Effects of Yellow Rectangular Rapid-Flashing Beacons on Yielding at Multilane Uncontrolled Crosswalks

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FOREWORD

The overall goal of the Federal Highway Administration's (FHWA) Pedestrian and Bicycle Safety Research Program is to increase pedestrian and bicycle safety and mobility. From better crosswalks, sidewalks, and pedestrian technologies to growing educational and safety programs, the program strives to make it safer and easier for pedestrians, bicyclists, and drivers to share roadways.

This study was part of a larger FHWA research study to quantify the effectiveness of existing and new engineering countermeasures in improving safety and operations for pedestrians and bicyclists. This effort involved data collection and analysis to determine whether these countermeasures increased driver yielding to pedestrians. In this study, the safety effectiveness of the rectangular rapid-flashing beacon (RRFB) for pedestrians was evaluated using a before-after time-series analysis.

This report will interest engineers, planners, and other practitioners who are concerned about implementing pedestrian and bicycle treatments as well as city, State, and local authorities who have a shared responsibility for public safety.

Monique R. Evans
Director, Office of Safety
Research and Development

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16. Abstract

The rectangular rapid-flashing beacon (RRFB) device is a pedestrian-activated beacon system located at the roadside below side-mounted pedestrian crosswalk signs. This study examined the effects of the RRFB at uncontrolled marked crosswalks. Several methods have been examined to increase driver yielding to pedestrians at multilane crosswalks at uncontrolled locations with relatively high average daily traffic (ADT). Previously, only treatments that employed a red phase have consistently produced sustained high levels of yielding at high-volume multilane crosswalks. A series of five experiments examined the efficacy of RRFBs. These studies found that RRFBs produced an increase in yielding behavior at all 22 sites located in 3 cities in the United States. Data collected over a 2-year follow-up period at 18 of these sites also documented the long-term maintenance of yielding produced by RRFBs. A comparison of RRFBs to a traditional overhead yellow flashing beacon and a side-mounted traditional yellow flashing beacon documented higher driver yielding associated with RRFBs that was not only statistically significant, but also practically important. Data from other experiments demonstrated that mounting additional beacons on pedestrian refuge islands, or medians, and aiming the beacons to maximize its salience at the dilemma zone increased the efficacy of the system, while two other variants were not found to influence the effectiveness of the system.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. INTRODUCTION

BACKGROUND

St. Petersburg, FL, has approximately 100 uncontrolled crosswalks located in close proximity to pedestrian generators and attractors that do not meet current pedestrian signal warrants. It is difficult for pedestrians to safely cross at these locations because these crosswalks are located along wide high-speed multilane roads, are not in close proximity to traffic signals, and have low percentages of drivers yielding to pedestrians.

With the Federal Highway Administration's (FHWA) permission to experiment, the city has taken steps to address this problem by installing solar-powered, radio-controlled, pedestrian-activated amber light-emitting diode (LED) rectangular rapid-flashing beacons (RRFBs) mounted under pedestrian crosswalk signs at 19 existing uncontrolled crosswalks. The purpose of this research was to evaluate the behavioral effects of this treatment on driver yielding at these crosswalks and to determine variables that influence the efficacy of this treatment.

STUDY APPROACH

The objective of the research effort was to evaluate whether RRFBs could increase driver yielding to pedestrians on high-volume, multilane crosswalks. Researchers selected three cities in the United States, with typically low percentages of drivers who yield to pedestrians: St. Petersburg, FL; Washington, DC; and Mundelein, IL. The research team also wanted to determine the optimum way to install the device. Because the RRFB is side mounted, researchers compared mounting the beacons on only the side of the road as well as mounting them on the side of the road plus in the median or refuge island to increase visibility in all traffic lanes.

CHAPTER 2. LITERATURE REVIEW

Drivers often fail to yield to pedestrians who have the right-of-way in marked crosswalks at uncontrolled locations. From the beginning of 2004 to the end of 2006, there were a total of 14,351 pedestrian fatalities and 212,786 pedestrian injuries resulting from pedestrian-automobile collisions nationwide.(1) Decreasing the occurrence of these crashes would increase the safety and overall walking experience for pedestrians. Anything less than a traffic signal has historically failed to produce over 70 percent yielding at crosswalks on multilane roads.

