**Traffic Control Devices Pooled Fund Study**

# Countdown Pedestrian Signals: A Comparison of Alternative Pedestrian Change Interval Displays

**Final Report**

**December 2004**




Prepared by:

Jeremiah P. Singer
Neil D. Lerner

Westat
1650 Research Blvd.
Rockville, MD 20850

This research project was sponsored by the Traffic Control Devices Pooled Fund Study, TPF-5(065). Members of the Pooled Fund Study Panel are as follows:

Gerry Meis, California Department of Transportation
Mark Wilson, Florida Department of Transportation
Keith Golden, Georgia Department of Transportation
Larry Gregg, Illinois Department of Transportation
Tim Crouch, Iowa Department of Transportation
Steven Buckley, Kansas Department of Transportation
John Smith, Mississippi Department of Transportation
Julie Stotlemeyer, Missouri Department of Transportation
Randy Peters, Nebraska Department of Transportation
Scott Thorson, Nevada Department of Transportation
Patt Ott, New Jersey Department of Transportation
Doug Bartlett, New Jersey Department of Transportation
David Woodin, New York Department of Transportation
Lori Cove, North Carolina Department of Transportation
Kenneth Williams, Pennsylvania Department of Transportation
Don Turner, South Carolina Department of Transportation
Greg Brinkmeyer, Texas Department of Transportation
Tom Notbohm, Wisconsin Department of Transportation
Roger Wentz, American Traffic Safety Services Association (ATSSA)
Lee Billingsley, Broward County, Florida Department of Transportation
John Fisher, Los Angeles, California Department of Transportation

Debra Chappell, Federal Highway Administration, Office of Safety
Butch Wlaschin, Federal Highway Administration, Office of Program Development
Scott Wainwright, Federal Highway Administration, Office of Operations
Joe Moyer, Federal Highway Administration, Office of Safety R&D
Bryan Katz, Science Applications International Corporation

The objective of the Traffic Control Devices Pooled Fund Study (TCD PFS) is to assemble a group composed of State and local agencies, appropriate organizations and the FHWA to 1) establish a systematic procedure to select, test, and evaluate approaches to novel TCD concepts as well as incorporation of results into the MUTCD; 2) select novel TCD approaches to test and evaluate; 3) determine methods of evaluation for novel TCD approaches; 4) initiate and monitor projects intended to address evaluation of the novel TCDs; 5) disseminate results; and 6) assist MUTCD incorporation and implementation of results.

To join the TCD PFS, or for more information about the TCD PFS
- Contact Joe Moyer at (202) 493-3370 or contact Scott Wainwright (202) 366-0857
- Visit www.pooledfund.org and search for study # TPF-5(065).

# ACKNOWLEDGEMENT

The authors would like to thank Bob Garbacz, Transportation Division Chief for the City of Alexandria, VA.  The contributions of Mr. Garbacz and his staff were invaluable to the conduct of the field study.

# EXECUTIVE SUMMARY

Countdown pedestrian signals (CPSs) can be used to supplement traditional pedestrian signals with flashing numbers that count down the number of seconds remaining until the end of the pedestrian change interval. The countdown is displayed during the pedestrian change interval, which is signified by a Portland orange flashing upraised hand, also known as the flashing DON'T WALK (FDW). Investigations of CPS effectiveness have generally concluded that CPSs provide pedestrians with useful information that helps them to cross the street more successfully. However, pedestrian comprehension of the concurrent flashing hand is relatively poor and compliance with the legal meaning of the flashing hand is low. Therefore, removing the flashing hand from the CPS may actually improve pedestrian comprehension and crossing decisions by eliminating the source of confusion. This project involved two studies conducted to determine the effects of replacing the standard CPS with an experimental design that excludes the flashing hand from the pedestrian change interval display.

Study 1 was a laboratory study to investigate pedestrians' comprehension of the experimental CPS (with countdown only), standard CPS (with flashing hand plus countdown), and conventional signal (with flashing hand only). Forty-five participants were shown pictures of a pedestrian in five different crossing scenarios. Each scenario was presented three times: once with each of the key pedestrian signal configurations. Based on the crossing scenario and signal configuration shown, participants were asked to provide the correct pedestrian behavior for the situation. Results indicate that the experimental CPS resulted in the fewest critical confusions. The standard CPS performed nearly as well. The conventional signal, however, led to many more critical confusions than the two CPSs. Participants were most likely to believe that they were allowed to begin crossing during the pedestrian change interval when presented with the experimental CPS, followed by the standard CPS, then the conventional signal. Group discussions among participants indicated a general preference for the inclusion of countdown information, but preferences were divided between the experimental CPS and the standard CPS.

Study 2 was an observational study of pedestrians, comparing behavior where the experimental CPS was in effect with behavior where the standard CPS was in effect. A before-and-after design with matched control site was used. At the experimental site, pedestrian behavior was observed during predetermined periods for one week with standard CPSs present. Then the standard CPSs were replaced with experimental CPSs and behavior was observed again for one week. To account for possible changes in pedestrian behavior over time, a second crosswalk that closely matches the characteristics of the experimental crosswalk was observed as a control site. The control site had standard CPSs installed during both the before and the after periods. Although there was no overall increase in the number of pedestrians observed beginning to cross during the pedestrian change interval with the experimental CPS, pedestrians began to cross later during the pedestrian change interval. Furthermore, for the experimental manipulation, there was no overall increase in the number of pedestrians completing crossing during the steady DON'T WALK phase (SDW), although pedestrians were more likely to finish

crossing later in the SDW. These shifts toward later starts and finishes are not unsafe per se, but may create more opportunities for pedestrian/vehicle conflicts and disruption of operations.

# TABLE OF CONTENTS

# LIST OF FIGURES



# LIST OF TABLES

# INTRODUCTION

## Background

Conventional pedestrian signals compliant with the 2003 Edition of the Manual on Uniform Traffic Control Devices (MUTCD; Federal Highway Administration, 2003) have three indications presented in the following sequence:

- **WALK**, signified by a white silhouette of a person, "means that a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning vehicles" (Section 4E.02).
- **Flashing DON'T WALK (FDW)**, which is presented during the pedestrian change interval and is signified by a Portland orange flashing upraised hand, "means that a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a steady WALKING PERSON (symbolizing WALK) signal indication shall proceed out of the traveled way" (Section 4E.02).
- **Steady DON'T WALK (SDW)**, signified by a Portland orange steady upraised hand, "means that a pedestrian shall not enter the roadway in the direction of the signal indication" (Section 4E.02).

Research on comprehension of pedestrian signals has consistently found that the FDW is by far the most poorly understood indication, with comprehension rates sometimes reported to be below 50% (City of Chicago, 2002). This low comprehension rate is often blamed for pedestrians' unsafe crossing behaviors and failure to comply with the FDW during the pedestrian change interval. One solution that promises to improve comprehension of the pedestrian change interval is the countdown pedestrian signal.

In recent years, a number of laboratory studies, surveys, and field implementations have investigated the effectiveness of countdown pedestrian signals (CPSs). Appendix A of this report presents a review of the literature on CPSs. CPSs present the same information as conventional pedestrian signals, but with the addition of a countdown timer that shows pedestrians how much time they have to complete their crossing. Due to early experimentation by different localities, there is some variation in the design and phasing of existing CPSs. In some cases, the countdown begins during the WALK phase while in other cases the countdown begins during the pedestrian change interval. In both cases, the countdown reaches zero at the end of the pedestrian change interval. The MUTCD's 2003 Edition provides specifications for the design and operation of CPSs. The MUTCD specifies that "the display of the number of remaining seconds shall begin only at the beginning of the pedestrian change interval." (Section 4E.07). New CPSs shall conform to this guidance.

Observational studies of pedestrians and motorists have been the primary means to determine the effectiveness of CPSs. The two measures most often investigated in observational studies of CPS effectiveness are signal compliance and crossing success. Compliance refers to the proportion of pedestrians who arrive at the crossing during the pedestrian change interval or SDW, but wait until the next WALK phase to begin crossing. Crossing success refers to the proportion of pedestrians who begin crossing during the WALK or pedestrian change interval, and complete crossing before the SDW phase begins. It is possible for a pedestrian to be noncompliant (begin crossing during the pedestrian change interval), yet still cross successfully (complete the crossing before the SDW phase begins). In fact, some studies have found that pedestrians are more likely to begin crossing during the pedestrian change interval when countdown information is provided to them, but fewer pedestrians remain in the crosswalk when the pedestrian change interval ends and the SDW phase begins (Botha et al., 2002; DKS Associates, 2001; Huang & Zegeer, 2000). The timing of pedestrian signal phases is based on conservative estimates of walking speed used to protect slower pedestrians. This means that there is often adequate time for many pedestrians to complete their crossing successfully even if they begin during the pedestrian change interval. Although poor judgment, poor signal comprehension, and willful disregard of the CPS may still lead to unsafe crossing behaviors, it appears that CPSs provide pedestrians with information that they can use to make decisions about whether it is safe to cross, even if these decisions are in violation of traffic regulations.

Despite the apparent advantages of CPSs over conventional pedestrian signals, there are limits to their effectiveness. CPSs appear to improve comprehension of the pedestrian change interval (e.g., City of Chicago, 2002; Mahach, Nedzesky, Atwater, & Saunders, 2002), but misunderstandings still occur frequently. Furthermore, Botha et al. (2002) found that 80 percent of pedestrians believe that it is legal to enter a crosswalk during the pedestrian change interval if they complete the crossing before the countdown reaches zero. The authors concluded that this finding might indicate that when the flashing hand and countdown are displayed concurrently, pedestrians may focus their attention on the countdown to decide whether to cross.

The flashing hand has been shown to be a key obstacle limiting the effectiveness of pedestrian signals. As discussed above, the addition of a countdown clock during the pedestrian change interval appears to provide more useful and salient information to pedestrians than the conventional FDW alone does. Therefore, removing the flashing hand from the CPS may actually improve decision-making by allowing pedestrians to focus on relevant information without the presence of confusing and ambiguous information.

## Research Objectives

This research investigated the effects of removing the flashing upraised hand from the pedestrian change interval of a CPS. As discussed above, the countdown timer appears to provide pedestrians with helpful information. In contrast, relatively few pedestrians understand the meaning of the flashing hand. The primary questions that this project addressed are:

- Will the removal of the flashing hand improve pedestrian comprehension of the pedestrian change interval?
- With the flashing hand removed from the pedestrian change interval display, will pedestrians be able to use the CPS to cross more safely and successfully?

**Project Overview**

This project consisted of two studies conducted to determine the effects of replacing the standard CPS with an alternative configuration that does not include the flashing upraised hand during the pedestrian change interval. Study 1 was a laboratory study to investigate comprehension of the experimental CPS relative to standard and nonstandard pedestrian signals. Study 2 was a field observational study to determine the effects of the experimental CPS on pedestrian behavior relative to the standard CPS. The comparison of CPS type involved observing pedestrian behavior at crosswalks with one of the two CPSs. Variables of interest include pedestrian compliance and crossing success as well as key behaviors (e.g., running, aborted crossings) and pedestrian/vehicle conflicts.

In addition to the potential for improved understanding of the pedestrian change interval, the modification made to the CPS for these studies has an implicit effect on pedestrian traffic law. By removing the flashing hand from the CPS, the rules associated with it are also removed (although it is still illegal for pedestrians to be in the crosswalk during the SDW). Without the flashing hand during the pedestrian change interval, there is no indication that pedestrians may not begin crossing during this phase. However, as noted above, compliance with the flashing hand does not ensure a successful crossing, nor does noncompliance ensure an unsuccessful crossing. In fact, it is possible that by restricting the use of the upraised hand to the SDW, the upraised hand will be less confusing and ambiguous to pedestrians and result in improved compliance with the SDW (e.g., fewer pedestrians beginning to cross during the SDW). Ultimately, the benefit of pedestrian signals should be determined by their ability to cultivate a safe roadway environment.

# STUDY 1 – LABORATORY COMPREHENSION

## Objective

Study 1 assessed comprehension of a variety of pedestrian signal displays, including a conventional pedestrian signal, a standard CPS, and the experimental CPS (with flashing hand removed). The primary objective of Study 1 was to determine how well people understand the experimental CPS relative to the standard CPS. This modification has not been investigated to date. The results of Study 1 also provide insight into the factors underlying pedestrian behavior observed in the observational study (Study 2).

## Method

### Participants

Forty-five participants were recruited from an advertisement for a “traffic symbol survey” placed in newspapers in Maryland suburbs of Washington, DC. The age groups eligible for this study were young (18-25), middle (30-55), and older (60+). An approximately equal number of participants were recruited from each age group and gender. Walking frequency was not used to prescreen participants, but on a questionnaire completed during the study session, more than 60 percent of participants reported walking on sidewalks for recreation or transportation at least once a week. About a quarter of participants reported walking once a month or less. Overall, males reported walking slightly more often than females and young participants reported walking slightly less often than middle and older participants.

### Design

The signal comprehension study was a within-subjects comparison of pedestrian signal comprehension. The study investigated the effects of two primary factors on signal comprehension: crossing scenario and pedestrian change interval display.

Each trial consisted of a photograph of a pedestrian at a crosswalk with an enlarged, inset pedestrian signal head (see **Error! Reference source not found.**). One of two photos was used for each trial. Both photos depicted the same crosswalk and were virtually identical except for the location of the pedestrian. One photo showed the pedestrian standing on the curb waiting to cross and the other showed the pedestrian halfway across the crosswalk. The photos depict the crossing of King Street at Patrick Street in Alexandria, VA, which is one of the sites used in the subsequent field observational study (Study 2). The buildings in the background of the photo were digitally darkened to focus participants’ attention to the critical elements of the photo and the display. The actual pedestrian signal is visible in the upper right-hand corner of the photo, but the signal head was edited out and replaced by the inset signal head in the upper left-hand corner. Each trial included a seven-second animation of a pedestrian display. Animations were used to provide context and realism. Some trials only showed one phase; others included transitions from one phase to the next. Some signals were presented early in a phase; others were presented near the end of a phase.


**Figure 1. Example study trial depicting a pedestrian and animated inset signal head**

There were five general crossing scenarios in which a pedestrian made a crossing decision based on the pedestrian change interval display. These scenarios are described in **Error! Reference source not found.**. Study participants were presented with each crossing scenario three times: once with each of the three pedestrian change interval displays, for a total of 15 "critical trials." An additional 12 non-critical trials were also included in the study. These trials presented nonstandard displays or did not include a pedestrian change interval display. The nonstandard displays were an animated eyes display and a warning triangle display. The animated eyes display is an option in the MUTCD (Section 4E.04) that presents a pair of white eyes with animated white eyeballs that appear to scan left and right. The animated eyes display is present above, and concurrent with, the WALK indication. The warning triangle display includes a red exclamation point inside a red equilateral triangle and was used as an alternative to the FDW (when flashing) and the SDW (when steady). Use of the warning triangle is not permitted by the MUTCD. The animated eyes and the warning triangle are shown in Figure 2.

