	1.45	1.81 - 0.98	1.26
Male (n = 29)	1.48	1.81 - 1.20	1.26
Female (n = 19)	1.40	1.81 - 0.98	1.20

Table 5 also presents the 15th percentile walking speed in meters per second, which is the speed that 85 percent of the subjects exceeded. Compared to Knoblauch's 1993 study, our 15th percentile score for total older subjects is closer to the average 15th percentile speed for Knoblauch's younger pedestrians (1.19 m/s) than to Knoblauch's older subject average 15th percentile speed of 0.92 m/s.

Figure 1 depicts the cumulative distribution of percentiles for the total older subject group. While the shape of the distribution curve of this walking speed data is comparable to the results attained by Knoblauch et al. (1993), the walking speeds for our older subjects appear to be faster than both Knoblauch's older "complier" group and Knoblauch's combined data from an ITE sample and a comparable subset from his study.

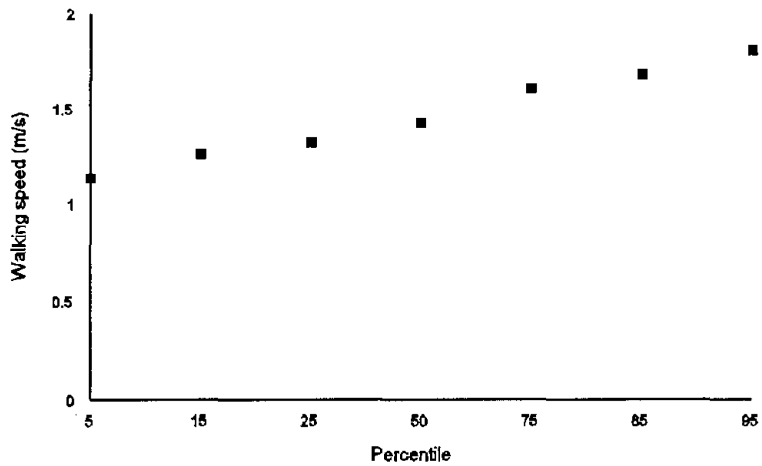


Figure 1. Cumulative distribution of percentile values for walking speed (n = 48).

Recommendations. Although the MUTCD standard appears to be easily met by 90 percent of the elderly subjects tested, these findings may not represent a typical population of seniors. Many of the retirees in the State College, Pennsylvania area are quite active and none appeared to have impairments that would have affected gait or balance. In addition, walking speeds tend to vary based on pedestrian volume and context. Neither of these factors were replicated in the test walk since subjects were timed individually and the "street" surface was flat and smooth with no curbs to be negotiated. In addition, there was no vehicle traffic to affect the subject's pace or divert their attention. Finally, the effects of adverse weather on walking speed were not tested; each day of testing was warm and sunny.

Based on these results, it is believed that the current MUTCD standard is probably adequate for most elderly pedestrians under optimal conditions. Further recommendations would not be appropriate given the limited testing circumstances.

Young Subjects

Forty-three school-age subjects, ranging in age from 11 to 15, participated in the video questionnaire study (table 6). These subjects were recruited through local youth organizations, including the Boy Scouts and swim teams. The age range was selected as being the most representative of child pedestrians unaccompanied by a parent and not yet able to drive.

Table 6. Mean age and school grade distribution for younger subjects (n = 43).

		Mean Age	GRADE 5	6	7	8	9
TOTAL		13	9	11	7	10	6
	Boys (n=22)	12.8	5	7	4	4	2
	Girls (n=21)	13.3	4	4	3	6	4

The comprehension of signals by this population is important in terms of pedestrian safety since this group can easily be independent of adult supervision and adult experience. Since driver's education is typically taught to high school sophomores, the oldest grade of the younger subjects was ninth grade. Older, non-driving high school subjects were not used in order to control for the possible effects of driver training that may include the teaching of pedestrian signals.

STUDY 1. VISIBILITY OF ACTUAL PEDESTRIAN SIGNALS

The field study of actual pedestrian signal visibility was necessitated by the fact that the preliminary study had several inadequacies. First, the mock-up traffic signals apparently had insufficient luminance for testing dot matrix signal designs. Because of the small area of the dots and the narrow stroke width they presented, a much higher luminance was needed for target recognition than that needed with continuous incandescent signals. The mock-up apparatus was unable to generate sufficient luminance for recognition by older subjects. For this reason, the data obtained with dot matrix symbols were not representative of what could be obtained from commercially available LED or fiber-optic signals. Second, the design of the mock-up signals created no phantom effect. This resulted in the intensity requirement for recognition being understated for incandescent signals. With incandescent signals, a significant phantom is generated that results in a much higher intensity requirement to overshadow the phantom effect.

One of the objectives of the field study was to test the daytime visibility of 7.6-cm letters and 15.2-cm symbols at distances greater than the 18.3-m standard. As stated in the 1988 MUTCD, crossing distances greater than 18.3 m require the use of 22.9-cm symbols or 11.4-cm letters. Another objective of the controlled static field study was to determine the daytime visibility of actual pedestrian signals at various voltage settings. In general, even across technologies, operating at lower voltages will reduce power consumption and increase lamp life. The degree of these effects will vary across technologies. Specifically, the study was designed to determine which signals were visible to older pedestrians when the signal voltage was set at 100 percent, 75 percent, and 50 percent of full power and produced various levels of signal intensity.

Site Selection, Apparatus, and Stimuli

The site for this study was a large, infrequently used parking lot owned by the local Army Reserve unit that is conveniently accessible to the pool of elderly subjects.

Actual pedestrian signals obtained from manufacturers as well as non-standard signals were mounted at recommended MUTCD heights, relative to the seated observers. Both symbol and text signal indications were used as test stimuli despite the proposed MUTCD changes that would phase out the word legends WALK and DON'T WALK. As a side note, the MUTCD Signals Committee has recently called for research on the proper maximum distance for pedestrian symbol legibility. While 7.6-cm text in 22.9-cm housing was originally recommended for a maximum of 18.3 m, the symbolic indications in these same housings were twice the height of the letters (15.2 cm), making them substantially more visible.

In our visibility study, several signal heads, 22.9-cm and 30.5-cm rectangular signal housings, and two round RAG signals with symbol masks were used. The signals were powered by a portable generator and the voltage from the generator was controlled by a variable transformer. Chromaticity measurements were taken at the voltage levels used in the study and showed that although the color of the signals changed slightly, they remained within ITE color-definition boundaries. Before installing the signal heads at the field test site, the incandescent lamps were seasoned according to Illuminating Engineering Society (IES) LM-54 to achieve stable intensity. Because there appears to be no standard practice, the same type, wattage, and name brand of incandescent lamp (Phillips 116 W) was used in all incandescent-type signal heads, including the 22.9-cm and 30.5-cm rectangular housings and round RAG signals.

Table 7 lists the test stimuli by signal configuration (type/size/color), technology, and subject group assignment. The test stimuli included eight standard configurations and four innovative configurations with two sizes each of a green walking man symbol and a red hand symbol. Fiber-optic test stimuli were displayed in 30.5-cm rectangular housing and were standard pedestrian text and symbol configurations in orange and white. All LED configurations were also in 30.5-cm housing and included a standard orange hand, a red hand used as an actual pedestrian signal, and an experimental green walking man. The color of the experimental LED could best be described as a pale yellow-green that did not match the RAG green in hue, saturation, or brightness. Two non-regulation signals were also displayed as catch-trials or "dummy" signals: a 15.2-cm orange walking man and a 15.2-cm white hand. These signals were included to prevent subjects from correctly guessing the signal message by color recognition alone. The 19 test stimuli are identified in table 7 with the two catch-trial signals indicated by shading. Signal size relates to the height of the housing and not letter or symbol height.

Table 7. Subject group assignment of test stimuli.

	Signal Stimulus	F/O	LED	Incandescent
30.5-cm signals	White Man	1		1 and 2
	Orange Hand	1	1	1 and 2
	Green Man		1 and 2	
	Red Hand		2	
	White WALK	2		1 and 2
	Orange DON'T WALK	2		1 and 2
22.9-cm signals	White Man			2
	Orange Hand			2
	White WALK			1
	Orange DON'T WALK			1
	Green Man (RAG)			1 and 2
	Red Hand (RAG)			1 and 2
	Orange Man			1 and 2
	White Hand			1 and 2

Estimation of Signal Intensity

In order to quantify the signal intensities of the various signals tested in this study, the Luminance-to-Intensity method developed by Finkle (1996, in press) was used. Measurements of all stimuli were taken with a Minolta LS-110 luminance meter at the three different voltage levels used in the study. These measurements were taken at night in order to minimize the error that can be introduced by high ambient light levels.

The measurement procedure required that the signals be measured from a different location than the distances used for subject observation. This was due to the limitations of the luminance meter, which had an aperture too small to fully encompass the signal stimuli at the observer location. Therefore, the intensity measurements were taken at 53.4 m from the signals, although the observers were located at either 18.3 m or 29.3 m. The signal heads were mounted at 1.7-, 2.0-, and 2.3-m heights off the ground, relative to the center of the signal head. The luminance meter and observer eye height was approximately 1.2 m. Therefore, the maximum angular offset from optical center of the signal stimuli was 3.3 deg at 18.3 m and 1.1 deg at 53.4 m. Due to the light-emitting characteristics of the signals, the measured intensities were slightly greater than the intensity actually reaching the observers. This intensity difference is rather small due to the fact that the angular difference is only 2.2 deg. However, it does indicate that any minimum intensity level estimated from the field data will be slightly conservative, thus erring on the side of safety.