Several techniques and technologies have been used to increase driver yielding to pedestrians at marked crosswalks. One older technology included the use of flashing overhead standard yellow beacons.(2) More recent approaches include the use of in-street signs labeled “YIELD TO PEDESTRIAN” and in-roadway lights.(2) Ellis et al. experimented with in-street signs placed vertically in center lanes.(3) The signs were placed at the crossing, 20 ft in advance of the crosswalk, and 40 ft in advance of the crosswalk. The installation of these signs produced an increase of two to three times the yielding percentage over the baseline, with maximum yielding of about 61 percent. However, a study by Turner et al. shows that in-street signs do not work well on multilane roads.(4) Several studies have shown only modest increases in yielding with in-pavement lighting.(4,5)

An inexpensive and effective alternative solution is the pedestrian crossing device that employs yellow LED RRFBs that are similar in operation to emergency flashers on police vehicles. Van Houten et al. reported the results of a preliminary evaluation of this device at two multilane sites in Miami-Dade County, FL.(6) They found that the RRFB produced a large increase in driver yielding to staged pedestrian crossings (crossings made by research assistants who crossed in a consistent manner) and that the data obtained with staged crossings accurately reflected the data obtained with nonstaged crossings at these sites. The purpose of this study was to identify variables related to the efficacy of the RRFB, determine the long-term effectiveness of the RRFB, compare the RRFB to standard incandescent yellow flashing beacons, and determine if similar results can be obtained in different regions of the United States. The first experiment compared the effects of installing RRFBs on pedestrian signs on both sides of the crosswalk (two sets of beacons) to installing them on both sides of the crosswalk plus on the median island (four sets of beacons). The second experiment compared RRFBs with a traditional overhead flashing beacon and traditional beacons mounted beside the pedestrian signs. The third experiment examined the long-term effects of RRFBs at 18 sites in St. Petersburg, FL, and the short-term effects of RRFBs at three sites in two other parts of the country. The fourth experiment examined the efficacy of direct-aim technology that allowed RRFBs to have maximum brightness at a particular point in the roadway. Finally, the fifth experiment examined the effect of placing additional RRFBs on the crosswalk advance warning signs.

CHAPTER 3. EXPERIMENT 1

METHOD

Participants and Setting

The first experiment took place in St. Petersburg, FL. Participants drove on several routes including: 1st Street N south of 37th Avenue, 58th Street N south of 3d Avenue, 22d Avenue N east of 7th Street, and 31st Street S north of 54th Avenue. The crossing at 1st Street N traverses four lanes and has a posted speed limit of 35 mi/h and an average daily traffic (ADT) of 8,596. This location provides a crossing between two bus stops and includes a median island. The 58th Street N crossing traverses four lanes of traffic and has a posted speed limit of 35 mi/h and an ADT of 19,192. It also has a median island and provides a crossing for residents from a nearby retirement center. The 22d Avenue N crossing traverses four lanes and has a posted speed limit of 35 mi/h and an ADT of 13,524. It is equipped with a center island and provides a crossing for neighbor residents and a dog park. The 31st Street S crossing traverses three lanes at the crossing itself and has a posted speed limit of 35 mi/h and an ADT of 9,600. It has a median island and provides a crossing between an overflow parking lot and a community sports complex. Each of these sites is on a road carrying two-way traffic. All sites have advance yield markings installed and no-pass solid lane lines in advance of the crosswalks to reduce the risk of multiple threat crashes. These features were present during the before-and-after conditions at each site.