**Table 1. Description of pedestrian crossing scenarios for critical trials shown for each signal configuration (experimental CPS, standard CPS, and conventional)**

| | |
|---|---|
| **Scenario 1** (At Curb 16) | The pedestrian arrives at the curb just as the pedestrian signal changes from WALK to the pedestrian change interval. On the countdown signals, the countdown begins at 16. |
| **Scenario 2** (Midway 16) | The pedestrian begins crossing during the WALK phase. When the pedestrian is halfway across the street, the signal changes from WALK to the pedestrian change interval. On the countdown signals, the countdown begins at 16. |
| **Scenario 3** (At Curb 7) | The pedestrian change interval is active as the pedestrian approaches the curb and continues when the pedestrian reaches the curb. On the countdown signals, the countdown shows 7 when the pedestrian reaches the curb. |
| **Scenario 4** (Midway 7) | The pedestrian change interval becomes active soon after the pedestrian begins crossing. The pedestrian change interval continues when the pedestrian is halfway across the crosswalk. On the countdown signals, the countdown shows 7 when the pedestrian is halfway across the crosswalk. |
| **Scenario 5** (At Curb SDW) | The pedestrian change interval is active as the pedestrian approaches the curb. If present, the countdown signal counts to zero, then the steady DON'T WALK phase begins as the pedestrian arrives at the curb. |

**Figure 2. Nonstandard displays used in Study 1: Animated eyes (left) and warning triangle (right)**

Non-critical trials were included to mask the focus of the study and to serve as distracter tasks between critical trials. Table 2 shows the list of 15 critical trials including the key crossing scenario that each trial represents. Table 3 shows the list of 12 non-critical trials. These tables show how each seven-second animation was divided approximately into two halves (the first three seconds and the final four seconds). For some trials, the second half of the display was a continuation of the first half. For other trials, the second half of the display transitioned into the subsequent pedestrian signal phase (e.g., pedestrian change interval to SDW). In both tables, the numbers in parentheses represent the first number shown on the countdown timer as the particular half of the display begins.

**Table 2. Signal displays for critical trials and the key crossing scenarios that they represent**

| Scenario | Location | Signal Display (7 sec total) | |
|---|---|---|---|
| | | **First 3 sec of display** | **Final 4 sec of display** |
| **1** | At Curb | WALK | Flashing Hand only |
| **1** | At Curb | WALK | Flashing Hand plus Countdown (16) |
| **1** | At Curb | WALK | Countdown only (16) |
| **2** | Midway | WALK | Flashing Hand only |
| **2** | Midway | WALK | Flashing Hand plus Countdown (16) |
| **2** | Midway | WALK | Countdown only (16) |
| **3** | At Curb | Flashing Hand only | Flashing Hand only |
| **3** | At Curb | Flashing Hand plus Countdown (10) | Flashing Hand plus Countdown (7) |
| **3** | At Curb | Countdown only (10) | Countdown only (7) |
| **4** | Midway | Flashing Hand only | Flashing Hand only |
| **4** | Midway | Flashing Hand plus Countdown (10) | Flashing Hand plus Countdown (7) |
| **4** | Midway | Countdown only (10) | Countdown only (7) |
| **5** | At Curb | Flashing Hand only | Steady Hand |
| **5** | At Curb | Flashing Hand plus Countdown (2) | Steady Hand |
| **5** | At Curb | Countdown only (2) | Steady Hand |

**Table 3. Signal displays for non-critical trials**

| Location | Signal Display (7 sec total) | |
|---|---|---|
| | **First 3 sec of display** | **Final 4 sec of display** |
| **Midway** | WALK | WALK |
| **Midway** | WALK plus Animated Eyes | WALK plus Animated Eyes |
| **At Curb** | Flashing WALK | Flashing WALK |
| **At Curb** | WALK plus Animated Eyes | Flashing Hand plus Countdown (16) |
| **At Curb** | WALK | Flashing Warning Triangle |
| **Midway** | WALK plus Animated Eyes | Countdown only (16) |
| **Midway** | WALK | Flashing Warning Triangle plus Countdown (16) |
| **Midway** | Flashing Warning Triangle | Flashing Warning Triangle |
| **At Curb** | Flashing Warning Triangle | Steady Warning Triangle |
| **At Curb** | Steady Hand | Steady Hand |
| **At Curb** | Steady Warning Triangle | Steady Warning Triangle |
| **At Curb** | Steady Hand | WALK |

Procedure

Each study session included between seven and ten participants, with a mix of ages and genders. Study sessions were conducted in a Westat meeting room with participants seated around a large rectangular table. The session moderator was located at the head of the table. As participants arrived, they were given an informed consent form to read and sign. When all participants had arrived and completed the consent forms, the moderator provided an overview of the study, then introduced and explained the experimental task. Participants were told that they would be shown a series of photographs depicting a pedestrian in crossing situations with an inset animated pedestrian signal (see **Error! Reference source not found.**). Each inset signal animation lasted seven seconds and then the display went blank. A beep sounded partway through the animation to tell participants exactly what part of the animation they should respond to in their answers. This beep occurred as soon as the second half (the final four seconds) of the display began (see Table 2 and Table 3). The photographs with inset pedestrian signals were created and presented using Microsoft PowerPoint and were projected on a large screen by means of a digital projector.

Based on the pedestrian's location and the signal display shown at the moment of the beep, participants were instructed to write down what action the pedestrian is *supposed* to take (not necessarily what the participant might *choose* to do). This response was open-ended. In other words, participants did not choose from a set of possible answers; they were allowed to write any behavior that they felt was correct. If participants were unsure of the correct action, they were instructed to write their best guess. For all trials, there was a correct action available to the pedestrian. In other words, the pedestrian was never shown in a situation in which there was no legal and presumably safe alternative. However, participants were not told that this was the case.

Participants were given an example of how to answer using an unsignalized midblock crosswalk as an example. This allowed the experimenter to demonstrate a correct and thorough answer without creating a bias in the study trials. Participants were instructed to emphasize action in their answers (e.g., what physical action should the pedestrian in the photo take?), though they were encouraged to write down the thought process and reasons for taking that action as well. Participants were then provided two practice trials identical to those in the set of critical trials, but with different, nonstandard signal displays. Each signal animation was shown twice. After each practice trial, the moderator checked participants' answers for clarity and completeness and gave feedback when improvements were necessary. No feedback was given regarding correctness. After the practice trials, participants completed the 27 study trials. The order in which trials were presented was randomized. Half of the study sessions received this randomized presentation and the other half received the reverse order. This was done to mitigate the effects that experience might have on participants' answers. Participants were allowed as much time as necessary to complete their answer; the moderator did not move on to the next trial until all participants had finished writing.

Group Discussion

After all study trials were completed, participants in the session engaged in a group discussion about options for the pedestrian change interval. The moderator began by giving an overview of the three pedestrian change interval options used in the study trials: flashing hand only, flashing hand plus countdown, and countdown only. Once participants were familiar with the meaning and operation of the displays, the moderator guided the group in a discussion of their preferences, misunderstandings, comparisons between signals, potential safety benefits, and suggestions for improvement. The moderator made an effort to involve all participants in the discussion and sought individual perceptions rather than group consensus. Each discussion session lasted about 15 to 20 minutes.

## Results

### Comprehension

Study 1 addressed pedestrian comprehension of the meaning of various pedestrian signal displays depending upon the crossing scenario. The findings that follow describe the results of the fifteen critical trials (5 crossing scenarios x 3 pedestrian change interval displays) that addressed comprehension of the three alternative pedestrian change interval displays: conventional signal (flashing hand only), standard CPS (flashing hand plus countdown), and experimental CPS (countdown only). Participants' open-ended answers were categorized by what they deemed was the correct pedestrian action: a) begin/continue to cross the street; b) do not begin to cross or return to the curb of origin; or c) the pedestrian must determine whether there is enough time to get across before conflicting traffic arrives. This last "pedestrian choice" crossing decision typically involved judging how much time is left before the end of the pedestrian change interval and/or looking for a sufficient gap in oncoming traffic. Insufficient, unclassifiable answers were uncommon; for each of the critical trials at least 43 participants (out of 45 total) provided valid answers.

In addition to correct action responses, particular attention was given to the occurrence of confusions in which the message conveyed to the participant contradicts the intended message An "incorrect" crossing decision, such as beginning to cross during the pedestrian change interval, was not necessarily a confusion. If a participant willfully disregards the signal, this may indeed create a dangerous situation, but it is not the result of a confusion. Furthermore, a participant may have a confusion that leads to the correct crossing decision, but also has the potential to create an unsafe situation such as running or hesitating mid-crossing. In the context of the scenarios used in this study, confusions may lead to varying degrees of risk. For instance, a confusion that occurs while the pedestrian is midway across the crosswalk and the pedestrian change interval is active probably results in a minimally risky situation because the pedestrian has the right of way. However, a confusion that leads to the pedestrian starting to cross during the SDW is more likely to put the pedestrian at risk.

The tables for each of the five scenarios that follow indicate the percentages of participants that chose each of the three pedestrian action alternatives. The "correct" answer for each scenario is highlighted. For Scenarios 1, 3, and 5 the pedestrian is at the curb as the pedestrian change interval begins, so the correct answer is "don't go." However, an exception must be made for the experimental CPS because the removal of the flashing upraised hand implicitly allows pedestrians to begin crossing during the pedestrian change interval. Therefore, any crossing decision is acceptable (and no decision is highlighted in the tables). For Scenarios 2 and 4 the pedestrian is halfway across the intersection, so the correct action is to complete crossing the street. It is legal for pedestrians to return to the curb of origin, but in the context of this study, that answer typically reflects a confusion.

The first three columns of each table (the "correct answer" choices) sum to 100 percent. The fourth column shows the percentage of participants whose misinterpretation of the signal caused a confusion. Chi-square tests were conducted for each of the five scenarios to determine whether there was a significant difference between participants' "correct action" responses as a result of the pedestrian change interval display presented. Confusions were not included as a factor in the chi-square tests.

*Scenario 1 (Start 16): The pedestrian arrives at the curb just as the pedestrian signal changes from WALK to the pedestrian change interval. On the countdown signals, the countdown begins at 16.*

**Table 4. Scenario 1 participant responses and confusions**

| | Go | Ped Choice | Don't Go | Confusions |
|---|---|---|---|---|
| Conventional Signal | 14.0% | 2.3% | 83.7% | 0.0% |
| Standard CPS | 46.7% | 22.2% | 31.1% | 2.2% |
| Experimental CPS | 72.7% | 20.5% | 6.8% | 0.0% |

The pedestrian change interval display had a significant effect on participants' choice of correct action in this scenario ($p<0.001$). For the conventional signal, only 14 percent of participants thought that the pedestrian should begin crossing. However, nearly half of participants thought the pedestrian should begin with the standard CPS and nearly three quarters of participants gave the same response for the experimental CPS. Furthermore, whereas nearly all participants gave a clear yes or no answer for the conventional signal, about one in five participants thought that the two CPSs allowed the pedestrian to decide whether or not it was safe to begin crossing. This finding indicates a perceived shift in decision making when the countdown timer is present that places less emphasis on signal compliance and more emphasis on pedestrian choice.

*Scenario 2 (Midway 16): The pedestrian begins crossing during the WALK phase. When the pedestrian is halfway across the street, the signal changes from WALK to the pedestrian change interval. On the countdown signals, the countdown begins at 16.*

**Table 5. Scenario 2 participant responses and confusions**

| | Go | Ped Choice | Don't Go | Confusions |
|---|---|---|---|---|
| Conventional Signal | 93.3% | 2.2% | 4.4% | 13.3% |
| Standard CPS | 97.8% | 0.0% | 2.2% | 2.2% |
| Experimental CPS | 100.0% | 0.0% | 0.0% | 0.0% |

In this scenario, there was no significant difference between participants' choices of correct action; the majority of participants in all conditions thought that the pedestrian should continue across to the other side of the street. However, there were a substantial number of confusions associated with the conventional signal. The confusions occurred because some participants thought that the flashing hand indicated that pedestrians are no longer allowed to be in the crosswalk and that there is a danger from vehicles which now have the right of way. Many of these participants wrote that the pedestrian should very carefully avoid moving traffic and/or run as they finish crossing the street.

*Scenario 3 (Start 7): The pedestrian change interval is active as the pedestrian approaches the curb and continues when the pedestrian reaches the curb. On the countdown signals, the countdown shows 7 when the pedestrian reaches the curb.*

**Table 6. Scenario 3 participant responses and confusions**

| | Go | Ped Choice | Don't Go | Confusions |
|---|---|---|---|---|
| Conventional Signal | 2.2% | 4.4% | 93.3% | 0.0% |
| Standard CPS | 7.0% | 9.3% | 83.7% | 4.7% |
| Experimental CPS | 18.2% | 18.2% | 63.6% | 6.8% |

Consistent with the findings of Scenario 1, there were significant differences between participants' choices of correct action depending upon the signal shown ($p<0.05$). Participants were most likely to believe that they are allowed to begin crossing the street during the pedestrian change interval of the experimental CPS. Many more participants answered that the pedestrian must decide whether it was safe to cross when presented with the experimental CPS than the other alternatives. Among the participants who decided that the pedestrian should not begin to cross when presented with the experimental CPS, those who gave a specific reason noted that there was not enough time to get to the other side. None indicated that it was illegal to begin crossing. In this scenario, there were more confusions in the two CPS conditions than in the flashing hand only condition. These confusions occurred when participants incorrectly believed that the countdown indicated the time remaining until the next WALK phase.

*Scenario 4 (Midway 7): The pedestrian change interval becomes active soon after the pedestrian begins crossing. The pedestrian change interval continues when the pedestrian is halfway across the crosswalk. On the countdown signals, the countdown shows 7 when the pedestrian is halfway across the crosswalk.*

**Table 7. Scenario 4 participant responses and confusions**

| | Go | Ped Choice | Don't Go | Confusions |
|---|---|---|---|---|
| Conventional Signal | 93.0% | 2.3% | 4.7% | 30.2% |
| Standard CPS | 93.2% | 2.3% | 4.5% | 9.1% |
| Experimental CPS | 97.8% | 2.2% | 0.0% | 0.0% |

There was no significant variation between the three signal configurations in terms of determining the correct action. Like in Scenario 2, the majority of participants believed that the pedestrian should continue across the street. However, the rate of confusions varied dramatically. Nearly a third of participants were confused by the conventional signal. Many thought that the flashing hand meant that the pedestrian is not allowed in the crosswalk at this time and that there is a danger of being struck by a vehicle. Some indicated that the pedestrian should not have begun crossing in the first place. Most indicated that the pedestrian should walk very carefully or run across the street to avoid being struck by a vehicle. Confusions in the standard CPS condition were less common, but included the same misunderstandings. No confusions were associated with the experimental CPS in this scenario.