Procedure

The 19 pedestrian signals were evaluated at the maximum crosswalk length of 29.3 m and at the 18.3-m distance used for the MUTCD signal size standard. Although the smaller signal heads were used at distances greater than the recommended 18.3 m, our reasons for doing so were twofold: (1) pedestrian signal manufacturers claim that the 7.6-cm letter height signals are visible to 61 m and (2) by using the smallest signal size with the longest possible crosswalk length, we created a worst-case scenario for testing signal recognition.

The elderly subjects were randomly divided into two groups. Each group of subjects viewed a selection of signals that were common to both groups as well as viewing a handful of signals that were unique to a particular group. For practical purposes, all signals were not shown to both groups since this would have significantly increased the overall length of the test session.

The signal array was capable of holding 14 pedestrian signal heads. After all subjects in the first group completed the study, the signals unique to group 1 were removed from the array and the group 2 signals were installed. The signal array was divided into two viewings by covering half of the array with black felt. This was done to reduce subject confusion by limiting the number of pedestrian signal head choices during a presentation. Groups of two to four elderly subjects were taken to the 29.3-m mark to view the signals. The 29.3-m distance is roughly equivalent to an eight-lane highway, which was previously determined to be the longest crosswalk length that would not require the use of a second signal at a midway pedestrian island.

Instructions and Training. Each subject was given an answer sheet (appendix A) and asked to identify the signal's location in the array and the signal's display configuration (WALK, DON'T WALK, walking man, or hand), and to assess the signal's brightness on the following scale:

1 = Nothing On
2 = Could Guess
3 = Certain On
4 = Clear
5 = Too Bright

A practice signal was energized at full voltage to train the subjects in the use of the answer sheet and to ensure subject understanding of the brightness categories. If the subject decided that nothing was on, they were instructed to not complete the location and message items.

Testing. After the instructions, seven of the signals were randomly presented at the lowest voltage level of 60 V from a distance of 29.3 m. Each signal was displayed one at a time until all subjects had made a response to location, message, and brightness. The responses were logged by the experimenter and the next signal was shown. In order to determine the presence of any phantom effects, a blank signal trial was also administered within the random order for a total of eight trials at each voltage level.

After all of the signals were shown at the first voltage level, the level was raised to 90 V and the procedure was repeated with a different random order of the eight test stimuli. A third randomization of the eight trials was next presented at 120 V. Once the signals on one side of the array were viewed at all three voltage levels, the side was obscured and the remaining side was uncovered and the procedure was repeated. In order to control for any fatigue or learning effects across subject groups, the array side first seen was alternated from one day to the next. By alternating sides, the effects of learning the task and using the answer sheet would be washed out across signal arrays. Similarly, subject groups would not always be seeing the same signal array at the end of the experimental session when fatigue may affect their answers.

Once all of the subjects were shown all of the signals from 29.3 m at all voltages, they were moved to the 18.3-m distance and the procedure was repeated for only the 22.9-cm signal heads. As before, the test stimuli and blank trials were randomly ordered. The array was first viewed at the lowest voltage level, then at 90 V, and again at 120 V. When all 22.9-cm signals were shown at the three voltage levels, the study was finished.

Ambient light levels were assessed at the beginning and the end of a test session using a Minolta T-1 hand-held illuminance meter. Test sessions were generally conducted between 11:45 a.m. and 2:30 p.m. with the sun overhead during the month of June. Only one day had intermittent clouds and most sessions had illuminance levels over 90,000 lux. By keeping the sun overhead and not directly hitting the signals, it was hoped that "phantom effects" would be reduced. Thus, any blank trials that resulted in a signal mistakenly being "seen" would be a more powerful indication that phantom effects are a significant problem.

Experimental Design

The visibility study used an incomplete 3 (technology) x 2 (symbol vs. text) x 2 (size) factorial design as shown in table 8. Some of the conditions were tested in a repeated-measures design, while others were tested between groups as shown in table 7. Color comparisons could be made for red vs. orange hand within the LED technology and the comparison of the orange hand could be made across all three technologies—FO, LED, and incandescent. Signal size could be compared within technologies, and both the FO and incandescent technologies could be compared for symbol vs. text. The independent variables were distance and signal intensity (which was controlled by voltage levels). Their effects on the visibility of each signal type were assessed.

Table 8. Experimental design.

	Incandescent				F/O		LED	
	Symbol (cm)		Text (cm)		Symbol (cm)	Text (cm)	Symbol (cm)	Text (cm)
	22.9	30.5	22.9	30.5	30.5	30.5	30.5	30.5
White	X	X	X	X	X	X		
Orange	X	X	X	X	X	X	X	
Red	X						X	
Green	X						X	

Visibility Study Results

The results of the visibility study were first analyzed in terms of the percent correct and the percent uncertain responses, each with respect to different size signals and different technologies. Because the effect of voltage level is not linear with signal intensity across different technologies and sizes of signals, all other analyses were done using signal intensity as the dependent variable. Comparisons were made of signal sizes, technologies, text vs. symbols, and phantom effects.

Percent Correct Responses

The visibility data were analyzed by calculating the percent of subjects correctly identifying the message of the signal that was energized. These results appear in table 9. Since increases in voltage can produce a higher intensity for any given signal, an increase in voltage resulted in an increase of correct responses. At 29.3 m, all of the FO signals were correctly identified across the three voltage levels, which confirms the suspicion that the mock-up used in the preliminary study did not have sufficient luminance. The 22.9-cm incandescent signals also performed well at both distances. Only two of these signals were missed by anyone at 29.3 m for the lowest voltage and none of the 22.9-cm incandescent signals was missed at 18.3 m. Of the two missed signals, only 2 percent (one subject) missed the 22.9-cm green man and 17 percent missed the 22.9-cm red hand. Since these two stimuli appeared as masks on RAG traffic symbols, the results may be an artifact of signal construction and are not due to color or technology.

Table 9. Percent correct, percent uncertain, and percent too bright for three voltage levels (overbright percentages included as superscripts).

	% Correct Message 29.3 m			% Uncertain 29.3 m			% Uncertain 18.3 m		
	Voltage			Voltage			Voltage		
	60	90	120	60	90	120	60	90	120
Incandescent Signals:									
22.9-cm Orange DON'T WALK	100	100	100	0	0	0	0	0	0
22.9-cm Orange Hand	100	100	100	8	0	0^{16}	4	0^{4}	0^{4}
22.9-cm White WALK	100	100	100	21	0	0	0	0	0
22.9-cm White Man	100	100	100	17	0	0^{4}	13	0	0^{8}
22.9-cm Green Man	98	100	100	27	0	0^{4}	13	0	0^{4}
22.9-cm White Hand	100	100	100	21	2	0	6	0	0^{4}
22.9-cm Orange Man	100	100	100	4	0	0^{4}	0	0^{4}	0^{8}
22.9-cm Red Hand	83	100	100	33	2	0^{4}	10	0^{8}	0^{8}
30.5-cm Orange Hand	88	100	98	38	0	0			
30.5-cm White Man	44	96	100	81	15	0			
30.5-cm Orange DON'T WALK	100	100	100	4	0	0^{4}			
30.5-cm White WALK	100	100	100	23	2	0			
LED Signals:									
Experimental Green Man	31	81	92	81	25	12			
30.5-cm Orange Hand	67	100	100	50	0	0			
30.5-cm Red Hand	63	92	100	58	25	0			
Fiber-Optic Signals:									
30.5-cm Orange Hand	100	100	100	0	0	0^{8}			
30.5-cm White Man	100	100	100	4	0	0^{8}			
30.5-cm White WALK	100	100	100	0	0	0^{4}			
30.5-cm Orange DON'T WALK	100	100	100	4	0	0^{4}			

Only three signals operating at 90 V resulted in any incorrect responses. These were the 30.5-cm experimental green LED man (at 22.6 cd), the 30.5-cm red LED hand (at 6.5 cd), and the incandescent 30.5-cm white man (at 14 cd). The experimental green LED man had the greatest inaccuracy with 20 percent missed at 90 V and 8 percent missed at full power (120 V). Only six signals performed poorly at the lowest voltage. These signals included the 30.5-cm incandescent symbols (orange hand and white man), the 30.5-cm LED symbols (orange hand and red hand), the experimental LED, and the 22.9-cm incandescent red hand noted above.

Percent Uncertain Responses

Table 9 also shows that all of the signals resulted in zero uncertainty at 120 V, with the exception of the experimental green LED man that was dropped from further consideration because of its poor overall performance. Subsequent analyses examined whether the responses were less than certain or whether the signals were judged too bright. An uncertain response was defined as a rating of 2 or less, i.e., the subject responded "nothing on" or "could guess." At 90 V, only the 30.5-cm incandescent white man, the 30.5-cm LED red hand, and the experimental LED resulted in more than 2 percent (one subject) being uncertain at 29.3 m. At 18.3 m, none of the 22.9-cm signals resulted in any uncertainty when operated at 90 V; 30.5-cm signals were not viewed at the shorter distance.

For signals judged "Too Bright," table 9 identifies those stimuli where at least 4 percent of the subjects used this rating. Four percent represents only 2 subjects among the full sample of 48 subjects and represents 4 subjects for signals tested by only half of the full sample. The decision to not include overbright signals rated by fewer subjects was arbitrary and was done to help focus attention on those stimuli where glare may be a problem. With few exceptions, judgments that the signal was too bright were confined to tests at 120 V.