Apparatus

The treatment in this experiment was a standard pedestrian warning sign with two rectangular yellow LED flashers attached (see figure 1). The warning sign was either yellow or yellow-green depending on whether it was a regular sign or a school crossing sign. Each LED flasher is 6 inches wide and 2.5 inches high and placed 9 inches apart. In addition, each unit is dual indicated, with LEDs on the front and back. Each side of the LED flasher illuminates in a wig-wag sequence (left and then right). The left LED flashes two times in a slow volley each time it is energized (124 ms on and 76 ms off per flash). This is followed by the right LED, which flashes four times in a rapid volley when energized (25 ms on and 25 ms off per flash) and then has a longer flash for 200 ms. This flash pattern violates a person's expectation and results in a pattern that can be described as a "stutter flash effect."(6) In addition to the LED beacons, four signs were installed at each crosswalk. Radio frequency transmitters linked the devices so that depressing any of the pedestrian call buttons activated the flashers on all four signs. A flashing LED display facing the pedestrians flashed to indicate to them that the system was operating. The system also presented an audible message informing pedestrians that the light flashing across the street indicated that the device was operating and instructing them to wait for cars to stop before crossing. This message was also visible on a plaque posted by the call button.

Figure 1. Photo. RRFB with two forward-facing LED flashers and a side-mounted LED flasher.

Experimental Design

For this experiment, a reversal design was used. The design allowed for control of several possible confounding variables. Following baseline conditions, the signs were installed and activated in an alternating series of LED beacons flashing on two side signs and LED beacons flashing on all four signs upon button activation. Each datasheet consisted of 20 pedestrian crossings when vehicles were present. Baseline sessions consisted of four sites, and researchers recorded the first site for 5 datasheets, the second site for 7 datasheets, the third site for 9 datasheets, and the fourth site for 11 datasheets. This allowed for a staged introduction of the treatment across sites. Once the treatment was introduced, two datasheets were collected at each site, with one datasheet used to record only two of the flashers switched on and the second datasheet used to record the other half of the crossing with all four systems switched on. After five sessions of data collection using this procedure, the treatment was switched off, and data were collected for five sessions without device activation (a return to the baseline condition). Next, the treatment was switched on again, and two sets of data were collected for each of the next five sessions, half with only the two curbside devices activated and half with both curbside devices plus the two median devices activated. This produced a total of 82 datasheets comprised of 1,640 crossings. Long-term data were collected approximately 14 months following the initial experimental sessions. Each of the four sites received at least 40 additional crossings during follow-up data collection.

Measures

During each session, data were collected for 20 pedestrians who crossed the street when vehicles were present, which could have influenced crossing behavior. Most data were collected on weekdays during daylight hours when it was not raining. Probe data were collected at night on a number of sessions. Observers measured the following behaviors:

- The number of drivers who did and did not yield to pedestrians in crosswalks.
- The number of vehicle/pedestrian conflicts that involved evasive action taken by a driver or pedestrian.
- The number of pedestrians trapped at the centerline by drivers who failed to yield.
- The percentage of drivers who yielded at less than 10 ft, more than 10 ft but less than 20 ft, more than 20 ft but less than 30 ft, more than 30 ft but less than 50 ft, more than 50 ft but less than 70 ft, more than 70 ft but less than 100 ft, and more than 100 ft.
- The number of drivers who passed or attempted to pass a stopped vehicle.
- The number of drivers in following vehicles who engaged in hard braking behind a stopped car.

Whether Drivers Yielded to Pedestrians

Observers recorded the percentage of drivers who did and did not yield to pedestrians. Drivers were recorded as yielding if they stopped or slowed and allowed pedestrians to cross. Conversely, drivers were recorded as not yielding if they passed in front of pedestrians but would have been able to stop when the pedestrians arrived at the crosswalk. The Institute of Transportation Engineers (ITE) signal formula for determining the duration of the yellow signal phase was used to decide whether a driver could safely stop.[(7)] Calculating the distance before which a driver can safely stop for a pedestrian is essentially the same problem as calculating the distance that a driver can stop for a traffic signal that changes to red. Traffic engineers use the signal-timing formula, which takes into account driver reaction time, safe deceleration rate, posted speed, and grade of the road.[(7)] This formula was used to measure the distance beyond which a driver could safely stop for a pedestrian by calculating the yellow time and then multiplying this time by the speed limit to determine a distance. A landmark associated with this distance was identified for each approach to the crosswalk. Drivers who passed this landmark before the pedestrian started to cross could be scored as yielding to pedestrians and not for failing to yield because they might not have sufficient distance to safely stop. Drivers who were located beyond the landmark when the pedestrian entered the crosswalk could be scored as yielding or not yielding because they had sufficient distance to safely stop. When pedestrians first started to cross, only drivers in the first half of the roadway were scored for yielding. Once pedestrians approached the painted median, the yielding behaviors of drivers in the remaining two lanes were scored. This procedure was followed because it conformed to the obligation of drivers specified in the Florida statutes.