*Scenario 5 (Start SDW): The pedestrian change interval is active as the pedestrian approaches the curb. If present, the countdown signal counts to zero, then the steady DON'T WALK phase begins as the pedestrian arrives at the curb.*

**Table 8. Scenario 5 participant responses and confusions**

| | Go | Ped Choice | Don't Go | Confusions |
|---|---|---|---|---|
| Conventional Signal | 0.0% | 0.0% | 100.0% | 0.0% |
| Standard CPS | 2.2% | 0.0% | 97.8% | 4.4% |
| Experimental CPS | 4.7% | 2.3% | 93.0% | 2.3% |

No significant difference was found between pedestrians' choice of correct action for the three signal displays. The majority of participants decided that the pedestrian should not begin crossing the street, regardless of pedestrian change interval display. This is not surprising because even though this scenario does include the three pedestrian change interval displays, participants were actually instructed to respond to the beginning of the SDW, which was identical for all signal configurations. Nonetheless, there were small differences between the alternatives. These differences may be attributable to carry-over from interpretations of the pedestrian change interval.

*Age and Gender Differences:*

Participants' responses were compared to determine whether age and gender influenced signal comprehension and crossing decisions. Figure 3 shows the findings for Scenarios 1, 3 and 5, in which the participant must decide if the pedestrian should begin to cross the street or wait for the next WALK phase. The figure shows the percentage of participants who understood the signals (i.e., did not have a confusion) and chose to wait. For these scenarios, waiting is the only legally correct choice for the conventional signal and the standard CPS, but an exception must be made in Scenarios 1 and 3 for the experimental CPS which does not include the flashing hand and therefore beginning to cross during the pedestrian change interval was not considered incorrect. Figure 3 shows that, for all three signal configurations, young males were the most likely to believe that the pedestrian should, or could, begin crossing. The difference between young males and young females is especially large. Older participants were generally more likely to believe that the pedestrian should wait than the young and middle groups were. In Scenario 5, which differs from the others because it assesses response to the SDW, males and females responded similarly to the conventional signal and the standard CPS, but responses to the experimental CPS differed. Although all females responded that the pedestrian should not begin to cross, nearly 14 percent of males responded that the pedestrian could begin to cross. If this finding were to replicate in a real crosswalk setting, it could be indicative of a significant safety problem.

Figure 4 shows the findings for Scenarios 2 and 4, in which the pedestrian is midway across the crosswalk and must decide what to do in response to the pedestrian change interval display. For these scenarios, completing the crossing is the correct choice. A response indicating that it is the pedestrian's choice to complete crossing or return was also considered correct if there was no confusion. Even though most participants decided that the pedestrian should complete the crossing, many answers were considered incorrect because they included confusions. The figure shows that the experimental CPS was best understood by males and females of all age groups. The improvement in comprehension relative to the other two signal displays was greatest among older participants.

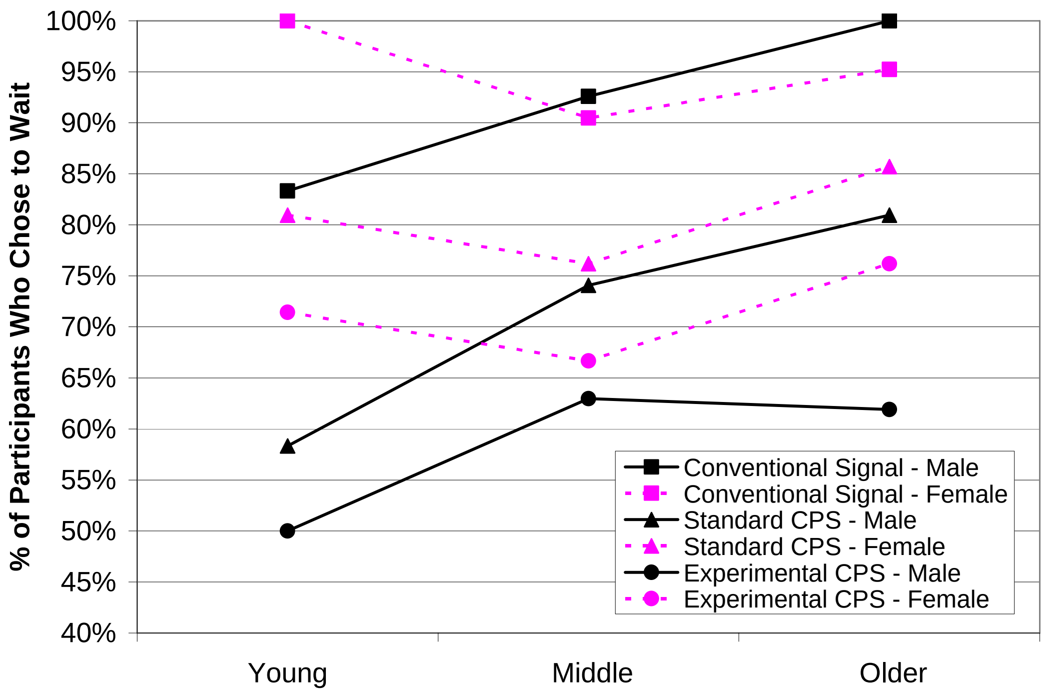


**Figure 3. Scenarios 1, 3, & 5 - Percentage of participants who understood the signal display and chose to wait on the curb instead of beginning to cross during the pedestrian change interval**

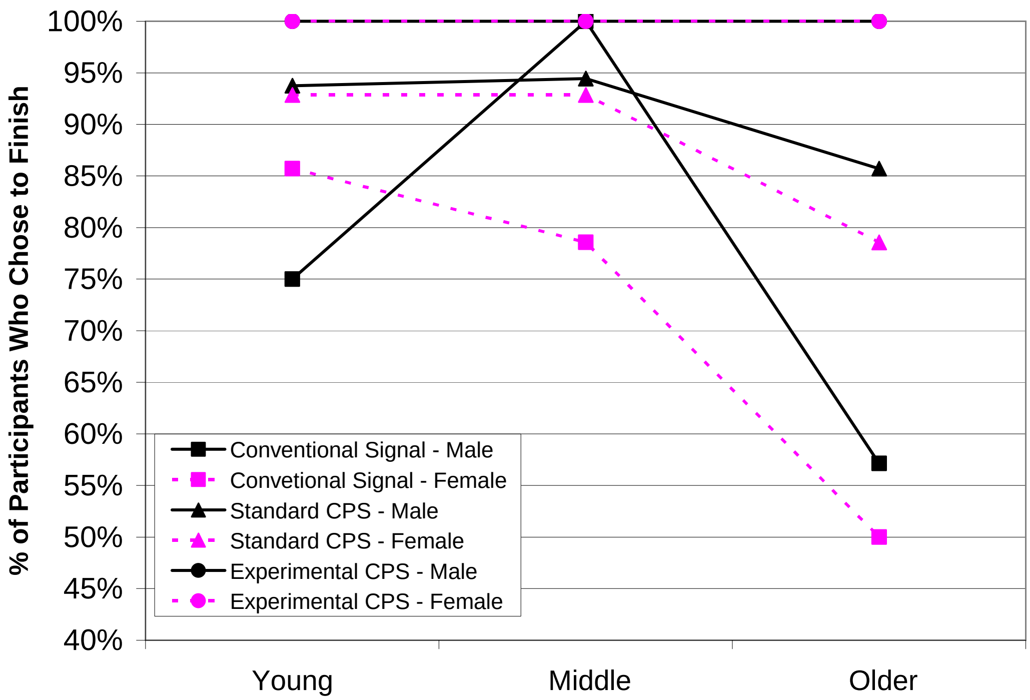


**Figure 4. Scenarios 2 & 4 - Percentage of participants who understood the signal display and chose to complete crossing**

Group Discussion

The group discussion revealed that nearly all participants preferred the two options with the countdown timer rather than the conventional flashing hand only display. Participants preferred to have countdown information because it gives them more information and lets them make better crossing decisions. The few who preferred the conventional signal did so because they didn't feel that the countdown information was reliable or because they thought that some pedestrians might misinterpret the countdown to mean that they could walk when the countdown reached zero. Some felt that it would be best to continue using the conventional signal because it is what pedestrians are accustomed to, especially for older pedestrians.

Participants had no clear preference between the standard CPS and the experimental CPS. Some felt that the experimental CPS was easier to understand because the countdown timer makes sense alone and there is no need for the flashing hand. Others felt that the flashing hand was necessary to let people know that they should not start crossing and that the meaning of the countdown timer was unclear without it. Participants also disagreed about which CPS would lead to safer behavior. When asked about potential improvements, participants generally responded that the CPSs are fine as they are. A few participants recommended changing the countdown numbers to white or green to make their meaning clearer.

## Discussion

The results of the lab study support the findings of previous pedestrian signal research and provide new insight into pedestrian comprehension of the experimental, countdown only CPS. The findings of Scenarios 1 and 3 show that participants were more likely to believe that they are allowed to begin crossing during the pedestrian change interval when presented with a CPS rather than the conventional flashing hand only signal. Between the two CPS alternatives, participants were most likely to believe that they were allowed to begin crossing during the pedestrian change interval of the countdown only display. These findings support the rationale put forth by Botha et al. (2002) that when a countdown timer is added to the pedestrian change interval, pedestrians shift their focus from the flashing hand to the countdown timer. Whereas the flashing hand indicates that pedestrians should not begin crossing, the countdown timer shows pedestrians how much time is remaining to cross the street, implicitly allowing them to make their own decision. The countdown only display eliminates the flashing hand altogether and therefore provides no explicit indication that pedestrians should not begin to cross the street.

In Scenarios 2 and 4 the majority of participants believed that the pedestrian should complete the crossing once the pedestrian change interval began. This was not surprising because the pedestrian in the photo was shown halfway across the crosswalk, making it just as logical to complete the crossing as to return to the curb of origin. The primary factor of interest in these scenarios was comprehension of the pedestrian change interval display and the occurrence of confusions. Confusions in these scenarios may lead to behaviors such as running, freezing in place to reevaluate, and aborting the crossing attempt. Although the risk posed by these confusions may be minimal since the pedestrian has the right of way during the pedestrian change interval, such unexpected behavior may create a danger to pedestrians from turning vehicles or may increase the likelihood that the pedestrian will complete crossing during the SDW or choose to remain in the intersection (e.g., on a median) until the next WALK signal. Substantially more confusions occurred with the flashing hand only display than with the two CPSs. Many participants incorrectly believed that the flashing hand indicated that pedestrians are no longer allowed to be in the crosswalk. The same confusion occurred to a lesser extent with the flashing hand plus countdown display, but did not occur at all with the countdown only display. These differences appear to indicate that the flashing hand is confusing to many pedestrians, but that a countdown timer can reduce the occurrence of confusions when used in addition to, or in place of, the flashing hand.

The differences between males and females and between young, middle, and older participants generally reflect trends observed in previous research and crash statistics. In the current study, older people and females tended to be the most cautious when deciding whether to cross the street, but were most likely to be confused by the pedestrian change interval when already in the crosswalk. Mahach et al. (2002) also observed in their laboratory study of pedestrian signal comprehension that older people (age 65 and above) were slightly more conservative than younger people (age 18 to 25) when crossing the street. In the current study, males, and especially young males, were less conservative and were more likely to believe that they were allowed to begin crossing during the pedestrian change interval and the SDW than females were. These findings were generally consistent across all three display alternatives and may be a factor in the relatively high rate of pedestrian crashes among males. Statistics provided by the National Highway Traffic Safety Administration indicate that male pedestrians of all ages are more likely to be killed or injured than female pedestrians of an equivalent age (*Traffic safety facts 2003: Pedestrians*, 2004). Overall, 69 percent of killed and 60 percent of injured pedestrians in 2003 were males. It should be noted, however, that these data are not adjusted for rate of exposure and include pedestrian crashes at all locations; not just at crosswalks.

Results also indicate that older participants benefited most from the experimental CPS, especially when the pedestrian change interval began with the pedestrian shown halfway across the intersection. This finding is especially important because older pedestrians often walk more slowly than others, and may be more likely than younger pedestrians to remain in the crosswalk at the termination of the pedestrian change interval if they misinterpret the signal while crossing. This finding is also important because traffic crashes involving older pedestrians are deadlier than those involving younger pedestrians. Although the rate of injury among pedestrians aged 65 and older is slightly lower than the rate among pedestrians aged 64 and younger, the fatality rate per 100,000 population of pedestrians age 65 and older (2.71) is nearly double the rate among pedestrians age 64 and younger (1.46) (*Traffic safety facts 2003: Pedestrians*, 2004). This is probably due in large part to the relative frailty of older people.

The results of Study 1 illuminate differences in pedestrians' comprehension and interpretations of the three pedestrian change interval displays. The results of this study provide evidence that the meaning of the countdown timer is well understood by pedestrians, even when presented without the flashing hand. However, it is important to note that although the countdown only display appears to cause the fewest confusions of all the displays, pedestrians are also much more likely to believe that they are allowed to begin to cross the street during the pedestrian change interval. This may present hazards of its own if pedestrians are more likely to remain in the crosswalk at the end of the pedestrian change interval. This possibility is investigated in the subsequent observational study (Study 2).

# STUDY 2 – FIELD OBSERVATIONAL STUDY

**Objective**

The objective of Study 2 was to compare the effectiveness of the standard CPS and the experimental CPS in an actual crosswalk setting. Whereas Study 1 addressed signal comprehension, Study 2 addressed the effects of the two CPSs on actual pedestrian behavior in the roadway environment. The study focused on compliance and crossing success but also addressed key events such as running, aborted crossings, and pedestrian/vehicle conflicts.

**Method**

Study 2 was a before-and-after-with-control-site study of pedestrian crossing behavior at crosswalks. Video observation was conducted during three time periods each day: morning, midday, and afternoon. Pedestrian behavior was first observed with standard CPSs (flashing hand plus countdown) installed at the experimental site. Next, the standard CPS was replaced by the experimental CPS (countdown only) and pedestrian behavior was observed again. Pedestrian behavior was also observed at a matched control site with standard CPSs installed during both observation periods.

Data Collection Sites

Data were collected at two geometrically and operationally comparable crosswalks in Alexandria, VA. The sites were located in a commercial area dominated by small businesses and approximately ½ mile from a Metro rail and bus mass transit station. The area is heavily trafficked by pedestrians and many crosswalks in the vicinity are controlled by CPSs. The experimental site (with standard CPS and then experimental CPS) was the east leg of the crossing of King Street at Patrick Street. The control site (with standard CPS only) was the west leg of the crossing of King Street at Henry Street. Patrick Street and Henry Street are both one-way streets, with Patrick carrying northbound traffic and Henry carrying southbound traffic. The two sites were located approximately 100 meters apart and were parallel to one another rather than sequential, so individual pedestrians were unlikely to cross at both crosswalks in a single trip. Both sites shared the following characteristics:

- both were located at fully signalized, four-leg, right angle intersections with no discernible grades or curves on the vehicular approaches;
- both crosswalks crossed the same street (King Street), which has a total of four lanes of two-way traffic (eastbound and westbound) and a curb-to-curb walking distance of 40 feet;
- the streets parallel to the crosswalks at both sites (Patrick Street and Henry Street are one-way streets that allow vehicular traffic to turn right, but not left, through the crosswalk;
- vehicles on both King Street and the intersecting streets were permitted to turn right on red;

- the speed limit for King Street and the intersecting streets was 25 mph (40 km/h);
- the pedestrian signals at both sites were automatic (not pushbutton actuated) and maintained the same cycle 24 hours a day; and
- both crosswalks had a total cycle time of 80 seconds allotted as shown in Table 9 (there was a one-second difference in timing distribution between the two sites).