In general, 90 V appears to provide a signal intensity that minimizes the frequency of both overbright and uncertain responses. This seems to be true for all of the signals tested, regardless of size, technology, or whether the message is symbol or text. Other analyses were conducted with respect to signal intensity and are described in later sections.

Incandescent 22.9-cm and 30.5-cm Signals

The amount of uncertainty and overbright response ratings for 22.9-cm and 30.5-cm incandescent signals are shown in table 10. At 60 V, all of the signals—except the orange DON'T WALK—produced some uncertainty. As will now be discussed, voltage is clearly not a reliable independent variable for evaluating these results. The comparisons shown in table 10 indicate that the 30.5-cm signals resulted in a higher rate of uncertainty than the 22.9-cm signals, and the uncertainty was much higher in the case of the two symbolic signals. Responses to the 30.5-cm white man were uncertain for 15 percent of respondents at the 90-V setting, which is about equal to the frequency of uncertainty for the 22.9-cm white man signal at the 60-V setting. The explanation may be found by referring to the estimated signal intensities shown in table 10. All four of the 30.5-cm signals had lower intensities than their 22.9-cm counterparts. In the case of the 30.5-cm incandescent white man, the intensity at 60 V was only 2 cd, compared with 8 cd for the 22.9-cm incandescent white man signal. The performance of the 30.5-cm incandescent signals was undoubtedly an artifact of using the same wattage lamps as were used in the 22.9-cm incandescent signals.

Table 10. Uncertainty (U) and intensity (I) for 22.9-cm and 30.5-cm incandescent signals at 29.3 m (overbright percentages included as superscripts).

	22.9-cm Signals						30.5-cm Signals					
	60 V		90 V		120 V		60 V		90 V		120 V	
	U (%)	**I (cd)**	**U (%)**	**I (cd)**	**U (%)**	**I (cd)**	**U (%)**	**I (cd)**	**U (%)**	**I (cd)**	**U (%)**	**I (cd)**
Orange Hand	8	14	0	66	0^{16}	175	38	5	0	22	0	58
White Man	17	8	0	45	0^{4}	111	81	2	15	14	0	41
Orange DON'T WALK	0	25	0	134	0	353	4	17	0	106	0^{4}	270
White WALK	21	10	0	62	0	173	23	9	2	37	0	204
Green Man	27	5	0	27	0^{4}	85						
White Hand	21	14	2	66	0	175						
Orange Man	4	10	0	50	0^{4}	139						
Red Hand	33	3	2	14	0^{4}	38						

For the 22.9-cm signals, intensity is correlated with uncertainty. As intensity increases, uncertainty decreases. The correlation between the percentage of people who were uncertain and the intensity of the 22.9-cm signals at 60 V was -0.79. Examination of the intensity for each 22.9-cm signal operated at 60 V revealed that the only signal with a 0 percent uncertainty had an intensity of 25 cd. Furthermore, none of the incandescent signals tested at any voltage level that produced an intensity greater than 24 cd resulted in anyone being uncertain in their response, except for the non-standard 22.9-cm white hand.

Using the 30.5-cm signals to cross-validate a criterion of 25 cd resulted in two errors among the test stimuli. One of these errors was a false positive, while the other was a false negative. A false positive results when a signal greater than 25 cd results in uncertain responses. The 30.5-cm white WALK signal at 90 V had an intensity of 37 cd and only 2 percent of respondents (one subject) were uncertain in their identification of its color or message.

In addition to that one false positive, there was also one false negative. A false negative occurs when a signal with an intensity less than 25 cd does not result in any uncertainty. This occurred with the 30.5-cm orange hand at 90 V. Its intensity was only 22 cd and it received no uncertain responses. Since false negatives result in energy wasted without any reduction in safety, the 25-

cd criterion appears to be justified as a minimum intensity specification for incandescent pedestrian signals.

The results for overbright signals are not so clear. One signal with an intensity of only 38 cd resulted in 4 percent of the subjects rating the signals too bright at 29.3 m. Only the incandescent orange hand resulted in a larger percentage of overbright responses. Its intensity of 175 cd resulted in 16 percent of the subjects judging the signal overbright. However, table 11 shows that this signal resulted in only 4 percent overbright responses at 18.3 m. Since fewer people judged the same signal overbright at a closer distance, we would conclude that the overbright rating may not be very reliable. While 25 cd provides a very reasonable minimum requirement, a maximum value of 100 cd would appear justifiable. This would remove many of the overbright signals reported at 29.3 m, while still providing four times the intensity needed for certain recognition by all subjects.

Table 11. Uncertainty and intensity for 22.9-cm incandescent signals at 18.3 and 29.3 m (overbright percentages included as superscripts).

	Intensity (cd)			% Uncertainty 18.3 m			% Uncertainty 29.3 m		
	60 V	**90 V**	**120 V**	**60 V**	**90 V**	**120 V**	**60 V**	**90 V**	**120 V**
Orange Hand	14	66	175	4	0^{4}	0^{4}	8	0	0^{16}
White Man	8	45	111	13	0	0^{8}	17	0	0^{4}
Orange DON'T WALK	25	134	353	0	0	0	0	0	0
White WALK	10	62	173	0	0	0	21	0	0
Green Man	5	27	85	13	0	0^{4}	27	0	0^{4}
White Hand	14	66	175	6	0	0^{4}	21	2	0
Orange Man	10	50	139	0	0^{4}	0^{8}	4	0	0^{4}
Red Hand	3	14	38	10	0^{8}	0^{8}	33	2	0^{4}

Comparison of 22.9-cm Signals at 18.3 and 29.3 m

Although the inverse square law would suggest that the intensity requirement at 18.3 m would be less than the 25-cd requirement at 29.3 m, a reduction in the minimum intensity required is limited by the phantom effect from the other signals. At closer distances, pedestrians will be unable to discriminate which signal is energized because a lower minimum required intensity would appear to be less than the phantom intensity of unlit signals. The data from this study suggest that this appears to have happened. The inverse square law would suggest that if 25 cd were needed at 29.3 m, 10 cd would provide the same illumination at 18.3 m. However, some of the signals that were greater than 10 cd resulted in a significant amount of uncertainty at 18.3 m, suggesting that the level of their illumination may have been too close to the phantom intensity of other signals.

The intensity of phantom signals was not measured. To be useful, such measurements would have to be taken continuously throughout the study and a value would have to be associated with each subject response in order to reflect the changes in ambient conditions during daylight due to passing clouds and the change in sun position. Time constraints and project resources did not allow for this to be done.

Table 11 above shows the signal intensity for each 22.9-cm signal at each of three voltage levels and the percent of uncertainty at 18.3 and 29.3 m. If 25 cd is used as the minimum specification, there would be no false positives for standard signals. However, if 10 cd was used as the minimum required intensity for 18.3-m intersections, then several of the stimuli meeting this standard would produce some uncertainty. Even at 14 cd, the orange hand and white hand had uncertainty in their responses. This result may be due to the phantom intensities that are more discernable at closer distances.

All of the signals with intensities of 25 cd or greater resulted in a zero level of uncertainty, except for the non-standard white hand at 66 cd and 29.3 m where one subject reported uncertainty. There were three false negatives, i.e., cases where no uncertain responses occurred for intensities less than 25 cd. These were the white WALK and orange man at 10 cd and the red hand at 14 cd.

Comparison of Technologies

The incandescent, FO, and LED technologies were compared using the results of the 30.5 cm signals at 29.3 m. A summary of these results is shown in table 12. Because the experimental procedure included the presentation of all technologies in a single session, LED's and FO signals had to compete with the higher phantom effects from incandescent signals. While the 25 cd criterion seems to be applicable to all technologies, it is very likely that lower intensities would be required if incandescent phantom signals were not present.

Table 12. Uncertainty and intensity for 30.5-cm signals at 29.3 m (overbright percentages included as superscripts).

	Intensity (cd)			% Correct Message			% Uncertain		
	60 V	**90 V**	**120 V**	**60 V**	**90 V**	**120 V**	**60 V**	**90 V**	**120 V**
30.5-cm Incandescent Signals:									
Orange Hand	5	22	58	88	100	98	38	0	0
White Man	2	14	41	44	96	100	81	15	0
Orange DON'T WALK	17	106	270	100	100	100	4	0	0^{4}
White WALK	9	37	204	100	100	100	23	2	0
30.5-cm FO Signals:									
Orange Hand	21	91	216	100	100	100	0	0	0^{8}
White Man	12	44	103	100	100	100	4	0	0^{8}
White WALK	15	68	166	100	100	100	0	0	0^{4}
Orange DON'T WALK	19	73	176	100	100	100	4	0	0^{4}
30.5-cm LED Signals:									
Orange Hand	1.4	20	63	67	100	100	50	0	0
Red Hand	1.3	6.5	22	63	92	100	58	25	0

With the exception of the incandescent orange DON'T WALK, the only 30.5-cm signals rated overbright were the four FO signals operated at greater than 100 cd. Even the white WALK at 204 cd did not produce any overbright ratings. Obviously, with a higher wattage lamp, the other incandescent signals may also have provided overbright ratings at 120 V. One reason FO signals may be judged more overbright at lower intensity levels than incandescent signals is that the small area of their image results in a greater luminance and may appear to irradiate.