Staged crossings always followed a specific crossing protocol. First, the staged pedestrian placed one foot in the crosswalk when an approaching vehicle was just beyond the landmark distance (this is the measured distance for the vehicle speed, which ensured a safe stopping distance for drivers traveling at the posted speed). If the driver made no attempt to stop, the pedestrian did not proceed to cross and scored the driver and any subsequent drivers as not yielding. If the driver clearly began to yield and the next lane was free, the pedestrian would begin crossing. The pedestrian always stopped at the lane line and made sure the next lane was clear. If a large gap appeared, the pedestrian finished the crossing. This is essentially the protocol followed by police officers when they conduct pedestrian-crossing-enforcement sting operations. This protocol ensured the safety of the staged pedestrians. Unstaged pedestrian crossings were only scored if the pedestrian initiated a crossing in the same manner as the staged pedestrian by placing at least one foot in the crosswalk. Pedestrians who did not place a foot into the crosswalk were not scored because according to the Florida statutes, drivers are not required to yield unless the pedestrian is in the crosswalk.

Conflicts Between Drivers and Pedestrians

A conflict between a driver and a pedestrian was recorded whenever a driver suddenly stopped or swerved to avoid striking a pedestrian or whenever a pedestrian jumped, ran, or suddenly stepped or lunged backward to avoid being struck by a vehicle. Conflicts were rare because of the use of the safe crossing protocol.

Pedestrian Trapped at the Centerline

Pedestrians were recorded as trapped at the center whenever they had to wait at the centerline for 5 s or more because at least one car in the second half of the roadway did not yield.

Yielding Distance

The distances of yielding drivers were also recorded. Each yielding driver represented a yielding distance. The distance at which a driver yielded was recorded by observing the colored flag the driver yielded behind. A series of small colored utility-like flags were placed alongside the curb in each direction of traffic at 10, 20, 30, 50, 70, and 100 ft. The colors of the flags were red, orange, yellow, green, blue, and red, respectively. This provided a simplified system for recording the distance of yielding drivers in the following divisions: less than 10 ft, more than 10 ft but less than 20 ft, more than 20 ft but less than 30 ft, more than 30 ft but less than 50 ft, more than 50 ft but less than 70 ft, more than 70 ft but less than 100 ft, and more than 100 ft. The distance of a yielding driver was recorded only after the pedestrian had completely cleared the lane and was no longer in the path of the vehicle so that the vehicle posed no threat.

Driver Passed or Attempted to Pass Stopped Vehicle

Drivers were recorded as passing a stopped vehicle if they passed another driver that was yielding to a pedestrian. Drivers were recorded as attempting to pass a stopped vehicle if they did not yield until after they were alongside or past a yielding vehicle and engaged in hard braking after seeing the pedestrian or if they were behind a yielding vehicle and changed lanes to go around but then yielded.

Driver Behind Yielding Vehicle Engaged in Hard Braking

A driver was recorded as hard braking if his or her vehicle was behind a yielding vehicle, and the front end of his or her vehicle was observed taking a sudden movement toward the ground.

RESULTS

Driver Yielding Behavior

The first site at 22d Avenue N east of 7th Street had an average baseline driver yielding percentage of 28 percent. The first two-beacon system produced an average yielding percentage of 82 percent, while the first four-beacon system produced an average yielding percentage of 95 percent. The reversal back to two beacons produced an average yielding percentage of 87 percent, and the second treatment of four beacons had an average yielding percentage of 91 percent.

The second site at 58th Street N south of 3d Avenue had an average baseline driver yielding percentage of 11 percent. The first two-beacon system produced an average yielding percentage of 78 percent, while the first four-beacon system produced an average yielding percentage of 88 percent. The reversal back to two beacons produced an average yielding percentage of 85 percent, and the second treatment of four beacons had an average yielding percentage of 89 percent.