**Table 9. Duration of Signal Phases**

| Signal Phase | Experimental Site | Control Site |
|---|---|---|
| Walk | 17 s | 16 s |
| Pedestrian Change Interval | 10 s | 11 s |
| SDW | 53 s | 53 s |

Pedestrian Signals

Two types of CPS were used in this study: The standard CPS and an experimental CPS (See Figure 5). The standard CPS was manufactured by GELcore and was compliant with MUTCD operational specifications. The experimental CPS was manufactured by Tassimco and had the same operational specifications as the standard CPS, except that the flashing upraised hand was not presented during the pedestrian change interval. The only major difference in appearance between the two signals was that the WALK indication and upraised hand appeared as an outline on the standard CPS and was filled on the experimental CPS (see Figure 5). Both signals were 16 inches tall by 18 inches wide and used identical housing components. During the "before" observation period, the standard CPSs were present at both the control and experimental sites. For the "after" observation period, the experimental CPSs were installed at the experimental site. All signals were installed, programmed, and maintained by the City of Alexandria. To maintain consistency, the same type of CPS (standard or experimental) was installed at all four crosswalks of each intersection.

Video Recording Apparatus

Pedestrian behaviors were recorded using video recording systems temporarily fastened to existing utility poles adjacent to each of the observed crosswalks. ADT Northwest's PATH (Portable Archival Traffic History) video system was used for this study (*PATH systems – portable video traffic surveillance*, 2003). It included a video camera, time-lapse VCR, battery, and housing components (see Figure 6). The camera was aimed parallel to the crosswalk so that the field of view included the crosswalk, the curb areas on both sides of King Street, the CPS, and approaching vehicular traffic on both King Street and the parallel street. The PATH system was programmed to record at predetermined time periods each day during the data collection period. The time-lapse VCR recorded every third frame of video (approximately ten frames per second), allowing as much as 24 hours of video to be recorded on one VHS cassette. Two PATH systems were used to allow simultaneous recording at both study sites.

| | Pedestrian Change Interval | SDW |
|---|---|---|
| **Standard CPS** |  |  |
| **Experimental CPS** |  |  |

**Figure 5. Pedestrian change interval and SDW phases of standard CPS (top) and experimental CPS (bottom)**


**Figure 6. The PATH video recording system installed at the control site**

Design

*Recording Period*: The study was conducted as a before-and-after study with a matched control site. Table 10 outlines this design. Video recording was scheduled for four two-hour time segments each day for one week. The time periods recorded were:

- 7:30 AM to 9:30 AM;
- 11:30 AM to 1:30 PM[1];
- 4:00 PM to 6:00 PM; and
- 7:00 PM to 9:00 PM

The 7:00 PM to 9:00 PM time periods were recorded but not included in analyses because of difficulties in observing behaviors in the dark as well as differences in the time of sunset between the before and after periods. Video was recorded for the "before" period in late June and early July. In mid July, the experimental CPSs were installed at the experimental site. No change was made to the signals at the control site. After a familiarization period of about two weeks, video was recorded for the "after" period in late July and early August. Both data collection periods lasted one week. Due to equipment failure, not all intended periods were successfully recorded. Table 11 shows the time periods that were recorded and included in analyses at each site. Video recording was automated by preprogramming the appropriate time periods. A video technician reported to the data collection sites approximately every two days to replace the VHS cassette and the battery. Videotapes were returned to the home office where video data were entered into a Microsoft Access database by office staff who were trained and evaluated for accuracy.

**Table 10. CPS in use by observation period and site**

| Site | Observation Period | |
|---|---|---|
| | Before | After |
| Experimental Site | Standard CPS | Experimental CPS |
| Control Site | Standard CPS | Standard CPS |

**Table 11. Time periods recorded and included in analyses at each site (E = experimental site; C = control site)**

| Time | Mon | Tues | Wed | Thurs | Fri | Sat | Sun |
|---|---|---|---|---|---|---|---|
| **BEFORE** | | | | | | | |
| **Morning** | | E | E | E / C | C | E / C | E / C |
| **Midday** | | E | E | | C | E / C | E / C |
| **Afternoon** | | E | E / C | E / C | E / C | E / C | E / C |
| **AFTER** | | | | | | | |
| **Morning** | E / C | | E / C | E / C | E / C | E / C | E / C |
| **Midday** | E / C | | E / C | E / C | E / C | E / C | E / C |
| **Afternoon** | E / C | E / C | E / C | E / C | E / C | E / C | E |

[1] For the "after" period, 11:00 to 1:00 was used instead of 11:30 to 1:30

*Pedestrians and Behaviors Observed:* Behaviors were recorded for all pedestrians crossing at the study sites during the recording periods. For purposes of this study, pedestrians included all individuals except:

- children below the age of 13 (estimated) who are traveling with an adult (e.g., walking close, holding hands, being carried, being pushed in a stroller);
- individuals in wheelchairs who are being pushed by another individual; and
- bicyclists, skaters, and other wheeled travelers (though bicyclists who dismount to walk across the street were recorded).

For every pedestrian crossing at the study sites, the following information was recorded:

- signal phase when the pedestrian arrived at the curb (prior to crossing):
  - WALK
  - Pedestrian change interval – early (first five seconds of pedestrian change interval)
  - Pedestrian change interval – late (remaining seconds of pedestrian change interval)
  - Steady DON'T WALK (SDW)
- whether the pedestrian began crossing at the time of arrival or waited for the next WALK phase
- signal phase when the pedestrian completed crossing:
  - WALK
  - Pedestrian change interval
  - SDW early (first five seconds of SDW)
  - SDW late (remaining seconds of SDW)
- estimated pedestrian gender and age category[2]:
  - under 20
  - 20 to 64
  - 65 and older)
- occurrence of key events:
  - pedestrian began running while on the sidewalk and entered street at a run (excludes exercising joggers)
  - pedestrian began (or continued) to run while in the street (excludes exercising joggers)
  - pedestrian returned to curb after beginning to cross (aborted crossing)
  - a pedestrian/vehicle conflict, as defined by Eccles, Tao, and Mangum (2004): "an interaction between a vehicle and a pedestrian when either a pedestrian or vehicle took evasive action to avoid a collision such as weaving, braking, or running."

For the signal phase when the pedestrian arrived at the curb, the pedestrian change interval was divided into two segments: early and late. This was done because pedestrians who begin crossing during the first five seconds of the pedestrian change interval are often aware that they can complete crossing before the end of the pedestrian

[2] There was no way to independently validate analysts' judgments of pedestrian age and gender categories. The analysts were confident in gender judgments but were often uncertain about age estimates.

change interval. Pedestrians who begin after the first five seconds rarely complete before the end of the pedestrian change interval. Similarly, for the signal phase when the pedestrian completed crossing, the SDW was divided into two segments: early and late. This was done because pedestrians have five seconds after the SDW begins to clear the intersection before conflicting traffic is given the right of way. Although pedestrians are not permitted in the intersection during any part of the SDW, their risk remains low during the first five seconds. The segmentation of the SDW allows a distinction to be made between pedestrians who are at low risk and those who may be exposed to greater risk.

Running was one of the key behaviors recorded in this study. Running was subdivided into two categories (running upon entry and running while in the crosswalk). This distinction was made because the reasons for running may differ between these two categories and because pedestrian/vehicle conflict scenarios and likelihoods may differ depending upon when and where the pedestrian begins running.

## Results

A total of 4,287 pedestrian crossings were observed and recorded from 129 hours of videotape. Table 12 presents a descriptive overview of the data. Overall, the rate of pedestrian crossings was greater at the experimental site than the control site. The table shows that the vast majority of pedestrians at both sites were estimated to be between the ages of 20 and 64 and were fairly evenly split between males and females. In this table and in all subsequent analyses, a “cycle” is defined as beginning with WALK and ending at the completion of the SDW. Only cycles in which at least one pedestrian crosses are included in the data.

**Table 12. Overview of data collected**

| | Expt Before | Expt After | Control Before | Control After | Expt Total | Control Total | Grand Total |
|---|---|---|---|---|---|---|---|
| **Total Hours of Video Observed** | 30 | 38 | 26 | 35 | 68 | 61 | 129 |
| **Total Pedestrians Observed** | 1225 | 1350 | 780 | 932 | 2575 | 1712 | 4287 |
| **Pedestrians per Hour** | 40.8 | 35.5 | 30.0 | 26.6 | 37.9 | 28.1 | 33.2 |
| **Males under 20** | 45 | 38 | 31 | 15 | 83 | 46 | 129 |
| **Males 20 to 64** | 558 | 616 | 297 | 357 | 1174 | 654 | 1828 |
| **Males 65 and above** | 38 | 28 | 38 | 41 | 66 | 79 | 145 |
| **Females under 20** | 56 | 31 | 42 | 19 | 87 | 61 | 148 |
| **Females 20 to 64** | 501 | 622 | 347 | 480 | 1123 | 827 | 1950 |
| **Females 65 and above** | 27 | 15 | 25 | 20 | 42 | 45 | 87 |
| **Total Cycles (with ped present)** | 643 | 740 | 412 | 528 | 1383 | 940 | 2323 |
| **Cycles per Hour** | 21.43 | 19.47 | 15.85 | 15.09 | 20.34 | 15.41 | 18.01 |
| **Pedestrians per Cycle** | 1.91 | 1.82 | 1.89 | 1.77 | 1.86 | 1.82 | 1.85 |

Descriptive analyses were conducted for key behaviors using three different criteria. The percentage of pedestrians who engaged in each behavior is presented in Table 13. The percentage of signal cycles (given that a pedestrian is present) in which each behavior occurred is presented in Table 14. Finally, the rate (per hour) at which each behavior occurred is presented in Table 15. The trends in the data are essentially the same across all three sets of measures. The primary statistical analysis was conducted on the individual pedestrian behavior, which provides the most detail.

**Table 13. Percentage of pedestrians who engaged in key behaviors**

| | Expt. Before | Expt. After | Control Before | Control After |
|---|---|---|---|---|
| Arrive During WALK | 51.2% | 50.3% | 46.4% | 47.6% |
| Arrive Early in PCI | 7.7% | 9.9% | 5.5% | 8.2% |
| Arrive Late in PCI | 7.3% | 5.9% | 5.3% | 4.8% |
| Arrive During SDW | 33.8% | 34.0% | 42.8% | 39.4% |
| Arrive Early in PCI and Begin Crossing | 98.9% | 94.0% | 86.0% | 98.7% |
| Arrive Late in PCI and Begin Crossing | 83.8% | 94.9% | 78.0% | 81.4% |
| Arrive During SDW and Begin Crossing | 27.5% | 27.2% | 11.7% | 12.8% |
| Complete Early in SDW | 7.7% | 6.0% | 3.2% | 7.5% |
| Complete Late in SDW | 5.4% | 7.1% | 3.3% | 4.8% |
| Arrive During WALK and Complete in PCI | 25.1% | 24.7% | 26.8% | 27.3% |
| Arrive During WALK and Complete in SDW | 0.5% | 0.9% | 0.3% | 1.4% |
| Arrive During PCI and Complete Early in SDW | 48.9% | 35.8% | 29.8% | 52.9% |
| Arrive During PCI and Complete Late in SDW | 14.7% | 22.2% | 26.2% | 14.0% |
| Run Into Crosswalk | 2.2% | 1.6% | 1.2% | 2.6% |
| Run While In Crosswalk | 2.0% | 1.6% | 1.9% | 1.3% |

**Table 14. Percentage of signal cycles in which each behavior occurred**

| | Expt. Before | Expt. After | Control Before | Control After |
|---|---|---|---|---|
| Arrive During WALK | 58.2% | 58.1% | 53.6% | 54.7% |
| Arrive Early in PCI | 10.4% | 12.0% | 8.3% | 9.8% |
| Arrive Late in PCI | 9.5% | 9.2% | 7.0% | 6.1% |
| Arrive During SDW | 42.1% | 42.0% | 50.2% | 46.2% |
| Begin Crossing Early in PCI | 10.4% | 11.5% | 7.3% | 9.7% |
| Begin Crossing Late in PCI | 8.4% | 8.8% | 5.6% | 5.1% |
| Begin Crossing During SDW | 15.1% | 13.8% | 7.3% | 7.6% |
| Complete Early in SDW | 10.1% | 9.3% | 5.3% | 8.5% |
| Complete Late in SDW | 7.9% | 10.0% | 8.0% | 6.3% |
| Complete During SDW (total) | 17.4% | 19.1% | 12.9% | 14.6% |
| Run Into Crosswalk | 3.6% | 3.0% | 2.2% | 4.4% |
| Run While In Crosswalk | 3.1% | 2.3% | 3.4% | 2.3% |

**Table 15. Rate (per hour) at which each behavior occurred**

| | Expt. Before | Expt. After | Control Before | Control After |
|---|---|---|---|---|
| Arrive During WALK | 20.9 | 17.9 | 13.9 | 11.4 |
| Arrive Early in PCI | 3.1 | 3.5 | 1.7 | 1.9 |
| Arrive Late in PCI | 3.0 | 2.1 | 1.6 | 1.2 |
| Arrive During SDW | 13.8 | 12.1 | 12.8 | 9.4 |
| Begin Crossing Early in PCI | 3.1 | 3.3 | 1.2 | 1.9 |
| Begin Crossing Late in PCI | 2.5 | 2.0 | 0.9 | 1.0 |
| Begin Crossing During SDW | 3.8 | 3.3 | 1.2 | 1.2 |
| Complete Early in SDW | 3.1 | 2.1 | 1.0 | 1.8 |
| Complete Late in SDW | 2.2 | 2.5 | 1.8 | 1.2 |
| Run Into Crosswalk | 0.90 | 0.58 | 0.35 | 0.62 |
| Run While In Crosswalk | 0.80 | 0.55 | 0.58 | 0.31 |

A stepwise logistic regression model was used to identify the independent variables that were significant predictors of key pedestrian behaviors. The model compared the proportion of pedestrians who engaged in key behaviors, but also included an adjustment for possible behavioral correlation among pedestrians crossing during the same signal cycle. The following sections present the results of these analyses.

One of the key dependent variables in this study was whether pedestrians who arrive at the curb during the pedestrian change interval begin to cross or wait for the next WALK signal. Regardless of the CPS present, pedestrians were very likely to begin crossing both during the first five seconds (early) of the pedestrian change interval (95%) and during the remaining seconds (late) of the pedestrian change interval (86%). About half (53%) of pedestrians who began crossing early in the pedestrian change interval reached the opposite curb before the end of the pedestrian change interval. However, almost none (3%) of the pedestrians who began crossing late in the pedestrian change interval reached the opposite curb before the end of the pedestrian change interval. Overall, the experimental CPS did not have a statistically significant effect on whether or not pedestrians began to cross during the pedestrian change interval, but when the analysis considered whether pedestrians arrived at the curb early or late in the pedestrian change interval, a significant effect was found. Relative to the standard CPS, the experimental CPS was associated with a decrease in the likelihood that pedestrians would begin to cross early in the pedestrian change interval and a slight increase in the likelihood that pedestrians would begin to cross late in the pedestrian change interval ($p<0.01$). Figure 7 shows this effect. Though unrelated to the experimental manipulation, a significant main effect was found for pedestrian age groups ($p<0.05$). The age difference shows a tendency for younger pedestrians to be more likely to begin crossing during the pedestrian change interval than older pedestrians (see Figure 8).