These findings confirmed the hypotheses generated by the preliminary study. First, FO signals require much more intensity than the maximum intensity of the mock-up signals to produce the luminance needed. Second, the 1- to 2-cd intensity needed for identification of the incandescent signals in the preliminary study was an artifact of not having to deal with phantom effects. With the phantom produced by actual signals, the intensity required is much higher than that suggested by the preliminary study.

Phantom Effects

As mentioned earlier, phantom images from signals that were not energized have the effect of raising the threshold intensity above what it would be if phantom images were not present.

Responses on trials when no signal was energized were analyzed to determine which signals were most often incorrectly thought to be energized. Randomly ordered blank trials were tested at each of the three voltage levels for each half of the signal array. Thus, six blanks were presented at 29.3 m and three blanks were presented at 18.3 m.

The two blank trials during the 60-V presentations at 29.3 m resulted in 21 incorrect responses that a signal was energized. Twelve phantom images for two blanks were detected during the 90-V presentations at 29.3 m and eight incorrect responses occurred for the two blanks shown during the 120-V presentations at 29.3 m. Thus, as voltage and signal intensities increased, the percentage of incorrect responses decreased. This trend was repeated for the three blank trials presented at 18.3 m where a total of eight phantom responses occurred. At higher intensity levels, subjects were better able to discern the difference between an energized signal and a phantom effect.

Of the 41 incorrect responses that a non-energized signal appeared lighted at 29.3 m, 30 responses were attributed to incandescent signals and 11 responses were given for the LED signals. For both viewing distances, the orange symbol and text presented the vast majority of phantom images for the incandescent signals with 23 incorrect responses. None of the FO signals was incorrectly identified during the blank trials, indicating the absence of phantom effects for this technology. These results suggest that if FO signals had been tested alone, the minimum intensity requirement would have been set much lower than 25 cd. The absence of any phantom effect from these signals would result in a lower threshold intensity.

It should be noted that the full array of signals was never viewed at the same time by the subjects. However, it appears that 30.5-cm signals had greater phantom effects than their 22.9-cm counterparts when viewed at 29.3 m. When only 30.5-cm signals were exposed, 25 phantom responses were reported. Contrastingly, only 10 phantom responses were given for the 22.9-cm signals in the array that contained six 22.9-cm signals and one 30.5-cm LED signal. An additional six phantom responses were attributed to the LED signal. At 18.3 m, the LED presented no phantom effects. It is unknown whether fewer 22.9-cm signals would have been incorrectly identified as energized if they had been viewed with the other half of the signal array containing 30.5-cm signals. Further study on the phantom effects of signal size, color, and technology appears to be indicated.

Symbol Versus Text Comparison

Since all of the FO signals performed very well, there were no meaningful differences between the text and symbol versions. Among the incandescent signals, the text versions resulted in much less uncertainty than the symbol versions. This difference can again be explained by examining signal intensity; both the orange and white symbol 30.5-cm signals had only about one-third the intensity of the text versions. A similar observation can be made of the 22.9-cm signals.

Recommendations

The results of the visibility study clearly suggest that a minimum intensity of 25 cd will be adequate for any pedestrian signal regardless of technology, distance, signal size, or text vs.

symbol. The data further suggest that 22.9-cm incandescent signals provide sufficient visibility with fewer phantom effects than 30.5-cm signals. If either LED or FO signals are used, the required minimum intensity will undoubtedly be lower than 25 cd and a maximum intensity would need to be established to avoid overbright signals. However, another study using only LED and/or FO signals will be necessary to establish these levels.

STUDY 2. COMPREHENSION OF PEDESTRIAN SIGNALS

The primary objective of the video questionnaire was to test pedestrian comprehension of actual and innovative pedestrian signals. Past research has included use of paper-and-pencil measures to determine comprehension of pedestrian signals. However, these types of questionnaires require the respondent to either imagine the signal indication or to respond to static, two-dimensional graphics. The advantage of a video questionnaire is its ability to present stimuli in a more realistic format.

Site Selection

For the elderly subjects who concurrently participated in the visibility study, the location of the video questionnaire was a classroom in the building adjacent to the visibility test site. Most of the younger subjects viewed the video in the same classroom or in a room at a local church. The older subjects were tested in small groups of 2 to 4, while up to 15 children participated in a test group at one time.

Stimuli and Symbol Selection

The test stimuli included current in-service and innovative signals. By using a video questionnaire, a variety of innovative stimuli could be tested in a non-risk environment. Most of the innovative signals in the video questionnaire were symbolic and many were presented in non-standard colors such as green, yellow, and red.

The decision to primarily test symbolic signals was based on David Kuemmel's presentation at the 1995 TRB Annual Meeting. At that time, Kuemmel reviewed the evolution of pedestrian signals and reported that the next revision of MUTCD may require symbolic pedestrian signals only. This revision would be based on the latest recommendation of the National Committee on Uniform Traffic Control Devices. Since the MUTCD may be phasing out pedestrian text signals, our main focus was to develop alternative symbols that could be more easily understood than the existing hand and walking man. Despite the apparent move to symbolic signals, we also included one example of innovative text—DON'T START—in the test stimuli.

Overall, 45 signals were created for the comprehension study and were presented in two different contexts. One context placed the subject on the curb, while the second context was a midway street crossing. The mid-crossing context presented a transition from one signal message to another, such as WALK to a flashing DON'T WALK, while the curb context presented only one message per stimuli. Current in-service signals included text WALK and DON'T WALK and the symbolic walking man (figure 2) and hand (figure 3). Innovative signals included a steady and flashing text "DON'T START" and a steady and flashing standing man (figure 4). Both of these indications were the equivalent of a flashing DON'T WALK or flashing hand in meaning. A steady "slash man" was also tested (figure 5). This signal was equivalent to the MUTCD R9-3a "No Pedestrian Crossing" sign and was used to symbolize "DON'T WALK."

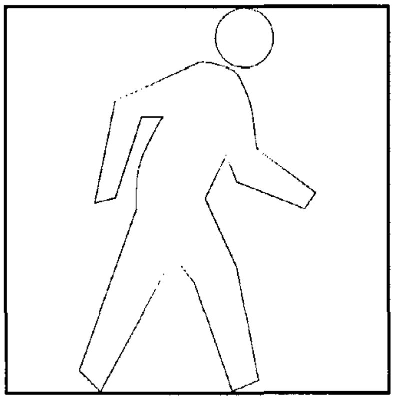


Figure 2. Walking man.

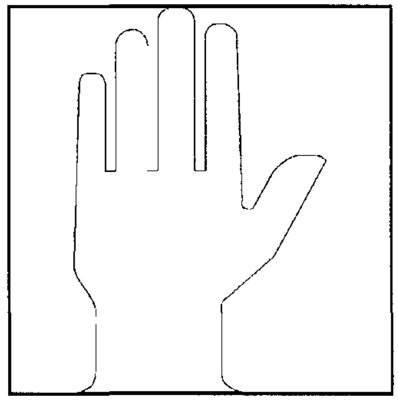


Figure 3. Hand.

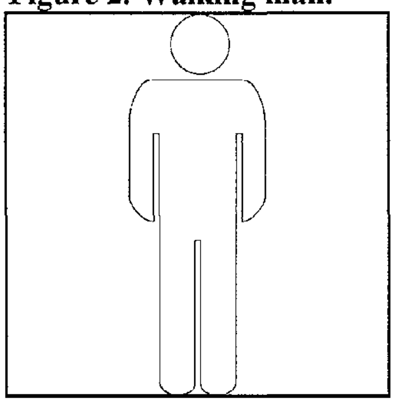


Figure 4. Standing man.

Figure 5. Slash man.

Finally, two versions of circular red-amber-green (RAG) signals were also used as test stimuli. One set of RAG's contained the standard, non-louvered round lenses, while the second version contained a standing man symbol superimposed on each colored lens. Its meaning was to show that the RAG was a pedestrian signal and not a vehicular traffic signal. The standing man RAG was not intended to symbolize DON'T WALK.

Apparatus

Using a video capture board, several video-recorded signalized intersections were digitized and used as background for the test stimuli. The test stimuli were created with a graphics software program and included text and symbol signals in white/orange, green/red, and yellow. The test stimuli were then overlaid onto the digitized background image using video-editing software. This software also allowed for the incorporation of a voiceover track and on-screen instructions. The voiceover was used to provide additional direction and context for the subjects.

Procedure

Before viewing the video questionnaire, each subject completed a short questionnaire to collect data on their familiarity with pedestrian signals. A variety of signals are installed throughout the State College, Pennsylvania area, including flashing textual WALK signals and the use of circular RAG traffic signals as pedestrian signal heads. However, symbolic pedestrian signals are not present at any of State College's signalized intersections. For this reason, subjects were asked how often they traveled outside of State College and how often they were pedestrians in large cities. Those subjects who traveled extensively were assumed to have experienced both symbolic and text pedestrian signals.

Instructions and Training

After completing the paper-and-pencil questionnaire on their travel history, each group of subjects was seated in the viewing classroom and given instructions and an answer sheet on which to record their responses. Subjects were told to not discuss their responses out loud and were instructed to provide the *meaning* of each signal, not how they would *behave* upon viewing the signal. The videotape was started by the experimenter who remained in the classroom. A voiceover provided additional instructions on how the respondents should complete their answer sheet and discussed the procedure.