The third site at 1st Street N south of 37th Avenue had an average baseline driver yielding percentage of 18 percent. The first two-beacon system produced an average yielding percentage of 87 percent, while the first four-beacon system produced an average yielding percentage of 90 percent. The reversal back to two beacons produced an average yielding percentage of 84 percent, and the second treatment of four beacons had an average yielding percentage of 90 percent. Night data were also collected at this location. During night collection, there was a baseline driver yielding percentage of 5 percent. The introduction of the two-beacon system increased yielding to 85 percent, while the activation of the four-beacon system further increased yielding to 100 percent. The yielding percentage decreased to 89 percent with the reversal back to the two-beacon system and increased to 99 percent during the last phase of the four-beacon system.

The fourth site at 31st Street S north of 54th Avenue had an average baseline driver yielding percentage of 15 percent. The first two-beacon system produced an average yielding percentage of 67 percent, while the first four-beacon treatment produced an average yielding percentage of 79 percent. Yielding averaged 79 and 81 percent during the final two-beacon and four-beacon conditions, respectively. The results showed an average yielding percentage of 15 percent for the baseline, 73 percent for two systems, and 80 percent for four systems.

A two-sample *t*-test for matched pairs was performed to test the significance of the reported yielding percentages between the two- and four-beacon systems. The test showed significance at the 0.05 level. Figure 2 illustrates the average yielding percentage per condition at night at one site where night data were collected.