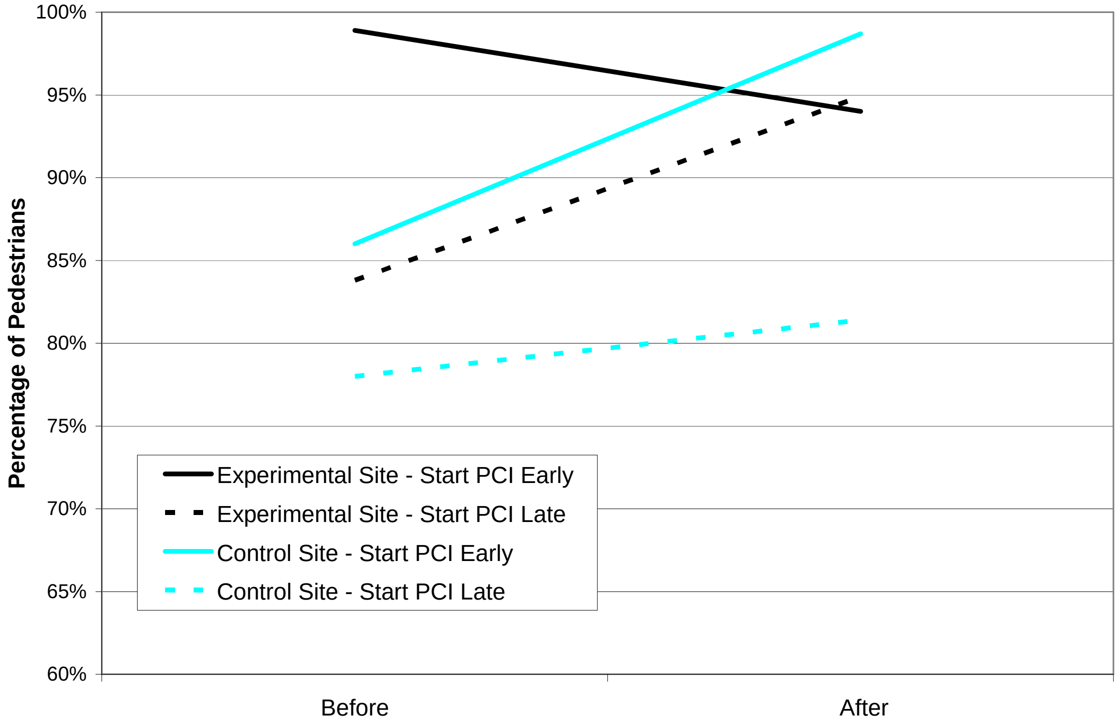


**Figure 7. Percentage of pedestrians who arrived at the curb during the pedestrian change interval (early and late) and began to cross immediately**

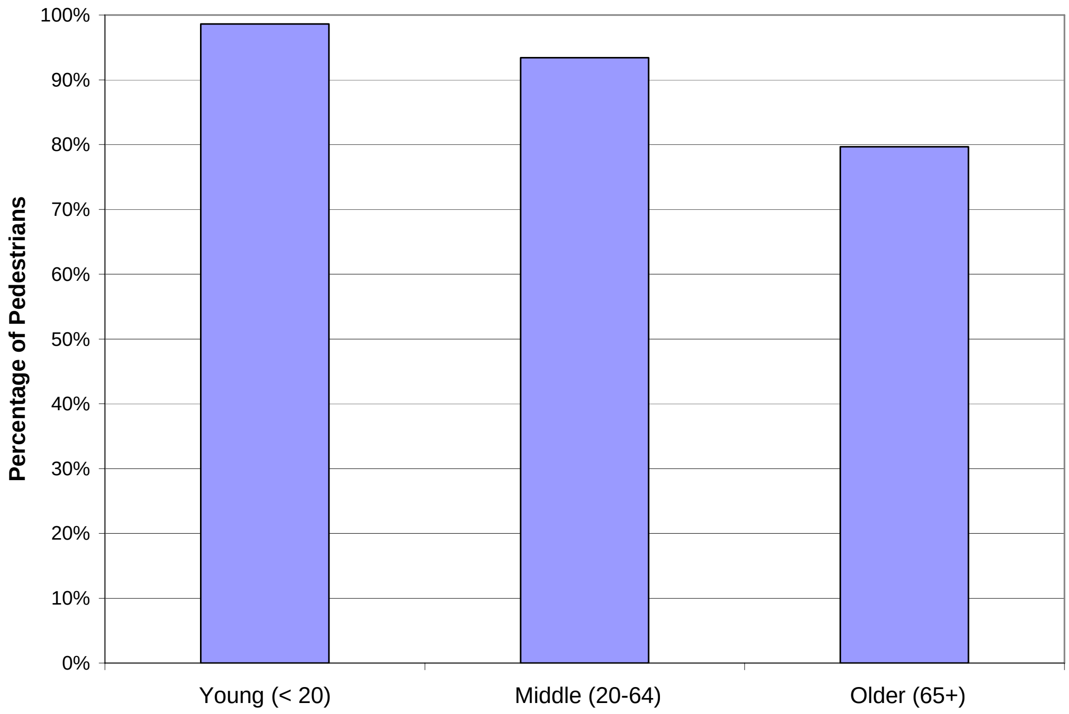


**Figure 8. Percentage of pedestrians who arrived at the curb during the pedestrian change interval and began to cross immediately, by estimated age group**

This study also investigated whether the type of CPS had any effect on the likelihood that pedestrians would begin crossing during the SDW. Figure 9 shows that the experimental CPS did not lead to an increase in crossings beginning during the SDW. However, this figure does indicate a rather large main effect of site (control vs. experimental). This difference is addressed further in the Discussion.

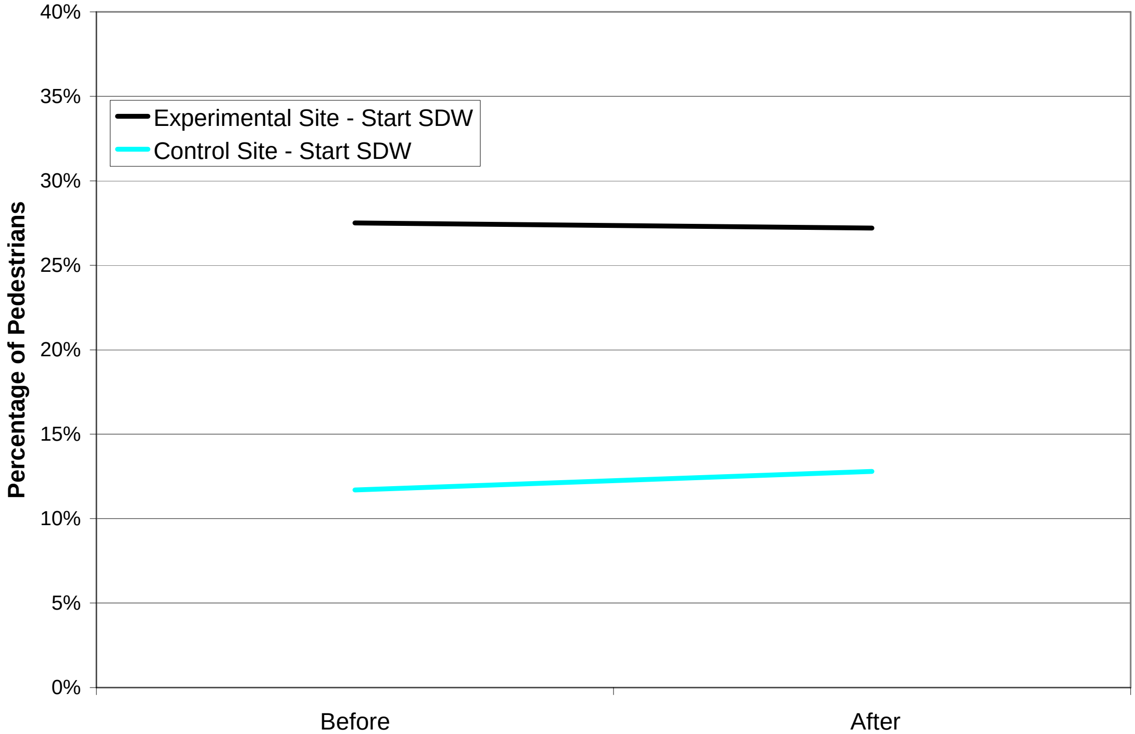


**Figure 9. Percentage of pedestrians who arrived at the curb during the SDW and began to cross immediately**

Another primary objective of this study was to determine whether CPS type had an effect on the likelihood that pedestrians who arrived at the curb during the pedestrian change interval completed crossing during the SDW phase. A logistic regression analysis found a significant effect of the experimental CPS. Relative to the standard CPS, the experimental CPS was associated with a reduction in the likelihood that pedestrians would complete crossing early in the SDW, but an increase in the likelihood that pedestrians would complete late in the SDW ($p<0.0001$). This effect appears to be in large part the result of the shift toward pedestrians beginning to cross later in the pedestrian change interval with the experimental CPS present. Figure 10 presents these findings.

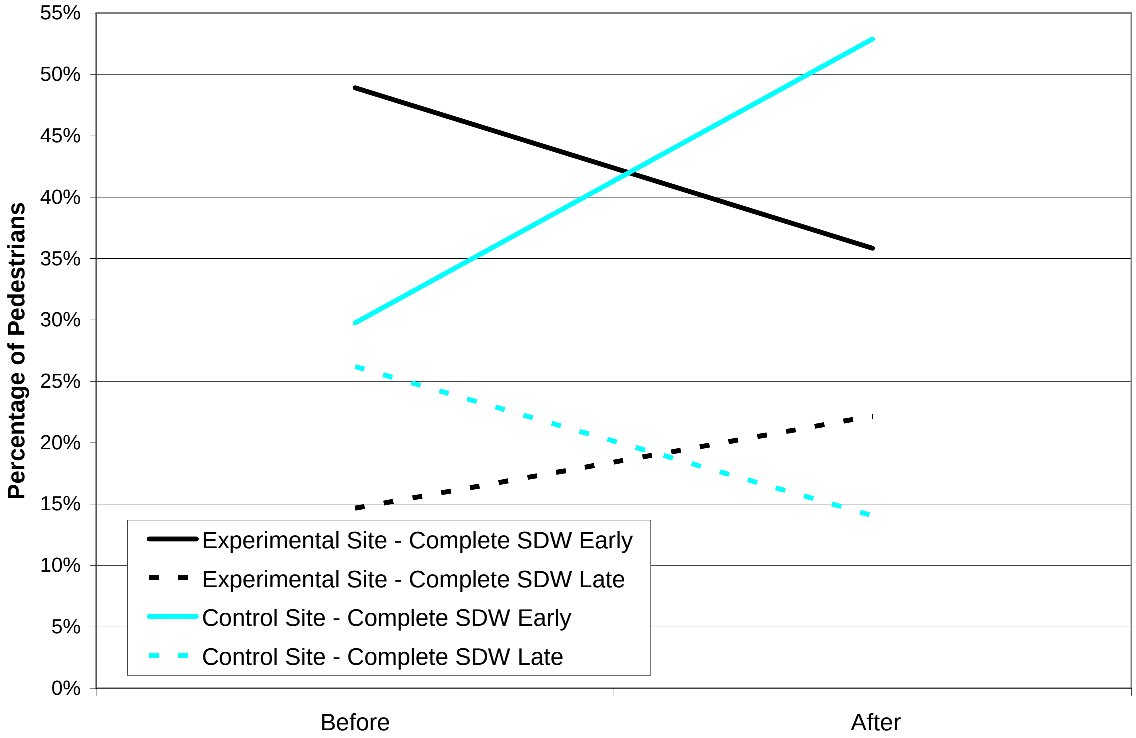


**Figure 10. Percentage of pedestrians who arrived at the curb during the pedestrian change interval and completed crossing during the SDW (early and late)**

The additional behaviors observed in this study were running, aborted crossings, and pedestrian/vehicle conflicts. Of these behaviors, only running occurred often enough to allow for meaningful reporting of findings. The percentage of pedestrians who ran at some point during their crossing is shown in Figure 11. The figure shows that the likelihood that a pedestrian would run increased as the signal cycle progressed from WALK to SDW ($p<0.0001$). Pedestrians were more often observed running into the crosswalk than continuing to run or beginning to run while in the crosswalk. The SDW phase was an exception to this trend. During the SDW, conflicting traffic had the right of way, so pedestrians were more likely to approach the curb and begin crossing cautiously, but then run once they had begun. A logistic regression analysis also revealed a small but significant effect of the experimental intervention. The experimental CPS was associated with fewer overall instances of running into the intersection than the standard CPS ($p<.05$). Specifically, the rate of running into the intersection was reduced from 2.2 percent to 1.6 percent of pedestrians. A decrease in running while in the crosswalk was also observed , but this decrease was not statistically significant. Overall, the rate of running at the experimental site decreased from 4.2 to 3.2 occurrences per 100 pedestrians when the experimental CPS was in effect. During the same period, the rate of running at the control site increased from 3.1 to 3.9 occurrences per 100 pedestrians. A significant main effect was also found for pedestrian age category, indicating an inverse relationship between pedestrian age and likelihood that they will run into the intersection ($p<0.05$).