A steady white WALK was first shown as a sample training stimulus. Prior to its appearance, the screen and the voiceover stated, "You are standing on the curb. What does the following signal mean?" After the signal was shown, the screen and the voiceover presented the instructions, "Please answer Sample Question 1." Within a few seconds, the voiceover provided the correct answer to the sample training question: "The answer to the sample question was A. It's okay to cross." The videotape then paused to allow time for the subjects to ask questions of the experimenter. A second sample question showing an orange flashing DON'T WALK and illustrating mid-crossing signals was then presented in a similar manner.

Testing

Before viewing each stimulus, the voiceover and the screen provided the upcoming signal context, such as "You are standing on the curb. What does the following signal mean?" or "You are halfway across the street. What does the following signal change mean?" After viewing the signal, both the screen display instructions and the voiceover informed the subjects to make their response. The videotape then paused to allow time for the respondents to record their answers.

All answers were multiple choice. Piloting of this procedure helped determine the number of choices and determined whether the same choices should be provided for both presentation contexts. The following choices were provided for the "curb" signals:

A. It's okay to cross.
B. Wait on the curb.
C. Hurry across the street.
D. Don't know.

A somewhat different set of choices, listed below, were provided for the mid-crossing context:

A. It's okay to keep crossing.
B. Turn around and go back.
C. Hurry across the street.
D. Don't know.

Additional piloting occurred before final production of the video to determine the most appropriate voiceover script.

Experimental Design

The 25 test stimuli that were "viewed" from the curb appear in appendix B. Appendix C is a listing of those stimuli that were shown in the mid-crossing context. Transition A represents a change from a "walk" display to a caution or "don't start" display. Transition B indicates the change from a caution or "don't start" presentation to a "don't walk" display. A total of 20 mid-crossing stimuli were tested.

Although the steady WALK and flashing DON'T WALK were used as training samples, they were also repeated as a test/retest measure of viewer understanding. A total of 45 randomly ordered test stimuli were presented to the subjects on the video questionnaire. Each stimuli took approximately 30 s for a complete viewing and answering cycle, thus yielding a 45-min video questionnaire, including the sample instructions.

Comprehension Study Results

Travel History

For current, in-use signals, signal familiarity was based on age and travel history. All innovative signals were considered to have low familiarity. Based on their responses to being a pedestrian in a large city, subjects were classified as having high, moderate, or low exposure to symbolic pedestrian signals. The high-experience group reported they were city pedestrians "frequently" or "a lot." Subjects with moderate experience reported that they were "sometimes" city pedestrians. The low-exposure group reported that they were "never" or "rarely" pedestrians in cities. For the purposes of this study, subjects were told that a city was defined as a large, east coast metropolitan area, such as Pittsburgh, Philadelphia, Washington, D.C., New York City, or Boston. Table 13 shows the frequency distribution of pedestrian experience in cities.

Table 13. Distribution of experience as a city pedestrian.

	OLD n=48	YOUNG n=43	TOTAL n=91
Low	14	10	24
Moderate	19	24	43
High	15	9	24

It would appear that both age groups would have strong signal familiarity with different signal types. Less than 30 percent of each age group would be considered a low-frequency city pedestrian. For those subjects who are rarely or never city pedestrians, a low familiarity with current symbolic pedestrian signals was anticipated and would be demonstrated by lower comprehension scores.

Analysis of Curb Signals

"It's Okay to Cross." Six of the signals displayed at the curb were intended to convey the message that it was permissible to start crossing the street. These green and white signals were shown in a steady mode and included the following:

Standard Signals	Innovative Signals
white WALK	green WALK
white walking man	green walking man
	green RAG (solid circular green)
	green RAG with standing man symbol

For analysis purposes, the subject responses were scored as 0, 1, or 2 for each signal. Answer B ("Wait on the curb") was given a score of 0, as was answer D ("Don't know"). A score of 2 was assigned to answer A ("It's okay to cross") and was considered to be the most correct response. Choice C ("Hurry across the street") was given a score of 1 since the respondent knew that crossing was permitted. However, this choice was not regarded to be the most accurate or best answer to a walk signal.

At least 90 percent of the subjects gave the most correct answer of "it's okay to cross" for all of the signals. If "hurry across the street" is also considered to be a correct response, then only the two RAG signals had fewer than 98 percent correct responses (table 14). Using a Friedman non-parametric test, the results indicated no significant differences between green vs. white, and text vs. symbol. Of the six signals tested, the white walking man had the lowest mean ranked score, although both green RAG signals had more "wrong" answers. Ten percent of the older subjects interpreted the green standing man RAG to mean "wait on the curb." Presumably, this may be due to the ambiguity of the standing man symbol, which possibly conveyed a "wait" meaning rather than indicating the RAG to be a pedestrian signal. Although it is possible to rank the walk stimuli, there was no significant difference across all signals ($p = 0.857$).

Table 14. Percent correct responses to curb walk signals.

Signal	% Correct
White WALK	100
Green WALK	100
Green Walking Man	100
White Walking Man	98.9
Green RAG	94.5
Green Standing Man RAG	93.4

The Mann-Whitney U non-parametric test was used to detect any effects that may be due to age. No significant differences were found between age groups for any of the signals except for a slight significance with the white walking man ($p = 0.053$). Ninety-six percent of the older subjects gave the "best" answer of "it's okay to cross," whereas only 84 percent of the younger subjects reported this signal to have this meaning. Fourteen percent of the younger subjects understood the signal as "hurry across the street."

"Wait on the Curb." Nineteen signals displaying the message "wait on the curb" were shown from the curb perspective. Responses to the signals were scored either 0 or 1, with the only correct response, "wait on the curb," scored as a 1.

Yellow Wait Signals. Since the color yellow is not used in standard pedestrian signals, all of the yellow test signals were considered to be innovative. No innovative text was tested with the yellow signals, which included the following:

Steady	Flashing
yellow hand	yellow hand
yellow standing man	yellow standing man
yellow walking man	
yellow RAG (solid circular amber)	
yellow RAG with standing man symbol	

Non-parametric tests were again used to determine whether there were significant differences between signals and between age groups. The Friedman test indicated no differences between flashing and steady signals for either the hand or standing man symbols. There were also no significant differences between either of the yellow RAG signals. However, there were significant differences ($p < 0.001$) across all yellow curb signals, with the yellow steady hand ranked highest among the seven test stimuli (table 15).

Table 15. Ranking of yellow wait signals based on percent correct responses.

Signal	"Wait on curb"	"OK to cross"	"Hurry across"	"Don't know"
Steady Hand	65.9	3.3	26.4	4.4
Flashing Hand	53.8	17.6	22.0	6.6
Steady RAG	51.6	5.5	33.0	8.8
Flashing Standing Man	45.1	12.1	36.3	6.6
Steady Standing Man RAG	41.8	23.1	25.3	9.9
Steady Standing Man	28.6	65.9	2.2	2.2
Steady Walking Man	2.2	75.8	19.8	2.2

Given the low percentage of correct responses, there appears to be significant viewer difficulty in yellow signal comprehension. Only the steady hand, flashing hand, and solid RAG had more correct responses than wrong responses. Noted above, the yellow walking man performed the worst. Over 75 percent of the subjects reported its meaning as "it's okay to cross."

Significant age effects were also found using the Mann-Whitney U non-parametric test. Older subjects gave significantly more correct responses to four of the signals: flashing hand ($p = 0.001$); steady hand ($p = 0.000$); steady standing man ($p = 0.041$); and steady RAG ($p = 0.004$). The younger subjects scored better than the seniors on only the poorly understood walking man signal, but not at a significant level ($p = 0.133$). The differences in age groups can possibly be attributed to the younger subjects having greater confidence in their ability to hurry and probably greater risk-taking behavior in a "caution" display mode. However, this interpretation assumes younger subjects were responding on the basis of how they would behave and not reporting their interpretation of the signal's meaning.

Based on these results, it would appear that the use of the color yellow in pedestrian signal messages would not be meaningful enough to hold pedestrians at the curb. The results indicate that yellow is frequently understood as "caution" or "hurry" and not "wait." More than 50 percent of the young subjects thought four of the yellow signals meant "hurry across the street"; these were steady hand, solid RAG, flashing standing man, and standing man RAG.

Orange Wait Signals. Innovative text and innovative symbols were tested in orange curb-viewed wait signals. The eight test signals included flashing and steady presentations and are listed below:

Standard Signals	Innovative Signals
orange steady hand	orange steady DON'T START
orange flashing hand	orange flashing DON'T START
orange steady DON'T WALK	orange steady standing man
orange flashing DON'T WALK	orange steady "slash man"

A Friedman non-parametric test indicated no significant differences across all eight signals ($p = 0.584$). A ranking of the orange wait signals based on total correct responses is shown in table 16.

Table 16. Ranking of orange wait signals based on percent correct responses.

Signal	"Wait on curb"	"OK to cross"	"Hurry across"	"Don't know"
Steady DON'T START	98.9	0.0	0.0	1.1
Steady DON'T WALK	97.8	2.2	0.0	0.0
Steady Hand	96.7	1.1	0.0	2.2
Steady Slash Man	96.7	1.1	0.0	2.2
Flashing DON'T START	95.6	0.0	2.2	2.2
Steady Standing Man	91.2	6.6	1.1	1.1
Flashing DON'T WALK	87.9	2.2	9.9	0.0
Flashing Hand	82.4	3.3	13.2	1.1

Although it is tempting to draw conclusions from a ranking of the signals, it must be kept in mind that there was no significant difference between the most comprehensible signal and the lowest ranked signal ($p = 0.116$). However, if one were to set a safety criteria that 90 percent of pedestrians must understand a signal's message, then two of the standard signals currently in use would not meet criteria based on this study's sample. Interestingly, both of these signals were in the flashing mode.