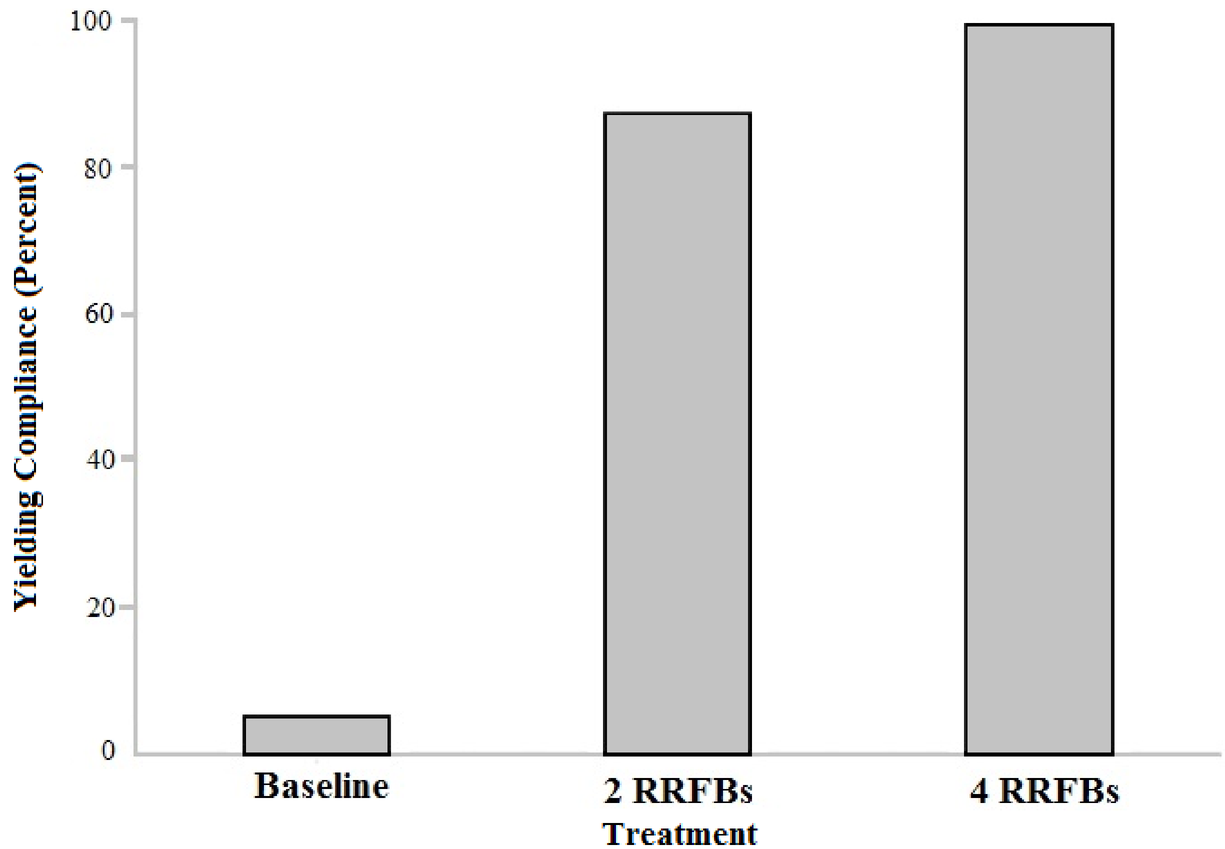

Figure 2. Graph. Yielding compliance for three conditions during nighttime observations at the third site at 1st Street and 37th Avenue S.

The data collected during each of the follow-up sessions show that the RRFB devices were able to maintain a high level of driver yielding behavior during the follow-up condition. The first original site at 22d Avenue produced an average yielding compliance of 99 percent for the four-beacon treatment. The second site at 58th Street N had an average yielding compliance of 90 percent. The third site at 1st Street N produced an average four-beacon yielding compliance of 100 percent. The final site at 31st Street S had an average yielding compliance of 93 percent during the four-beacon system follow-up evaluation. The third site was evaluated during nighttime conditions as a follow-up to previous night evaluations. This location was evaluated for 60 consecutive crossings with an average yielding compliance of 97 percent. Brief reversals back to the baseline for the above follow-up locations produced low yielding compliances similar to pre-installation. These data are shown in table 1 and figure 3.

Table 1. Average yielding compliance per condition including follow-up for each site.

	Percent Yielding Compliance					
Location	**Baseline**	**2 RRFBs**	**4 RRFBs**	**4 RRFBs**	**Baseline**	**4 RRFB**
Site 1: 22nd Avenue N	28	85	93	99	23	98
Site 2: 58th Street N	11	82	89	90	5	92
Site 3: 1st Street N	18	86	93	100	28	100
Site 4: 31st Street S	15	73	80	93	15	N/A
Average	18	82	89	96	18	95

N/A = data not available.