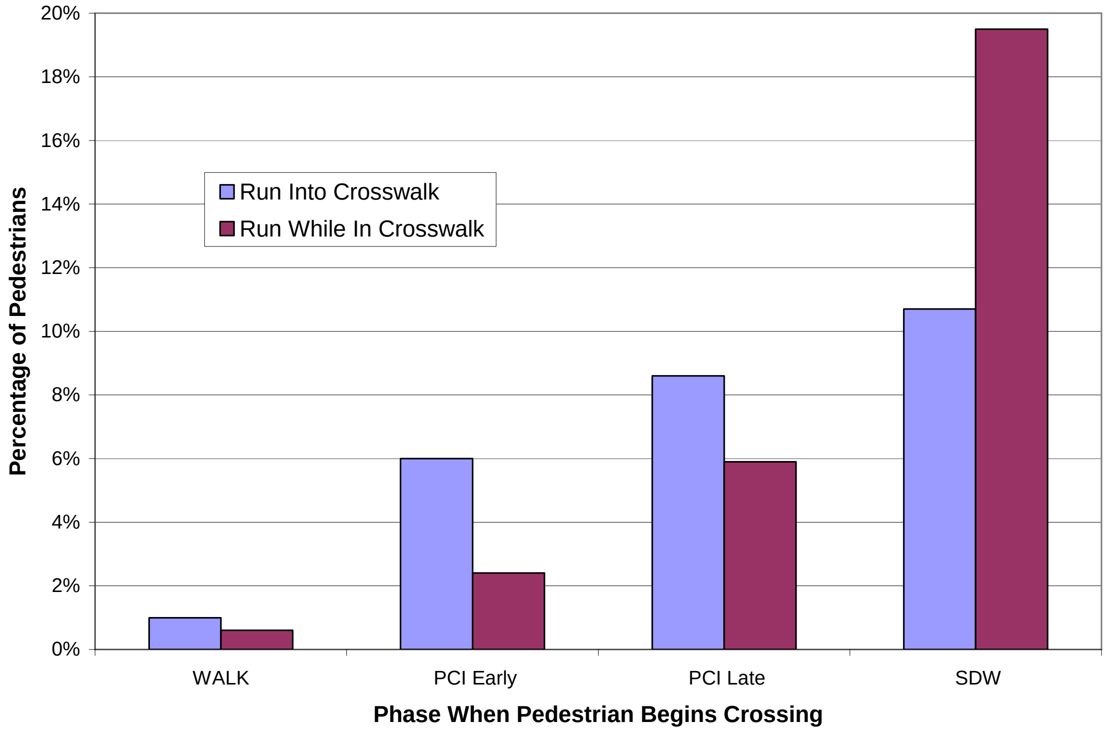


**Figure 11. Percentage of pedestrians who ran, by phase when they began crossing**

## <u>Discussion</u>

The experimental CPS had a significant effect on pedestrian crossing behaviors. Pedestrians who arrived at the curb early in the pedestrian change interval were less likely to begin to cross, but pedestrians who arrived at the curb late in the pedestrian change interval were more likely to begin to cross. Although the safety implications of this finding are unclear, it is important to note that pedestrians who began crossing late in the pedestrian change interval were about twice as likely to finish crossing during the SDW as pedestrians who began crossing early in the pedestrian change interval. Therefore, a shift of pedestrian crossing from early in the pedestrian change interval to late in the pedestrian change interval may be more likely to put pedestrians at risk, even if the overall number of pedestrians beginning during the pedestrian change interval remains the same.

The experimental CPS also had a significant effect on the time that pedestrians completed crossing. For pedestrians who arrived at the curb during the pedestrian change interval, the experimental CPS was associated with a decrease in the likelihood of completing early in the SDW, but an increase in the likelihood of completing late in the SDW. This finding in part reflects the previously noted shift in pedestrian likelihood of beginning to cross, from early in the pedestrian change interval to late in the pedestrian change interval. Other factors may be responsible for this effect as well. For instance, without the flashing hand present, pedestrians may have perceived less urgency to complete crossing, and therefore walked more slowly. Some support for this is provided by the finding that fewer pedestrians ran into the crosswalk when the experimental CPS was present than when the standard CPS was present.

Running, aborted crossings, and pedestrian/vehicle conflicts were rare events during the observation periods. Only one pedestrian/vehicle conflict and nine aborted crossings were observed during the 129 hours of video that was recorded. A small but significant decrease in the frequency of pedestrians entering the crosswalk while running was attributed to the experimental CPS. This could be due to an improved understanding of the CPS, secondary effects of changes in crossing decisions, a reduction in crossing urgency because of the lack of the flashing hand, or some combination of these factors. However, the magnitude of the effect was very small and there was not a complementary finding for running while in the crosswalk. Overall, one less incident of running was observed for every hundred pedestrians when the experimental CPS was in effect. Although the overall magnitude of this effect is small, it represents a decrease of more than 20 percent. Nonetheless, there are a variety of reasons that pedestrians may run and the degree of risk posed by running is unclear, so the impact of this finding is not known.

This study reported a high percentage of pedestrians beginning to cross the street during the pedestrian change interval. However, this high rate may be due in part to pedestrians having their choice of multiple crossing options. When a pedestrian arrives at the curb, there may be more than one direction of travel that is acceptable to them. Therefore, if a pedestrian arrives at the curb and sees the pedestrian change interval or SDW, he or she may cross perpendicularly at the other crosswalk which currently shows a WALK indication. This means that pedestrians who would have waited to cross if they had no other alternatives were instead not recorded at all because they cross at a different location. Conversely, pedestrians who intended to cross at the perpendicular crosswalk may instead cross at the experimental crosswalk because it currently shows a WALK indication. A comparison of expected (according to exposure time) versus actual arrival times at the experimental crosswalk supports this assumption (see Figure 12). Although some of the difference shown in the figure may be attributable to pedestrians adjusting their walking speed on approach to the crosswalk, the magnitude of the effect appears to validate the assumption that pedestrians often choose between more than one crossing options by selection the direction in which a WALK indication is present. In future research, this apparent confound could be avoided by selecting crosswalks where pedestrians have no likely walking alternatives other than the studied crosswalk.

An unexpected finding in this study was the difference between the two sites in the before period in terms of the percentage of pedestrians who begin crossing when they arrive at the crosswalk during the pedestrian change interval and the SDW. Even though both sites were controlled by standard CPSs and were geometrically and operationally comparable, pedestrians at the experimental site were more likely to begin crossing early and late in the pedestrian change interval and during the SDW (see Figure 7 and Figure 9). This difference is especially difficult to attribute considering that the control site had one additional second of pedestrian change interval time (11 seconds vs. 10 seconds).

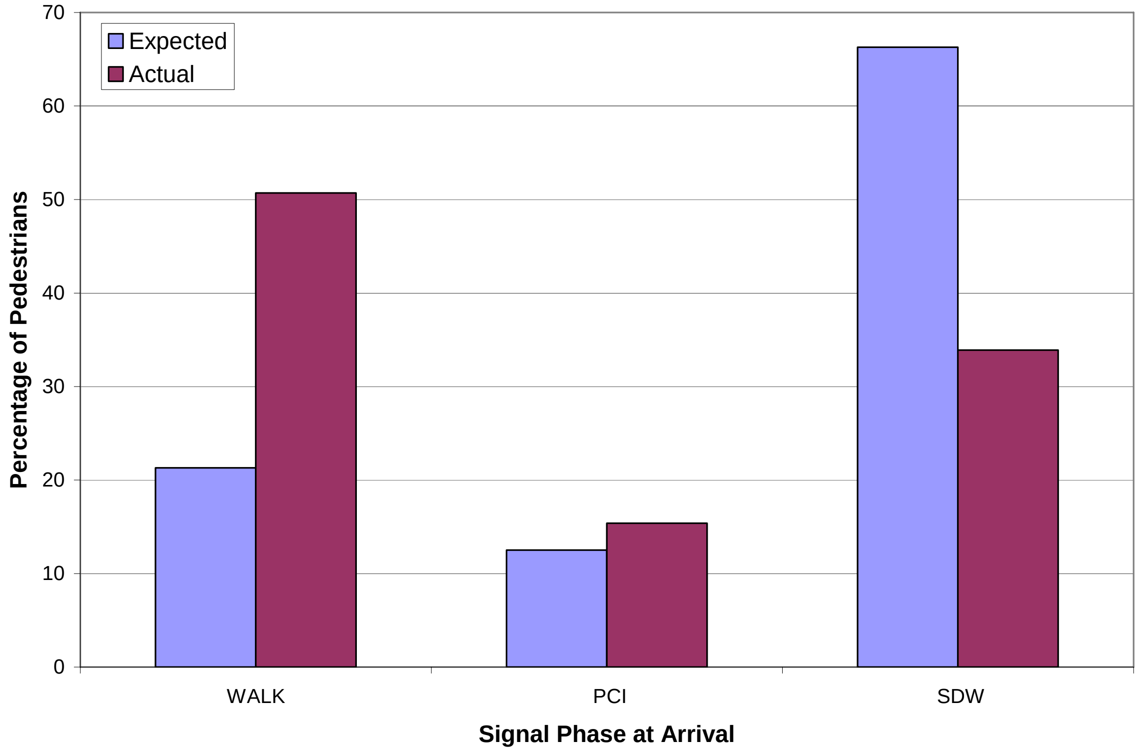


**Figure 12. Percentage of pedestrians who arrived at the experimental site during each signal phase: actual vs. expected**

It is also important to note that the experimental intervention in this study involved replacing standard CPSs with experimental CPSs. This is a relatively small change, and since the intersections surrounding the experimental site were controlled by standard CPSs, it is possible that many pedestrians did not notice the experimental intervention or thought that the lack of the flashing hand was a malfunction. Such reactions may have weakened potential effects of the experimental CPS. This issue is addressed further in the General Discussion. An alternative study design would be to first observe pedestrian behavior at two comparable crosswalks equipped with conventional signals. After the "before" observation, the conventional signals at one site (experimental) could be replaced by the experimental CPS and the conventional signals at the other site (control) could be replaced by the standard CPS. This design would allow a comparison between the two CPSs using sites where CPSs are newly installed and a pedestrian population that is less familiar with CPSs.

# GENERAL DISCUSSION

The two studies described in this report provide insight into the effects of an alternative CPS configuration (with flashing hand removed from the pedestrian change interval display) on pedestrian comprehension and crossing behavior. Study 1 was a laboratory study that compared pedestrian understanding of a conventional pedestrian signal, a standard CPS, and the experimental CPS. Study 2 was a field observational study that investigated pedestrian behavior in response to an experimental CPS in an actual crosswalk setting.

The experimental CPS had a significant effect on pedestrian behavior in Study 2. Pedestrians who arrived at the curb early in the pedestrian change interval were less likely to begin to cross, but pedestrians who arrived at the curb late in the pedestrian change interval were more likely to begin to cross. Furthermore, for pedestrians who arrived at the curb during the pedestrian change interval, the experimental CPS was associated with a decrease in the likelihood of completing early in the SDW, but an increase in the likelihood of completing late in the SDW. These shifts toward later starts and finishes are not unsafe per se, but may create more opportunities for pedestrian/vehicle conflicts and disruption of traffic operations.

In Study 2, the lack of an overall increase in crossings beginning during the pedestrian change interval was somewhat surprising. The results of Study 1 indicated that participants were significantly more likely to believe that they were allowed to begin crossing during the pedestrian change interval when the experimental CPS was present than when the other two signals were present. It is likely that participants in the laboratory study were more acutely sensitive to the subtle differences between signal configurations, given the nature of the study. The direct comparison between different signal configurations may have led participants to attribute more substantial differences between the meanings of the signals than they would have if they had seen one of the signals at an actual crosswalk. Another possibility is that, as proposed by Mahach et al. (2002), when a countdown timer is added to the pedestrian change interval display, pedestrians shift their focus from the flashing hand to the countdown timer. If the countdown timer is pedestrians' primary source of information, it follows that pedestrian behavior will be little changed if the flashing hand is removed altogether. It is also possible that most pedestrians in Study 2 were simply "set in their ways." In other words, they were experienced walkers who understood what the pedestrian change interval meant and would not react differently to a different pedestrian change interval display.

One effect of the experimental CPS observed in Study 1 was a small increase in the likelihood that male participants would think that a pedestrian can begin crossing during the SDW. This effect was not replicated in Study 2. Again, the effect observed in Study 1 may have been due to the sensitivity of the study methodology to differences between the signal configurations in the laboratory setting. In an actual crosswalk setting, it appears that the type of CPS in use has no effect on pedestrians' compliance with the SDW.

Study 1 also indicated that the experimental CPS was associated with slightly fewer confusions during the pedestrian change interval than the standard CPS was, especially when the pedestrian was shown midway across the crosswalk. In Study 2, however, behaviors that might have indicated confusion, such as aborted crossings, occurred quite rarely regardless of the CPS in effect. This lack of a complementary finding may reflect the particular sensitivity of Study 1 to differences in comprehension or the overall safety awareness of pedestrians at the study sites. It is possible that confusions may be more apparent in the form of unsafe behaviors at other locations.

Some cautions are in order when interpreting the results of these studies. First, Study 2 was limited to one experimental site, so it would be inappropriate to assume that the results of this study necessarily generalize well to other locations. A number of roadway and pedestrian factors may influence pedestrian behaviors and response to the experimental CPS. Roadway factors include the presence of a pedestrian refuge median, the width of the roadway, speed and volume of vehicular traffic, pedestrian sight distance, and the presence of turning traffic, among many others. Pedestrian factors include demographics, amount of experience crossing streets, and comprehension of conventional and countdown pedestrian signals. Pedestrian volumes may also influence crossing decision factors. This study was conducted in a relatively affluent urban neighborhood in which many crosswalks are controlled by CPSs. The pedestrian population in this neighborhood was therefore probably quite experienced in crossing streets and also familiar with CPSs. The lack of pedestrian/vehicle conflicts and aborted crossing attempts observed in this study may partially reflect the experience and safety-consciousness of pedestrians and drivers in this neighborhood. It may also reflect the characteristics of the study sites. Traffic operations were designed with pedestrians in mind and pedestrian injuries in the area are rare. More hazardous crossings, such as broad suburban arterials with high speed traffic, may be more likely to experience unsafe behaviors and events. Future research would benefit from the inclusion of multiple experimental sites that encompass a variety of roadway and pedestrian factors.

There are also additional factors and situations not investigated in these studies that may be relevant to the investigation of the experimental CPS. For instance, children were not included as participants in the comprehension study and were very rarely observed making independent crossings in the observational study, but they may not react to the experimental CPS in the same way that adults do. Also, practical limitations prevented the observation of pedestrian behaviors at night in the observational study.

# CONCLUSIONS

Taken together, the results of these two studies indicate that the experimental CPS has advantages and disadvantages when compared to the standard CPS. Study 1 indicated that the experimental CPS may lead to fewer confusions than the standard CPS, particularly among older pedestrians, and, despite the findings of the comprehension study, the experimental CPS does not appear to cause an overall increase in crossings beginning during the pedestrian change interval or crossings being completed once the SDW has begun. However, there was an increase in the number of pedestrians beginning to cross late in the pedestrian change interval and completing late in the SDW. These late starts and late finishes may increase the likelihood that pedestrians will be involved in conflicts with vehicles and disrupt traffic operations. CPS type did not have any effect on the likelihood of pedestrians beginning to cross during the SDW. The experimental CPS was associated with a small decrease in instances of running, but the reasons for this and the implications for safety are not clear.

The results of the present studies do not provide dramatic evidence in favor of, or against, the use of the experimental CPS rather than the standard CPS. Nor do the results lend themselves to simple interpretations or statements of CPS effectiveness. For instance, with only one experimental site in the observational study, the extent to which the results of the study can be generalized is not known. It is possible that the effects of the experimental CPS would differ depending on the characteristics of the crosswalks where they are installed. Prior to any conclusive recommendations, further research is needed to investigate additional crosswalk settings, pedestrian populations, and so forth.

Nonetheless, some trends in these studies are noteworthy and may indicate situations in which the experimental CPS is particularly promising. In the most general terms, the experimental CPS can be expected to provide the greatest benefit to pedestrians who are confused by the flashing hand. The laboratory study indicates that older pedestrians are one such group who may benefit from the removal of the flashing hand. Because of the tendency of the experimental CPS to lead to later starts and later finishes than the standard CPS, it is also possible that the experimental CPS would be most appropriate for inherently conservative pedestrians who would err on the side of caution rather than beginning to cross late and potentially remaining in the crosswalk when conflicting traffic is given the right of way.