Analyses to determine the effects of age and pedestrian experience were also conducted using the Mann-Whitney U non-parametric test. With the exception of the steady "slash man" and the steady standing man, older subjects demonstrated greater comprehension of the orange signals than did the younger subjects. These differences were significant for the flashing hand ($p = 0.015$).

Young subjects scored significantly better on the steady standing man ($p = 0.040$). More than 12 percent of the older subjects thought the steady standing man meant it was okay to cross or hurry across the street. As noted in earlier discussions, the standing man symbol appears to have enough ambiguity that color does not always override its perceived message.

The age effects found with the flashing hand and the steady standing man do not appear to be related to city pedestrian experience. No significant differences were found between high and low pedestrian signal exposure for either signal using the Mann-Whitney U non-parametric test. There were also no significant differences within an age group between high and low experience.

Red Wait Signals. Of the four red signals used in the video questionnaire, all would be considered non-standard and two used innovative symbols (the slash man and the standing man). None of the red signals employed text to convey the meaning "wait" and none were tested in the flashing mode.

<u>Non-Standard Signals</u>

red steady "slash man"
red steady RAG (solid circular red)
red steady RAG with standing man symbol
red steady hand

Overall, the red innovative signals performed superbly in conveying the "wait" message. At least 95 percent of the total subjects understood each signal and 100 percent of the young subjects correctly understood the red steady hand and red solid RAG. Using the Friedman non-parametric test, no significant differences were found between the steady "slash man" and the steady hand. There were also no significant differences found between the two RAG signals. More notably, the four red signals are virtually interchangeable with almost no difference between any of them ($p = 0.988$). The Mann-Whitney U non-parametric test revealed no age effects.

Given the performance results for the other colors for the standing man, hand, and RAG signals, the understandability of these red signal messages is most likely due to the powerfulness of red, which is so easily associated with the meaning, "stop." A between-color analysis of the 19 wait signals is presented below and shows additional support for the strength of red in conveying a wait message when viewed from the curb.

Between-Color Analysis of Wait Signals. Several of the symbolic curb-viewed wait signals were created with more than one color to analyze the effects of color on signal comprehension. Friedman non-parametric statistical tests were used to determine whether there were any significant differences between signals that displayed the same symbol and mode, but varied in color. Since the steady hand was tested in yellow, orange, and red, separate Friedman tests were completed on each possible pairing of colors and across all three colors. The results of the Friedman tests are illustrated in table 17.

Table 17. Between-color analysis based on mean rank score.

Signal	Mean Rank Score Yellow	Orange	Red	Significance
Steady Hand	1.68	2.14	2.18	p = 0.001
	1.35	1.65		p = 0.003
	1.34		1.66	p = 0.002
		1.49	1.51	p = 0.834
Steady Standing Man	1.18	1.82		p = 0.000
Flashing Hand	1.36	1.64		p = 0.006
Steady Slash Man		1.50	1.50	p = 1.00
Steady RAG	1.27		1.73	p = 0.000
Steady Standing Man RAG	1.23		1.77	p = 0.000

Of the two red signals that shared a common symbol and mode with orange, there were no significant differences. For the steady "slash man," the differences between red and orange were non-existent (p = 1.00). Thus, these colors appear to be interchangeable in meaning when coupled with either the "slash man" or the steady hand. Yellow signals performed significantly worse than either orange or red within symbol and mode.

When all 19 curb wait signals are entered together in the Friedman test, yellow signals group conspicuously at the bottom of the rank order (table 18). When the yellow signals were removed from the data analysis, no significant differences were found between any of the 12 orange and red signals (p = 0.80).

The yellow signals were intended to be equivalent in meaning to the flashing orange or red signals. However, yellow's effectiveness is considerably worse than all of the flashing orange or red signals, particularly for the young subjects. Noted earlier, fewer than 40 percent of the young observers correctly understood any of the yellow signals to mean "wait on the curb."

Table 18. Rank order of all curb wait signals, using the Friedman non-parametric test based on mean rank score.

Signal	Mean Rank Score
Red Steady Hand	12.25
Orange Steady DON'T START	12.25
Orange Steady DON'T WALK	12.14
Red Steady RAG	12.14
Orange Steady Hand	12.03
Red Steady Slash Man	12.03
Orange Steady Slash Man	12.03
Red Steady Standing Man RAG	11.93
Orange Flashing DON'T START	11.93
Orange Steady Standing Man	11.61
Orange Flashing DON'T WALK	11.18
Orange Flashing Hand	10.65
Yellow Steady Hand	9.26
Yellow Steady RAG	7.87
Yellow Flashing Hand	7.87
Yellow Flashing Standing Man	7.23
Yellow Steady Standing Man RAG	6.91
Yellow Steady Standing Man	5.63
Yellow Walking Man	3.07

Conclusions. Our objective in conducting the video questionnaire was to test the comprehension of innovative and standard pedestrian signals. In designing the innovative signals, we varied color, symbol, and mode.

Symbol vs. Text. As the reader may recall, the only comparisons between symbol and text for the same signal meaning were for the walk signals and for the orange wait signals. Since no significant statistical differences were found between symbol and text, one may infer that comprehension is basically the same. However, the DON'T WALK and DON'T START were slightly more understandable than the hand and "slash man." These differences are negligible and may be an artifact of a subject sample that is more familiar with text messages. When text is paired with the flashing mode, the meaning of the text signal is more clear than a flashing symbolic signal.

The innovative standing man was generally the least successful of all the symbols and may contribute to greater pedestrian confusion, especially when paired with a weakly understood color such as yellow. Its use on a traffic RAG to indicate that the signal is for pedestrians may have also increased ambiguity since its meaning on the non-RAG signals was intended to mean "wait." Further study could show this symbol to be more powerful if its meaning was not compromised by dual use within the same questionnaire.

The more promising of the innovative symbols is the "slash man." It performed well with either red or orange and its comprehension was virtually the same as with the hand. Comprehension of the "slash man" may also be reinforced by pedestrians who recognize this symbol on traffic signs. Intuitively, the "slash man" may be more opposite in its meaning to the walking man since the slashed circle is widely known to mean "no." Thus, if the walking man means "walk," then the slashed circle over a walking man would mean "no walking."

If the "slash man" is used as a symbolic pedestrian signal, then greater flexibility can occur with the use of innovative colors. One of the commonly held arguments that red should not be used as a pedestrian signal is the possibility that motorists may confuse the pedestrian signal with the traffic signal. This argument is strengthened by the use of the symbolic hand, which may appear as a ball of color due to glare or halation. Since the critical detail of a "slash man" is outlined rather than solid, there is less likelihood that this pedestrian symbol would halate and be interpreted as a vehicular traffic signal.

Color. Red and green colors were tested for several signal types in an effort to provide information on the feasibility of their use given the energy savings of non-incandescent technology. When only color was varied, practically no differences in comprehension were found between green and white or between orange and red. Since no adverse color effects were found for red or green, reconsideration of these colors for use in pedestrians signals may be warranted. Red appears to have an especially strong meaning of "wait" and can override the ambiguity of symbols. Although red was not tested in a flashing mode, future studies may wish to determine whether red can also counteract the confusing effects of flashing and promote better understanding of signals that appear in this mode.

Innovative signals were also tested in yellow. As discussed earlier, this color lacked the ability to convey a wait message and presented the greatest confusion of all the signals tested. It is strongly recommended that this color not be used as a substitute for either red or orange. A more innovative application of yellow pedestrian signals is to consider their use in a three-color-phase presentation, whereby yellow would convey its more typical meaning of "hurry" or "caution." For example, a steady yellow hand or standing man could replace the flashing orange hand, which would then change to a steady red hand or slash man.

Flashing vs. Steady Mode. Although there were no significant differences between flashing and steady modes within a signal type, flashing signals were generally less understandable than steady signals. Since fewer than 90 percent of the subjects understood two of the flashing orange signals correctly, it would appear that this mode presents some difficulty. It is generally held that flashing pedestrian signals have historically been confusing. According to Kuemmel's 1995 TRB presentation, the flashing walk signal was dropped from the current MUTCD because of the ambiguity associated with the flashing message.

The results from this study may possibly be attributed to the continuing existence of flashing walk signals in the State College area. Thus, subject experience with a flashing WALK signal may confound their understanding of a flashing DON'T WALK signal. Given this caveat, it is difficult to make strong recommendations to reconsider the use of flashing signals, particularly given the lack of statistical significance.

Analysis of Mid-Crossing Signal Changes

"It's OK to Keep Crossing." Ten of the test stimuli displayed from a mid-crossing perspective showed a signal changing from a steady "walk" to a steady or flashing "don't walk" mode. The characterizations of these Transition A signals are listed below:

White to Orange	Green to Orange	Green to Yellow
WALK to flashing DON'T WALK	WALK to flashing DON'T START	Walking man to steady walking man
Walking man to flashing hand		Walking man to flashing hand
Walking man to steady standing man		Walking man to steady standing man
WALK to steady DON'T START		RAG to steady RAG
		Standing man RAG to steady standing man RAG

Subject responses to these signals were scored 0, 1, or 2. The "best" answer was scored a 2 and corresponded to choice A, "It's OK to keep crossing." A score of 0 was assigned to either "Turn around and go back" (choice B) or "Don't know" (choice D), since both of these answers indicated lack of signal comprehension. Choice C, "Hurry across the street," was scored as a 1 since subjects correctly understood that they should continue to cross, although hurrying was probably not necessary.