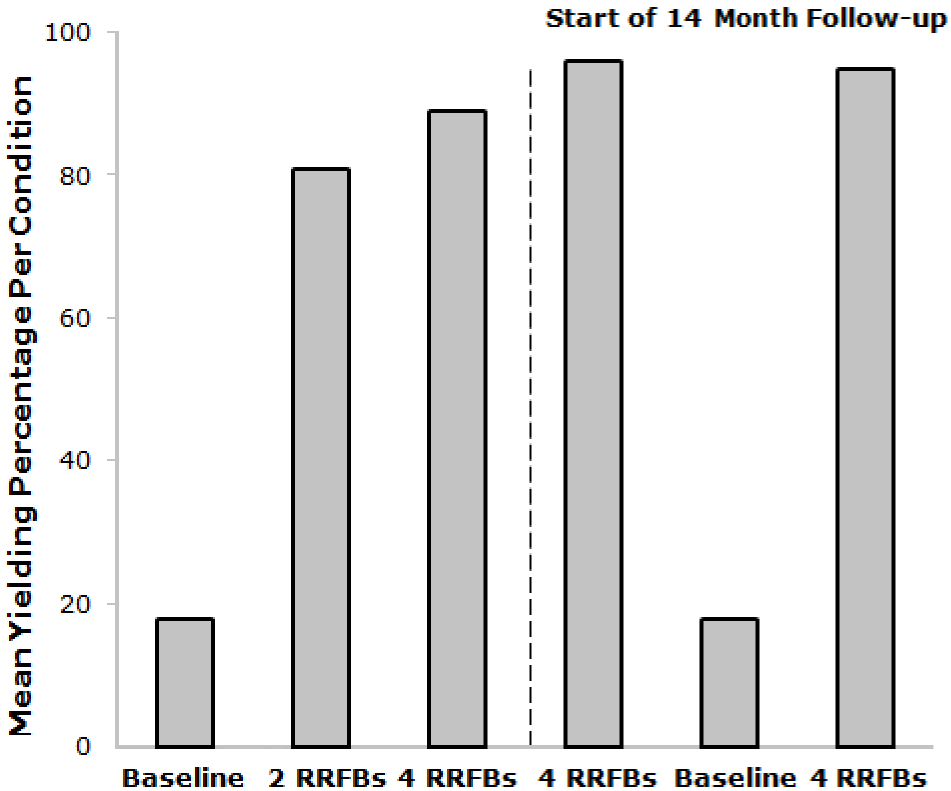

Figure 3. Graph. Mean yielding percentage for each condition.

Figure 3 represents all of the data from the four experimental sites averaged together per treatment condition. The data to the right of the dashed line show yielding during the follow-up data collected 14 months after installation.

Distance of Driver Yielding Behavior

The majority of yielding across all four sites during each condition occurred at the 30- to 50-ft interval. Yielding increases of 3.1 and 8 percent occurred at more than 30 ft over the baseline for the two-beacon and four-beacon system treatments, respectively. Yielding doubled at more than 100 ft. The total average yielding distances for all four sites (more than 30 ft) is shown in table 2. The presence of advance yielding markings at all sites throughout the study likely influenced yielding distance.

Table 2. Average percentage of drivers yielding in each distance category for each experimental condition.

Condition	Less than 10 ft	Between 10 and 20 ft	Between 20 and 30 ft	Between 30 and 50 ft	Between 50 and 70 ft	Between 70 and 100 ft	Greater than 100 ft
Baseline	3	10	17	37	16	11	7
2 RRFBs	3	7	12	31	18	14	15
4 RRFBs	2	6	13	32	18	12	17

Driver Passed or Attempted to Pass Stopped Vehicle

During the baseline across all four sites, there was a total of 48 passes or attempted passes. There were only eight of these occurrences for both two- and four-beacon systems combined during all of the treatment phases.

There were no significant results reported for evasive pedestrian-vehicle actions such as pedestrians trapped in a median or drivers behind a yielding vehicle slamming on their brakes.

Interobserver Agreement

Both observers stood in such a way that they had the same vantage point, but they were not able to see what the other observer recorded. A measure of interobserver agreement was computed by dividing the number of times both observers agreed on the occurrence of each pedestrian behavior by the number of times they agreed plus the number of times they disagreed on its occurrence. The interobserver agreement on the occurrence of a yielding behavior averaged 92 percent with a range of 78 to 100 percent. The interobserver agreement on evasive conflicts was 100 percent. In addition, the interobserver agreement averaged 100 percent on whether the pedestrian was trapped in the center of the road, averaged 100 percent on vehicle passes or pass attempts, averaged 100 percent on vehicles that slammed on brakes, and averaged 95 percent on stopping distance.

CHAPTER 4. EXPERIMENT 2

METHOD

Participants and Setting

The second experiment took place in St. Petersburg, FL. Participants consisted of drivers traveling past two sites. The first site is on 58th Street N south of 3d Avenue. The site traverses four lanes and has a posted speed limit of 35 mi/h and an ADT of 19,192. It also has a median island and provides a crossing for residents of a nearby retirement center. There is also a pedestrian-activated standard overhead incandescent yellow flashing beacon at this site. The second site is at 4th Street S and 18th Avenue. It is equipped with a side-mounted, pedestrian-activated, standard overhead incandescent yellow flashing beacon system. This roadway traverses four lanes and has a posted speed of 35 mi/h and an ADT of 9,600.

Apparatus

The treatment in this experiment was the standard overhead yellow flashing beacon (see figure 4) and a standard side-mounted yellow beacon. These systems are activated when the pedestrian call button is pressed. The system has two 12-inch-diameter yellow beacons facing both directions of traffic. The beacons flash 55 times per minute, and the illumination period of the beacon is 50 percent of the time.