# REFERENCES


Botha, J.L., Zabyshny, A.A., Day, J.E., Northouse, R.L., Rodriguez, J.O., & Nix, T.L. (2002). *Pedestrian countdown signals: An experimental evaluation – Volume 1*. Retrieved October 16, 2003 from City of San Jose, California website: www.ci.san-jose.ca.us/dot/forms/report_pedcountdown.pdf

City of Chicago Department of Transportation. (2002). *Countdown pedestrian signal study final report*. Retrieved October 16, 2003 from American Traffic Safety Services Association website: http://www.atssa.com/pubinfo/downloads/11-15-02a.PDF

DKS Associates. (2001). San Francisco pedestrian countdown signals: Preliminary evaluation summary. San Francisco, CA: *San Francisco Dept. of Parking and Traffic.*

Eccles, K.A., Tao, R., & Mangum, B.C. (2004). Evaluation of pedestrian countdown signals in Montgomery County, Maryland. In *Proceedings of the Transportation Research Board 83rd Annual Meeting,* TRB 2004 Annual Meeting CD-ROM.

Federal Highway Administration. (2001). *Manual on uniform traffic control devices, millennium edition, proposed revision no. 2,* Washington, DC.

Huang, H., & Zegeer, C. (2000). *The effects of pedestrian countdown signals in Lake Buena Vista*. Retrieved October 16, 2003 from Florida Department of Transportation Website: www11.myflorida.com/safety/ped_bike/handbooks_ and_research/ research/CNT-REPT.pdf

Mahach, K., Nedzesky, A.J., Atwater, L., & Saunders, R. (2002). A comparison of pedestrian signal heads. *ITE Annual Meeting Compendium.*

*PATH systems – portable video traffic surveillance* (2003). Retrieved October, 2003 from the ADT Northwest website: http://www.adtnorthwest.com/path.html

*Traffic safety facts 2003: Pedestrians* (2004). Report no. DOT HS 809 769. U.S. Department of Transportation, National Highway Traffic Safety Administration.

# APPENDIX A – LITERATURE REVIEW

The purpose of this literature review is to provide a concise summary of research conducted on countdown pedestrian signals. The scope of this review excludes conventional pedestrian signals and more general issues of pedestrian safety, though some of these issues are addressed within the context of the studies under review. Research studies are reviewed with an emphasis on methodological rigor, safety issues, and signal design features. Studies are reviewed comparatively, with differences between studies addressed, as well as their strengths and weaknesses. The synthesis also includes a critical look at the body of literature as a whole, including a review of general trends, gaps in the literature, and recommendations for future research and methodological improvements.

Conventional pedestrian signals compliant with the 2003 Edition of the Manual on Uniform Traffic Control Devices (MUTCD; Federal Highway Administration, 2003) have three phases presented in the following sequence:

- **WALK**, signified by a white silhouette of a person, "means that a pedestrian facing the signal indication is permitted to start to cross the roadway in the direction of the signal indication, possibly in conflict with turning vehicles" (Section 4E.02).
- **Flashing DON'T WALK (FDW)**, signified by a Portland orange flashing upraised hand, "means that a pedestrian shall not start to cross the roadway in the direction of the signal indication, but that any pedestrian who has already started to cross on a steady WALKING PERSON (symbolizing WALK) signal indication shall proceed out of the traveled way" (Section 4E.02).
- **Steady DON'T WALK (SDW)**, signified by a Portland orange steady upraised hand, "means that a pedestrian shall not enter the roadway in the direction of the signal indication" (Section 4E.02).

Research on comprehension of pedestrian signals has consistently found that the FDW is by far the most poorly understood phase, with comprehension rates sometimes reported to be below 50% (City of Chicago, 2002). This low comprehension rate may contribute to pedestrians' unsafe crossing behaviors and failure to comply with the FDW. An alternative that may improve pedestrian crossing success is the countdown pedestrian signal.

Countdown pedestrian signals (CPSs) are optional traffic control devices that can be used to supplement conventional pedestrian signals with numbers that count down the number of seconds remaining until the end of the pedestrian change interval. The purpose of CPSs is to provide pedestrians with an accurate and understandable display of the amount of time they have to cross the street safely. The countdown is displayed adjacent to, and concurrent with, the flashing hand. In the past, there has been some variation in the design and phasing of CPSs. In some cases, the countdown began during the WALK phase while in other cases the countdown begins during the pedestrian change interval.

However, specifications for CPS design and operation can now be found in the 2003 Edition of the MUTCD. The MUTCD specifies that the countdown timer should begin concurrent with the pedestrian change interval and should go blank at the onset of the SDW.

A number of studies have been conducted in order to learn more about CPSs. These studies vary widely in their methods, but typically address signal comprehension, behavioral effects, and/or pedestrian satisfaction. The following sections of this literature review summarize research findings within each of these categories.

**Signal Comprehension**

Signal comprehension studies generally use laboratory, interview, or survey methods to determine how well respondents understand the meaning of CPSs. Comprehension studies tend to focus on the pedestrian change interval, which is represented by the flashing upraised hand, because this is where confusion most often occurs. A laboratory study by Mahach, Nedzesky, Atwater, and Saunders (2002) found that only 31 percent of participants could correctly identify the appropriate action to take while crossing the street during the pedestrian change interval. Similarly, a survey conducted by the City of Chicago (2002) found that only 40 percent of respondents could correctly identify the meaning of the FDW on a conventional signal, but 100 percent understood the countdown signal. However, this report does not specify the criteria for "understanding." In the same study, about 95 percent of respondents preferred the CPS and felt that it was more understandable than the conventional signal.

Minnesota Department of Transportation (Mn/DOT) conducted pedestrian interviews at intersections with CPSs in the Twin Cities region of Minnesota (Cook Research & Consulting, Inc., 1999; Farraher, 2000). Only 8 percent of pedestrians reported being unsure when it was safe to begin crossing with the CPS. These pedestrians reported being confused by the flashing lights, being unable to understand the numbers, or that they cross by watching traffic rather than signals. Pedestrians were also shown the CPS during the pedestrian change interval and were asked what they would expect to do in this situation. Although the interviewer did not specify whether the pedestrian should imagine being at the curb or in the crosswalk, 86 percent of respondents correctly answered that they would either continue crossing or wait for the next WALK signal. When asked what the countdown meant, pedestrians generally responded that it gives the amount of time left to cross or the amount of time until the concurrent vehicular traffic signal changes. Only 11 percent of respondents incorrectly believed that the countdown gives the amount of time until pedestrians can cross or the amount of time that they have to wait before they can cross. Overall, 78 percent of respondents felt that the CPS was easier to understand than the conventional signal. Only 6 percent felt that it was more difficult to understand.

Mahach, et al. (2002) conducted a laboratory study to evaluate participants' comprehension of seven pedestrian signals. The set of signals included the conventional pedestrian signal, a CPS (with the countdown beginning during the WALK phase, in contrast to MUTCD specifications), and five other signals including an animated walking man icon and various signals using text as well as yellow and red warning triangles (triangles with exclamation points inside) to represent the pedestrian change interval and SDW signal phases. For each study trial, participants were shown a simulated, first-person perspective of a pedestrian crossing a street at a crosswalk with one of the seven signals present. Participants were instructed to press a button at any point if they believe that they no longer have enough time to complete the crossing safely. The simulated pedestrian began crossing at the beginning of the WALK phase and continued crossing as the pedestrian change interval began. Participants were always provided with enough time to finish crossing before the end of the pedestrian change interval, though they were not aware of this. Therefore, pressing the button represented a misunderstanding of the signal. Results indicate that the CPS was better understood than the conventional pedestrian signal. However, factors not directly related to comprehension, including limitations of the simulation methodology, may have also influenced participants' button-pressing behaviors. Specifically, the use of mean button press latency to represent comprehension may not accurately reflect the subtleties that influence comprehension and button press behaviors. Furthermore, the report does not specify how many participants did not press the button at all (representing correct interpretations of the signal).

Mahach, et al. (2002) also asked participants to answer questions about each signal lens seen during the crossing simulation. Participants were asked to describe the lens, the appropriate action when standing on the curb, and the appropriate action when crossing the street. Comprehension rates for the conventional signal and the CPS were comparable when standing on the curb, but comprehension of the CPS was substantially higher than comprehension of the conventional signal when walking across the street (65 percent versus 31 percent).

In Montgomery County, Maryland, 107 pedestrians were surveyed at locations with CPSs (Eccles, 2003). Although approximately 80 percent of respondents reported crossing at the same location at least once every week, less than 70 percent were aware of the presence of the countdown. About 62 percent of pedestrians correctly responded that the countdown numbers indicate the time remaining for pedestrians to reach to opposite curb. An additional 32 percent reported that the countdown displays the amount of time remaining until the concurrent traffic signal turns red. Although the latter answer is incorrect, it is consistent with the countdown's purpose and should not cause any dangerous confusions. More than 75 percent of respondents preferred the CPS to the conventional signal. Only two of the 107 respondents preferred the conventional signal. The majority of respondents who preferred the CPS did so because it provided more information. Fewer than half of respondents (38 percent) reported that they crossed differently with the CPS than with a conventional signal. Reported changes in crossing behavior included being more aware and attentive, making better judgments and estimates of crossing time, being more confident and comfortable, and being more likely to obey the signal.

Pedestrian interviews were conducted in Saint-Laurent, Quebec in an early study of CPS comprehension (Belanger-Bonneau, et al., 1994). Pedestrians were interviewed before and after CPSs were installed. Results suggested that the CPSs did not increase pedestrian comprehension of the WALK, pedestrian change interval, or SDW phases. This failure of CPSs to increase comprehension is inconsistent with most other studies of comprehension, possibly because this study was conducted before most pedestrians had experienced such signals elsewhere.

Although pedestrians tend to understand the practical meaning of the countdown timer, evidence suggests that the legal meaning of the countdown is less understood. Studies in San Jose, CA (Botha, et al. 2002) and San Francisco, CA (DKS Associates, 2001) both reported that when conventional signals were replaced by CPSs, fewer pedestrians were aware that beginning to cross during the pedestrian change interval was a violation (decreases from 76 percent to 59 percent, and from 40 percent to 17 percent, respectively). Botha and his associates also found that 80 percent of pedestrians believed that they could begin crossing during the pedestrian change interval as long as they reach the opposite curb before the countdown reaches zero.

Signal Comprehension Summary

Most studies have found that comprehension of the CPS is substantially greater than comprehension of the conventional pedestrian signal. However, CPS comprehension rates vary widely, probably the result of different questioning procedures and different definitions of a correct answer. Even though CPSs appear to increase understanding, comprehension rates are still sometimes reported to be below 70 percent (e.g., Eccles, 2003; Mahach, et al., 2002). Part of the problem may relate to the lack of understanding of the legal meaning of the CPS. Evidence suggests that when conventional signals are replaced by CPSs, fewer pedestrians are aware that it is a legal violation to begin crossing during the pedestrian change interval (Botha, et al., 2002; DKS Associates, 2001). This could be the result of a shift in pedestrians’ focus from the flashing hand to the countdown timer. Despite the lack of awareness of the legal meaning of the CPS, pedestrians appear to be able to use the additional information provided by CPSs to cross more successfully.

One major limitation of comprehension studies is that there is no proven association between comprehension rates and behavioral outcomes. From a safety standpoint, pedestrian behavior is the most important measure of CPS success and signal comprehension is only important to the extent that it influences behavior. Comprehension does not necessarily lead to appropriate behavior, nor does incomprehension necessarily lead to inappropriate behavior.

## **Behavioral Effects**

Signal Compliance and Crossing Success

Behavioral effects of a CPS are typically studied using direct observation of pedestrians at locations where a CPS is installed. The two primary measures of pedestrian behavior are signal compliance (Do pedestrians who arrive at the crosswalk during the pedestrian change interval or SDW wait to cross until the next WALK signal?) and crossing success (Do pedestrians complete the crossing before the SDW begins?). A well-designed before and after study of pedestrian behavior was conducted by the City of San Jose, CA (Botha, et al., 2002). CPSs were installed at four intersections in and around downtown San Jose, including two four-leg intersections, one five-leg intersection, and one midblock crossing. Two additional intersections were used as control sites. Both control sites were geometrically similar four-leg intersections. Researchers found that pedestrians who arrived at the crosswalk during the pedestrian change interval were about 14 percent less likely to comply with the pedestrian change interval at intersections with CPSs than intersections with conventional signals. In fact, 41 percent of pedestrians incorrectly believed that they were allowed to begin crossing during the change interval of the CPS, versus 24 percent with a conventional signal. However, compliance rates were quite low even before CPSs were installed (three of the four observed sites had compliance rates below 20 percent), which indicates that site factors may have had a substantial influence on compliance. It is possible that many pedestrians were aware that they were not supposed to cross, but did so because they could easily complete the crossing without any conflicts. Despite the fact that more pedestrians entered the intersection during the change interval, fewer pedestrians completed crossing during the SDW phase at all four intersections after CPSs were installed. Decreases ranged from 2.2 percent to 4.4 percent indicating that pedestrians were able to start and complete crossing during the pedestrian change interval.

Minnesota Department of Transportation (Mn/DOT) conducted a before-and-after study of CPSs at five intersections in the Minneapolis and Saint Paul metropolitan area (Cook Research and Consulting, Inc., 1999; Farraher, 2000). After replacing conventional pedestrian signals with CPSs, researchers observed an increase in crossing success from 67 percent to 75 percent. The greatest increase was observed for teenagers, whose rates of compliance and success both increased by 20 percent.

The City of San Francisco, CA conducted a preliminary evaluation of pedestrian behavior before and after conventional signals were replaced by CPSs (DKS Associates, 2001). The CPS pilot program involved 14 intersections, though the number of intersections actually observed during the study was not reported. No control sites were observed. Investigators found a significant increase in crossing success (from 86 percent to 91 percent) when conventional pedestrian signals were replaced by CPSs, though pedestrian behavior differed substantially between sites. There was also a small, statistically insignificant increase in compliance with the pedestrian change interval after the CPS was installed.

Eccles (2003) conducted a before-and-after evaluation of pedestrian compliance with CPSs and crossing success at five intersections in Montgomery County, Maryland. No control sites were observed. Pedestrians were observed at all four legs of each intersection. At six of the twenty observed legs, there was a significant increase in the percentage of pedestrians entering the intersection during the WALK phase. Decreases were reported at two legs. The researchers also observed the number of pedestrians remaining in each intersection at the beginning of conflicting traffic's green signal phase. After CPSs were installed, significantly fewer pedestrians remained in crosswalks at three of the five intersections. Minor, insignificant increases were reported at the other two intersections. Although the overall results of this study indicate that CPSs result in higher rates of compliance and crossing success than conventional signals do, there is substantial variability between different crossing locations.

Huang and Zegeer (2000) conducted an observational study of CPS effectiveness in Lake Buena Vista, Florida. Five intersections were observed: two with CPSs and three control sites without CPSs. The intersections were not observed before CPS installation, so potential differences between individual sites cannot be fully accounted for. One crosswalk was observed at each intersection. The researchers found that significantly fewer pedestrians began crossing during the WALK signal at CPS locations (47 percent) than at conventional signal locations (59 percent). In other words, pedestrians were more likely to begin crossing during the pedestrian change interval rather than wait for the next WALK indication. Contrary to expectations, slightly more pedestrians who began crossing during the WALK indication or pedestrian change interval remained in the intersection at the beginning of the SDW phase at crosswalks with CPSs (10.5 percent) than at crosswalks with conventional signals (7.7 percent), although this difference is not significant. The authors did not specify whether there were any differences between individual crosswalks.