Table 19 shows the signals ranked according to percentage of total correct responses. The green walking man changing to the steady yellow walking man was ranked the highest with more than 96 percent of the subjects reporting the signal to mean continue to cross. Using a Friedman non-parametric test, no significant differences were found across all signals ($p = 0.10$), age groups, or between city pedestrian experience.

Table 19. Ranking of walk to don't walk mid-crossing signals based on total correct responses.

Ranking	Signal Description	% Correct
1	Green man to yellow man	96.7
2	Green RAG to yellow RAG	95.7
3	Green man to steady yellow standing man	91.2
4	Green man to flashing yellow hand	89.1
5	White WALK to flashing orange DON'T WALK	89.1
6	Green standing man RAG to yellow standing man RAG	89.0
7	White man to flashing orange hand	84.7
8	White man to steady orange standing man	80.3
9	Green WALK to flashing orange DON'T START	78.0
10	White WALK to steady orange DON'T START	78.0

Although the signals were not significantly different statistically, the results clearly point to some interesting trends. First, it would appear that green-to-yellow transitions convey a stronger message that pedestrians should continue to cross. Given the poor comprehension of yellow signals at the curb, this finding may be due to the overall weakness of yellow in having a significant meaning to pedestrians. The poorest performing curb signal, the yellow walking man, now emerges as one of the strongest mid-crossing walk-to-don't-walk transition signals. This reversal further supports the notion that the walking man symbol is closely associated with walking behavior and yellow does not significantly contribute to a don't walk message. Thus, the use of yellow in pedestrian signals may help pedestrians from unsafely returning to their curb of origin, but it will also not safely hold pedestrians at the curb.

A second trend worth noting is the relatively poor showing of current signals. Should a safety criterion of 90 percent comprehension be applied, then neither of the standard white-to-orange signals would meet this criterion (rankings 5 and 7). Friedman tests conducted within these white-to-flashing-orange signals found no significant differences between standard text and standard symbol ($p = 0.345$). There were also no differences found between other white-to-orange signals, including innovative text and standard text (rankings 10 and 5), innovative symbol and standard symbol (rankings 8 and 7), or between innovative text and innovative symbol (rankings 10 and 8).

Across all signals, there appears to be no overall effect for the flashing mode, although all of the flashing "don't walk" transitions performed below the 90 percent safety criterion. The DON'T

START signals, which had performed so admirably as curb signals, appear to be less understandable when appearing at a mid-crossing transition. Both of these innovative text signals had the lowest percentage of correct responses in either a flashing or steady mode. This finding was unexpected since it was hypothesized that the DON'T START would be powerful enough to "tell" subjects that since they are at mid-crossing and have already started, they should continue to cross. More than 12 percent of the total subjects reported not knowing the meaning of the green WALK to flashing orange DON'T START.

The most surprising finding was the percentage of subjects who thought three of the white-to-orange signal transitions meant "turn around and go back." Ten percent or more gave this response for the standard WALK to flashing DON'T WALK and for the standard walking man to flashing hand. Reported earlier, 13 percent reported this meaning for the white WALK to steady orange DON'T START. This result is particularly remarkable when one considers that the pedestrians have started their crossing on a walk signal and are at the halfway point of the intersection. The distance to their destination curb is no further than the curb they have left, yet many would reverse their direction. In reality, pedestrians may not turn back if they were at the halfway point, but this finding suggests a strong likelihood of turning back during mid-crossing signal transitions. This effect was especially true for older pedestrians and is even more apparent in the next set of mid-crossing signals—the caution-to-don't-walk transitions.

"Hurry Across the Street." The last 10 stimuli were signals viewed from a mid-crossing perspective as they changed from a steady or flashing "caution" to a steady "don't walk" mode. Five of these signals were symbolic and switched in color from yellow to red. The remaining signals were text or symbol transitions within orange:

Orange to orange	Yellow to red
Flashing DON'T WALK to steady DON'T WALK	Flashing hand to steady hand
Flashing hand to steady hand	Steady walking man to steady "slash man"
Flashing DON'T START to steady DON'T WALK	Steady RAG to steady RAG
Steady DON'T START to steady DON'T WALK	Steady standing man RAG to steady standing man RAG
Steady standing man to steady hand	Steady standing man to steady hand

Subject responses to these signals were also scored 0, 1, or 2, with a score of 0 again assigned to "turn around and go back" and "don't know." However, it was decided that the best answer for these mid-crossing signals was "hurry across the street" since this conveyed a higher level of understanding that the signal was in its last cycle phase. A score of 1 was given to "it's okay to keep crossing," which was also a correct response.

The results are probably best analyzed by examining the distribution of responses and assessing the overall comprehension of these signal types. Using this method, it becomes apparent that these signals presented a great amount of difficulty in comprehension. Based on the number of correct responses, only one of these signals would meet a 90 percent safety criterion—the yellow standing man RAG to red standing man RAG. More alarming is the percentage of subjects who erroneously believed the signals to mean "turn around and go back." Table 20 presents a ranking of these signals based on total percent correct responses and also shows the frequency distributions of subject responses. All RAG signals were shown in a steady mode.

Table 20. Ranking of Transition B signals based on total percent correct responses.

Rank	Signal	"Ok to keep crossing"	"Turn around"	"Hurry across"	"Don't know"	% Correct
1	Yellow standing man RAG to red standing man RAG	65.9	4.4	25.3	3.3	91.2
2	Yellow steady standing man to red steady hand	40.7	8.8	42.9	5.5	83.6
3	Yellow flashing hand to red steady hand	33.0	14.3	39.6	13.2	72.6
4	Yellow steady walking man to red steady "slash man"	26.4	18.7	44.0	9.9	70.4
5	Yellow RAG to red RAG	19.8	26.4	46.2	6.6	66.0
6	Orange flashing hand to orange steady hand	27.5	12.1	35.2	24.2	62.7
7	Orange flashing DON'T WALK to orange steady DON'T WALK	15.4	19.8	45.1	18.7	60.5
8	Orange flashing DON'T START to orange steady DON'T WALK	20.9	19.8	38.5	19.8	59.4
9	Orange steady standing man to orange steady hand	17.6	23.1	36.3	22.0	53.9
10	Orange steady DON'T START to orange steady DON'T WALK	18.7	19.8	31.9	28.6	50.6

Similar to the Transition A mid-crossing signals, this ranking indicates the apparent strength of yellow to carry the pedestrians through the intersection. All of the yellow-to-red innovative signals had a higher percentage of correct responses than the orange signals.

With all 10 signals entered, no significant differences were found between signal characteristics using a Friedman non-parametric test. Within the orange transitions, there were also no significant differences between the two standard signals—between the flashing and steady DON'T START signals, or between the two symbolic innovative signals. Similarly, no significant differences were found between the two yellow-to-red RAG's or between the yellow-to-red innovative symbolic signals.

Using Mann-Whitney U non-parametric tests, significant effects were found for age and city pedestrian experience. Across all 10 signals, the young subjects demonstrated greater comprehension and performed significantly better on the test stimuli appearing in table 21.

Table 21. Age effects for Transition B mid-crossing signals.

	Mean rank score		
Signal	**Young**	**Old**	**Significance**
Flashing orange DON'T WALK to steady orange DON'T WALK	51.14	41.10	p = 0.056
Flashing orange DON'T START to steady orange DON'T WALK	52.74	39.96	p = 0.013
Steady yellow walking man to steady red "slash man"	53.31	39.45	p = 0.007
Steady yellow RAG to steady red RAG	53.88	38.94	p = 0.004

The higher comprehension by the young subjects is largely attributed to the greater number of old subjects who reported that the signals meant "turn around and go back." Young subjects used this response more than old subjects on only one signal—the standard flashing orange hand to steady orange hand. On five of the test stimuli, more than 25 percent of the old subjects understood the signals to mean "go back," including the standard flashing orange DON'T WALK to steady orange DON'T WALK.

Significant differences were also found between high and low city pedestrian experience for both of the orange DON'T START to DON'T WALK signals (flashing: $p = 0.014$; steady: $p = 0.024$) and for the yellow standing man to red steady hand innovative signal ($p = 0.027$). For all of the signals, high city pedestrian experience scored higher, although the flashing yellow hand to steady red hand was ranked almost equally between high and low experience groups.

Conclusions. The most singular finding from evaluating the mid-crossing signals is the apparent paradoxical effect of yellow when compared to its performance in curb signals. Similarly, the standing man symbol emerges as a stronger message when viewed from a mid-crossing perspective. It can be argued that both of these signal characteristics have such weakness or ambiguity that their interpretation is overpowered by other signal cues. However, these results may also point to the viability of using a three-phase pedestrian signal cycle that more closely corresponds to vehicle traffic signals.

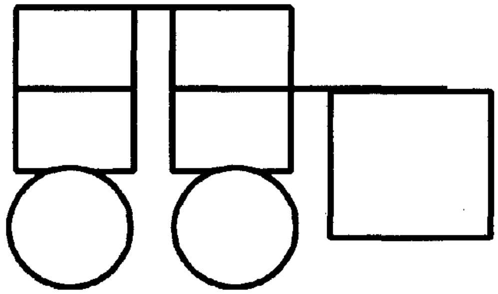
Recommendations

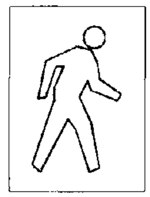
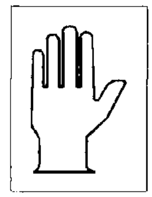
If the next revision of MUTCD pedestrian signal standards requires the use of symbolic messages only, then the evolution of these signals could include the green walking man, yellow standing man, and red "slash man" or hand. The results of this study clearly indicate the strength of red and green as contributing powerful messages to stop and go. Yellow may be too weak to prevent a crossing start, but appears to be useful in preventing the unsafe return to a curb.

Should text continue to be allowed as a pedestrian signal standard, the use of DON'T START needs to be carefully considered. When viewed from the curb, this message is as easily understood as the hand and is ranked above the current DON'T WALK. However, DON'T START performs poorly as a mid-transition signal. It ranked below all symbol and text signals for walk-to-caution transitions, and had fewer than 60 percent correct responses for the caution-to-don't walk modes. Based on these results, it is recommended that text messages remain as WALK and DON'T WALK.

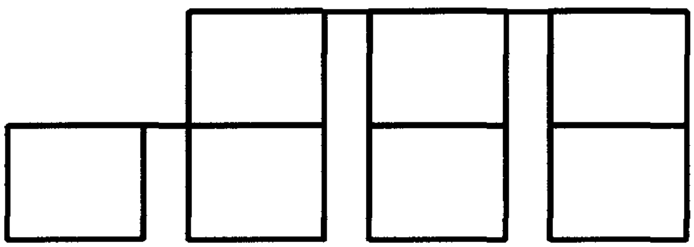
Observational field studies of these colors and symbols would be needed to determine their effects on pedestrian and motorist behavior. Although the video questionnaire allows a three-dimensional approach to evaluating signals, it also requires the use of the subject's imagination, particularly with the mid-crossing perspective. In addition, these results assumed that the subjects were responding as instructed and were providing their beliefs as to signal meaning and not how they would behave. Previous research has already noted that pedestrian behavior can be influenced by many factors. Thus, the results of the video questionnaire do not provide a complete basis for predicting actual pedestrian behavior in response to the test signals.

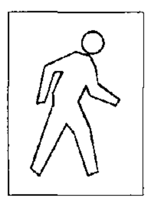
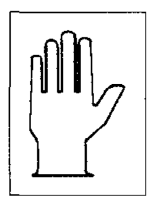
APPENDIX A. VISIBILITY PEDESTRIAN FIELD STUDY SUBJECT ANSWER SHEET



☐ DONT WALK ☐ WALK ☐  ☐ 

1	2	3	4	5
Nothing On	Could Guess	Certain On	Clear	Too Bright



☐ DONT WALK ☐ WALK ☐  ☐ 

1	2	3	4	5
Nothing On	Could Guess	Certain On	Clear	Too Bright

Preceding page blank

APPENDIX B. CURB VIEWING

Steady Mode

Color	Walking Man	Standing Man	Hand	Slash Man	WALK	DON'T WALK	DON'T START	RAG	RAG+SM*
White	x				x				
Green	x				x			x	x
Yellow	x	x	x					x	x
Orange		x	x	x		x	x		
Red			x	x				x	x

Flashing Mode

Color	Walking Man	Standing Man	Hand	Slash Man	WALK	DON'T WALK	DON'T START	RAG	RAG+SM*
White									
Green									
Yellow		x	x						
Orange			x			x	x		
Red									

* SM = Standing man

Preceding page blank

APPENDIX C. MID-CROSSING VIEWING

Transition A: WALK to CAUTION modes							
Signal #	**Color**	**Mode**	**Mask**	**Changes to**	**Color**	**Mode**	**Mask**
1	White	Steady	Walking Man	⇒	Orange	Steady	Standing Man
2	Green	Steady	Walking Man	⇒	Yellow	Steady	Standing Man
3	White	Steady	Walking Man	⇒	Orange	Flashing	Hand
4	Green	Steady	Walking Man	⇒	Yellow	Flashing	Hand
5	Green	Steady	Walking Man	⇒	Yellow	Steady	Walking Man
6	Green	Steady	RAG	⇒	Yellow	Steady	RAG
7	Green	Steady	RAG SM*	⇒	Yellow	Steady	RAG SM*
8	White	Steady	WALK	⇒	Orange	Flashing	DON'T WALK
9	White	Steady	WALK	⇒	Yellow	Steady	DON'T START
10	Green	Steady	WALK	⇒	Yellow	Flashing	DON'T WALK

*SM = Standing man

Preceding page blank

Transition B: CAUTION to DON'T WALK modes							
Signal #	**Color**	**Mode**	**Mask**	**Changes to**	**Color**	**Mode**	**Mask**
11	Orange	Steady	Standing Man	⇒	Orange	Steady	Hand
12	Yellow	Steady	Standing Man	⇒	Red	Steady	Hand
13	Orange	Flashing	Hand	⇒	Orange	Steady	Hand
14	Yellow	Flashing	Hand	⇒	Red	Steady	Hand
15	Yellow	Steady	Walking Man	⇒	Red	Steady	Slash Man
16	Yellow	Steady	RAG	⇒	Red	Steady	RAG
17	Yellow	Steady	RAG SM*	⇒	Red	Steady	RAG SM*
18	Orange	Flashing	DON'T WALK	⇒	Orange	Steady	DON'T WALK
19	Yellow	Steady	DON'T START	⇒	Orange	Steady	DON'T WALK
20	Orange	Flashing	DON'T START	⇒	Orange	Steady	DON'T WALK

*SM = Standing man

REFERENCES

Bailey, S.S., Jones, S.A., Stout, R.J., Bailey, J.H., Kass, S., and Morgan, J.B.B. (1991, December). *Issues of Elderly Pedestrians.*

Bryant, J.F.M. and Smith, G. (1976). "The Shape of Traffic Signal Arrows." *ARRB Proceedings, 8.*

Cairney, P.T. (1988, March). "Should the Flashing Man be Red or Green?" *Australian Road Research,* 18(1), 38-40.

Coffin, Ann and Morrall, John. (1995, January). *Walking Speeds of Elderly Pedestrians at Crosswalks* (Paper No. 950230). Washington, D.C.: Transportation Research Board 74th Annual Meeting.

Corbin, J., Janoff, M., and Lewin, I. (1995, April). "Requirements for Application of Light-Emitting Diodes (LEDs) to Traffic Control Signals." *Research Results Digest,* (205), 1-11.

Federal Highway Administration (in press). Revised edition of *Manual on Uniform Traffic Control Devices.* Washington, D.C.: U.S. Government Printing Office.

Institute of Transportation Engineers. (1985, March). "Pedestrian Traffic Control Signal Indications." *A Standard of the Institute of Transportation Engineers.*

Janoff, M.S. (1990a, March). *Review of Traffic Signal Intensity Standards.* NCHRP Final Report.

Janoff, M.S. (1990b, April). *Traffic Signal Intensity: A Synthesis of Human Factors and Visual Science Literature.* NCHRP Draft Report.

Knoblauch, Richard L., Nitzburg, Marsha, Dewar, Robert, Templer, John, and Pietrucha, Martin. (1993, December). *Older Pedestrian Characteristics for Use in Highway Design* (Final Report). McLean, VA: Federal Highway Administration.

Kuemmel, David A., P.E. (1995, January). *Pedestrian Signals and the MUTCD: Past and Current Changes.* Washington, D.C.: Transportation Research Board 74th Annual Meeting.

Lalani, N. and Baranowski, B. (1993, January). "Reducing Public Confusion About the Use of Pedestrian Signals." *Institute of Transportation Engineers Journal,* 63(1), 41-45.

Petzold, R.D. (1977, December). *Urban Intersection Improvements for Pedestrian Safety, Executive Summary* (Report No. FHWA-RD-77-142). Washington, D.C.: Federal Highway Administration.

Robertson, H.D. (1977, June). "Pedestrian Preferences for Symbolic Signal Displays." *Transportation Engineering*, 38-42.

Robertson, H.D. (1977). *Urban Intersection Improvements for Pedestrian Safety* (Report No. FHWA-RD-77-145). McLean, VA: Federal Highway Administration.

Smith, G. and Weir, R. (1978). "Laboratory Visibility Studies of Directional Symbols Used for Traffic Control Signals." *Ergonomics*, 21(4), 247-252.

Tidwell, J.E. and Doyle, D. (1993, December). *Driver and Pedestrian Comprehension of Pedestrian Law and Traffic Control Devices*. Washington, D.C.: AAA Foundation for Traffic Safety.

Virkler, Mark R., Elayadath, Sathish, and Saranathan, Geethakrishnan. (1995, January). *High-Volume Pedestrian Crosswalk Time Requirements* (Paper No. 950203). Washington, D.C.: Transportation Research Board 74th Annual Meeting.

Wagner, J. (1981). "Crossing Streets: Reflections on Urban Pedestrian Behavior." *Man-Environment Systems*, 11(1 and 2), 57-61.

Wiener, E.L. (1967). "Why Does a Pedestrian Cross the Street?" *Medicine, Science, and the Law*, 7(8), 117-122.

Zegeer, C.V., Opiela, K.S., and Cynekci, M.J. (1985). *Pedestrian Signalization Alternatives* (Report No. FHWA/RD-82/102). McLean, VA: Federal Highway Administration.

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 487-4650