CPSs were also installed and evaluated at two intersections in Monterey, California (Leonard, Juckes, & Clement, 1999). After CPSs were installed, fewer pedestrians were observed beginning crossing late in the pedestrian change interval phase. Rather than strictly obeying the CPSs, pedestrians apparently used them to decide whether it was safe to cross and adjusted their behavior depending on the amount of time remaining to cross.

An early study of CPSs was conducted in Saint-Laurent, Quebec (Belanger-Bonneau, et al., 1994). The CPSs were installed at two intersections. Two additional intersections with conventional signals were used as control sites. The countdown signal was presented on a separate signal head adjacent to the conventional signal. The countdown began during the WALK phase and continued through the pedestrian change interval. Effects of the CPS on signal compliance were inconclusive, but significantly fewer pedestrian/vehicle conflicts were observed. However, the authors further speculate that an increased sense of security associated with CPSs may lead to less careful crossing behaviors.

### Other Behavioral Effects

Compliance with the signal and crossing success are not the only measures used to determine the effects of CPSs. A number of studies have addressed other factors such as pedestrian walking speeds, occurrences of running or unusual pedestrian behaviors, conflicts with motor vehicles, and motorist speed. Botha, et al. (2002) reported little difference in walking speed, unusual behaviors, or motorist behavior between the CPS and conventional signal. However, a minor, statistically insignificant reduction in pedestrian/vehicle conflicts was reported. In San Francisco, decreases were reported in the frequency of pedestrians running or aborting crossing attempts, as well as the frequency of pedestrian/vehicle conflicts, although pedestrians often increased their walking speed to cross before the end of the pedestrian change interval (DKS Associates, 2001). Huang and Zegeer (2000) also reported significantly fewer instances of running at locations with CPSs (3.4 percent) than at locations with conventional pedestrian signals (10.4 percent). In Monterey, California, investigators reported an increase in pedestrian walking speeds at locations where CPSs were installed (Leonard, et al., 1999). Pedestrians were also more likely to wait at a mid-crossing median for the next WALK phase. The CPSs did not appear to have any adverse effect on motorist behavior.

Eccles (2003) investigated driver approach speeds at intersection legs parallel to pedestrian signals. The question was: If drivers can see the countdown timer approaching zero, will they speed up to beat the red light? The researchers observed speeds of non-platooned vehicles in the final seconds of their green signal phase before and after conventional pedestrian signals were replaced by CPSs. Results indicated that CPSs did not lead to an increase in mean speeds or 85$^{th}$ percentile speeds. The same study also addressed pedestrian/vehicle conflicts. A significant decrease in conflicts was observed at all four observed intersections after conventional signals were replaced by CPSs.

Summary of Behavioral Effects

Signal compliance is one commonly investigated measure of CPS effectiveness. Although definitions vary somewhat between studies, compliance generally refers to the likelihood that pedestrians will begin crossing the street during the WALK phase rather than the pedestrian change interval or SDW. The effects of CPSs on compliance vary from positive to neutral to negative, depending upon the study and the crosswalk being investigated. Positive effects may be due in part to the additional information provided to pedestrians. Negative effects may be due in part to pedestrians who arrive at the crosswalk during the pedestrian change interval but determine that they have enough time to cross the street before encountering conflicting traffic. Furthermore, pedestrian surveys indicate that pedestrians are more likely to incorrectly believe that they are allowed to enter the intersection during the pedestrian change interval when crossing at a CPS (Botha, et al., 2002; DKS Associates, 2001).

Although effects on signal compliance are mixed, CPSs have been shown to have generally positive effects on crossing success. Overall, increases in the rates of crossing success range from about 3 percent to about 10 percent, though there is substantial variability between studies and even between locations within studies. Some studies have found that pedestrians are more likely to begin crossing during the pedestrian change interval when countdown information is provided, but fewer pedestrians remain in the crosswalk when the pedestrian change interval ends (Botha, et al., 2002; DKS Associates, 2001; Huang & Zegeer, 2000). This may be due in part to pedestrians walking more quickly if they enter during the pedestrian change interval, though Botha and his associates reported no increase in walking speed after CPS installation. Despite inconclusive walking speed findings, studies have generally found that there are fewer instances of running when countdown information is provided (DKS Associates, 2001; Huang & Zegeer, 2000). One possible explanation for this is that pedestrians are willing to begin crossing during the pedestrian change interval even if they must walk more quickly to reach the opposite curb before the end of the pedestrian change interval, but they will not begin crossing if they expect that they will need to run.

If pedestrians do, in fact, estimate their ability to complete the crossing before the countdown reaches zero and make a decision to cross or not based on this, it would be of interest to know whether this behavior varies across ages and genders. For instance, it would be helpful to know whether older pedestrians or pedestrians with mobility impairments who may be slower than other pedestrians are more likely to cross conservatively (e.g., do not begin crossing after the start of the pedestrian change interval) or whether they are just as likely to begin crossing as late as faster pedestrians and, as a result, be more likely to remain in the crosswalk when the SDW begins. Unfortunately, previous research has not investigated the effects of pedestrian demographics at this level of detail in a field observational study.

One limitation of crossing success studies is that they typically define success as completion of the crossing before the beginning of the SDW phase. However, a definition that is more directly relevant to safety would define success as completion of the crossing before the release of potentially conflicting traffic. Though jurisdictional practices vary, this definition typically provides pedestrians with additional crossing time during the vehicular yellow phase and the vehicular all-red phase. The latter definition would limit the set of unsuccessful crossers to those who are actually at risk of vehicle conflicts. Although this may be an improvement, more research is needed to define surrogate measures that accurately reflect pedestrian safety issues.

In addition to crossing success, CPSs appear to have a positive effect on other behaviors. Decreases have been reported in pedestrian/vehicle conflicts (Belanger-Bonneau, et al., 1994; Botha, et al., 2002; DKS Associates, 2001; Eccles, 2003) and in frequency of aborted crossing attempts (DKS Associates, 2001). The effects of CPSs on driver speed and red light-running appear to be negligible (Botha, et al., 2002; Eccles, 2003; Leonard, et al., 1999). Many of the effects on unusual pedestrian and driver behaviors are statistically weak, however, due to a limited number of observations.

The direction and magnitude of behavioral effects sometimes vary widely between studies, as do the conclusions drawn by investigators. To some extent, these variations can be attributed to differences in methodology. For instance, some studies treat groups of pedestrians as one individual data point while others treat each group as one single data point. Likewise, the definition of an “unsuccessful crossing” varies between studies. Numerous other variations in methodology may contribute to inconsistent findings. However, variations between studies are not the only source of inconsistency. In fact, studies that have investigated CPSs at more than one location have sometimes found different results at each study location, even though the methodology is the same. For example, Eccles (2003) found that of 20 observed crosswalks, significant improvements in compliance were observed at six crosswalks, significant decreases were observed at two crosswalks, and no significant difference was observed at the remaining 12 crosswalks. Such results indicate that the effects of CPSs may be situational. More research is needed to better understand the factors that influence CPS effectiveness. Such research could ultimately be used to help target CPS installations to locations where they will provide the greatest benefit.

## Pedestrian Satisfaction and Preference

Pedestrian satisfaction studies generally use interview or survey methods to assess pedestrians' opinions about signals, including perceived ease of use, safety, comparison with other signals, confusions, and suggestions for improvement. In San Francisco, 78 percent of pedestrians reported CPSs to be "very helpful," versus only 34 percent for conventional signals (DKS Associates, 2001). In the same study, 92 percent of pedestrians expressed a preference for the CPS.

Minnesota Department of Transportation (Mn/DOT) conducted pedestrian interviews at intersections equipped with CPSs in the Twin Cities region (Cook Research & Consulting, Inc., 1999; Farraher, 2000). Researchers found that 79 percent of pedestrians at the experimental sites preferred the CPS to the conventional signal. Satisfaction was greatest among teens (91 percent) and lowest among older pedestrians (59 percent). The most often reported reasons that pedestrians preferred the CPS were that it gave them additional information about how much time they had to cross, it let them know how quickly they had to cross, and that it improves safety and makes pedestrians more cautious. Those who preferred the conventional signal did primarily because they did not understand the CPS numbers and found the conventional signal easier to understand. Some older pedestrians expressed confusion associated with the simultaneous presentation of the pedestrian change interval and the countdown. Nonetheless, 92 percent of pedestrians reported that the CPS was at least "somewhat more helpful" when crossing than the conventional signal.

Mahach, et al. (2002) conducted a laboratory study to assess pedestrian signal preference among a set of seven signals, including a conventional pedestrian signal and a CPS (with the countdown beginning during the WALK phase, in contrast to MUTCD specifications). Nearly 60 percent of participants selected the CPS as their favorite. The conventional signal was preferred by only 4 percent of participants.

In a relatively early study, CPSs were evaluated in Saint-Laurent, Quebec (Belanger-Bonneau, et al., 1994). Although 89 percent of pedestrians found the CPS easy to understand, only 30 percent said they would pay attention to it and only 3 percent would go out of their way to use it. Forty-two percent of respondents felt that a sign was necessary to explain the CPS. However, interpretation of these results must acknowledge that this study was conducted early in the development of CPSs and pedestrians were likely less familiar with CPSs than they are now.

Summary of Pedestrian Satisfaction and Preference

Pedestrians overwhelmingly approve of CPSs and typically prefer them to conventional signals. Cook Research & Consulting, Inc. (1999) found a noteworthy age difference in CPS satisfaction, where satisfaction was highest among teens and lowest among older pedestrians. Age differences such as this warrant additional investigation. It is also unknown what relationship may exist between pedestrian satisfaction, comprehension, and safety.

## Conclusions

Despite some inconsistencies in the data, some conclusions can be drawn from the literature on CPSs. The general consensus of the literature is that even though CPSs do not appear to substantially reduce (and in fact, may increase) the number of pedestrians entering the crosswalk during the pedestrian change interval, they do provide pedestrians with additional information that helps them to cross the street more successfully. Furthermore, CPSs are associated with a reduction in undesirable events such as aborted crossings, running, and pedestrian/vehicle conflicts. Contrary to some concerns, CPSs do not appear to cause drivers to increase their speeds. Pedestrians have a better understanding of the meaning of the CPS than of the conventional pedestrian signal, but less often realize that entering the crosswalk during the pedestrian change interval is a legal violation. Pedestrians also overwhelmingly prefer CPSs to conventional and alternate signals and feel that CPSs make them safer and more informed pedestrians.

Although trends are apparent in the data, there is also substantial variability in measures of CPS effectiveness. To some extent, this may be a result of inconsistent methodologies and measures. However, some studies that were conducted at multiple sites reported different results at each site. For instance, Eccles (2003) observed pedestrian behavior before and after conventional signals were replaced by CPSs at 20 crosswalks (four crosswalks at each of five intersections). Results showed significant increases in crossing success at six crosswalks, significant decreases at two crosswalks, and no significant change at the other crosswalks. The variability between these sites may have something to do with site factors, pedestrian characteristics, or other factors. As CPSs begin to receive more widespread attention and use, it is becoming increasingly important to determine factors that influence their effectiveness. This knowledge will help engineers decide where CPSs will provide the greatest benefit.

Despite the advantages offered by CPSs, there is still further room for improvement. CPSs have been shown to increase the rate of crossing success, but these increases are typically modest. Additional improvements may help to bring success rates higher. Another emphasis of further research should be to use measures that accurately reflect safety. For instance, pedestrians who begin crossing during the pedestrian change interval are technically in violation of the law even if they complete the crossing successfully before the SDW. Such possibilities may indicate that crossing success is a more accurate measure of safety than signal compliance.

One change that may improve the effectiveness of CPSs is to remove the flashing orange hand from the pedestrian change interval, leaving only the countdown timer. Investigations of CPS effectiveness have generally concluded that CPSs provide pedestrians with useful information that helps them to cross the street more successfully. However, pedestrian comprehension of the concurrent flashing orange hand is relatively poor and compliance with the legal meaning of the pedestrian change interval is low. Therefore, removing the flashing hand from the CPS may actually improve pedestrian comprehension and crossing success by eliminating the source of confusion.

## References


Belanger-Bonneau, H., Lamothe, F., Rannou, A., Joly, M., Bergeron, J., Breton, J., Laberge-Nadeau, C., & Maug, U. (1994). Projet d'Experimentation et d'Évaluation d'une Signalisation Numerique Pietionnière: Le Décompte Visual. Unité de Santé Publique, Hopital du Sacré-Coeur de Montréal, Centre de Recherche sur les Transport.

Botha, J.L., Zabyshny, A.A., Day, J.E., Northouse, R.L., Rodriguez, J.O., & Nix, T.L. (2002). Pedestrian Countdown Signals: An Experimental Evaluation – Volume 1. Retrieved October 16, 2003 from City of San Jose, California Web site: www.ci.san-jose.ca.us/dot/forms/ report_pedcountdown.pdf

City of Chicago Department of Transportation. (2002). Countdown Pedestrian Signal Study Final Report. Retrieved October 16, 2003 from American Traffic Safety Services Association Web site: http://www.atssa.com/pubinfo/downloads/11-15-02a.PDF

Cook Research & Consulting, Inc. (1999). Countdown Pedestrian Indication Market Research. Minneapolis, MN: Mn/DOT's Metropolitan Division Traffic Engineering Section.

DKS Associates. (2001). San Francisco Pedestrian Countdown Signals: Preliminary Evaluation Summary. San Francisco, CA: San Francisco Dept. of Parking and Traffic.

Eccles, K.A. (2003). Evaluation of Pedestrian Countdown Signals. Silver Spring, MD: Prepared by BMI-SG for Montgomery County Maryland and Maryland State Highway Administration.

Farraher, B.E.B. (2000). Pedestrian Countdown Indication – Market Research and Evaluation. Retrieved October 16, 2003 from Minnesota Department of Transportation Web site: http://www.dot.state.mn.us/metro/trafficeng/signals /files/compendium.pdf

Federal Highway Administration. (2003). Manual on Uniform Traffic Control Devices for Streets and Highways, 2003 Edition. Washington, DC: Federal Highway Administration.

Huang, H., & Zegeer, C. (2000). The Effects of Pedestrian Countdown Signals in Lake Buena Vista. Retrieved October 16, 2003 from Florida Department of Transportation Web site: www11.myflorida.com/safety/ped_bike/handbooks_ and_research/ research/CNT-REPT.pdf

Leonard, J., Juckes, M., & Clement, B. (1999). Safety & Behavior: Behavioral Evaluation of Pedestrians and Motorists Towards Pedestrian Countdown Signals. Laval, Quebec: Prepared by Dessau-Soprin Inc. for the city of Monterey, California.

Mahach, K., Nedzesky, A.J., Atwater, L., & Saunders, R. (2002). A comparison of pedestrian signal heads. ITE Annual Meeting Compendium.