Experimental Design

The comparison of the first site with a standard overhead beacon with the RRFB system was carried out at the 58th Street N south of 3d Avenue site. Following the baseline, the standard overhead beacon was introduced, followed by the RRFB system. First, only the two curbside beacons were activated, and then all four beacons were activated (curbside plus median beacons). Five baseline datasheets were collected in the absence of activation of the standard system. The system was activated during treatment, and 7 datasheets, each comprised of 20 crossings, were collected. Following the standard beacon treatment, two RRFBs were implemented, followed by the four-beacon system. Each rapid-flash treatment was observed for 5 datasheets each, creating a total of 680 crossings.

Figure 4. Photo. Northbound view of standard overhead beacon system and crosswalk at 58th Street N with advance yield markings.

At the second site (4th Street S and 18th Avenue), the standard side-mounted incandescent beacon system was compared to the RRFB system. The baseline consisted of 46 crossings. After the baseline, a side-mounted standard beacon system was evaluated for 70 crossings at 7- and 30-day intervals. Next, a two-beacon RRFB system was installed and evaluated for 70 crossings at 7- and 30-day intervals. All crossings at this site were staged.

RESULTS

Statistical Analysis

For the first site at 58th Street N, a *z*-test for proportions was performed. The difference in driver yielding behavior between the baseline and the standard overhead beacon was not significant at the 0.01 level ($z = 1.06$ with 85.5 percent confidence level). The difference in driver yielding behavior between the baseline and the two-beacon system was significant at the 0.01 level ($z = 12.75$ with 100 percent confidence level). The difference in yielding behavior between the baseline and the four-beacon system was also significant at the 0.01 level (100 percent confidence interval), and the difference between the two- and four-beacon system was significant at the 0.01 level ($z = 1.85$ with 96.8 percent confidence level).

The difference in the proportion of drivers yielding less than 30 ft before the crosswalk was significantly greater at the 0.01 level for the standard beacon condition than the baseline condition ($z = -2.70$ with 99.7 percent confidence level).

There were no significant results reported for evasive actions such as pedestrian/vehicle, pedestrian trapped in median, or car behind a yielding car or drivers slamming on brakes (inadequate number of occurrences of these events to perform the tests).

For the second site at 4th Street S, a *z*-test for proportions was performed. The difference in driver yielding behavior between the baseline and the standard side-mounted beacon was significant at the 0.01 level ($z = 6.03$ with 100 percent confidence level). The difference in driver yielding behavior between the standard side-mounted beacon and the two-beacon RRFB was significant at the 0.01 level ($z = 11.58$ with 100 percent confidence level). The difference in proportions of drivers yielding more than 30 ft between the standard side-mounted beacon and the RRFB was significant at the 0.01 level ($z = 4.65$ with 100 percent confidence level). No test was performed between the baseline and either condition because no vehicle yielded during the baseline condition. The level of conflicts observed at this site was not sufficient to perform a statistical analysis at this site. It should be noted that the low level of conflicts was likely a result of the research assistant consistently using the safe crossing procedure during crossing. This effect was most marked during the baseline condition when driver yielding was low.

Driver Yielding Behavior

The average yielding compliance at the first site at 58th Street N Avenue during the baseline recording was 11 percent. The activation of the overhead standard beacon produced an average yielding percentage of 16 percent—an increase of 5 percentage points above the baseline. The introduction of a two-beacon RRFB system produced an increase in yielding compliance to 78 percent. A four-beacon RRFB system was associated with 88 percent yielding compliance. Reversal back to the two-beacon system produced a yielding compliance of 85 percent followed by 89 percent yielding compliance for the second four-beacon system treatment. The average yielding compliance for a two-beacon system was 82 percent. The average yielding compliance for the four-beacon system was 89 percent. The introduction of a two- and four-beacon system produced 71 and 78 percentage point increases over the baseline and increases of 66 and 73 percentage points over the standard-beacon system, respectively (see figure 5).

Baseline data from the second site at 4th Street and 18th Avenue showed zero percent yielding compliance. Activating the side-mounted standard beacon produced a yielding compliance of 15 percent after 30 days. The RRFB system produced a yielding compliance of 87 percent after 30 days. The RRFB percentages are representative of a two-beacon system only (see figure 6).

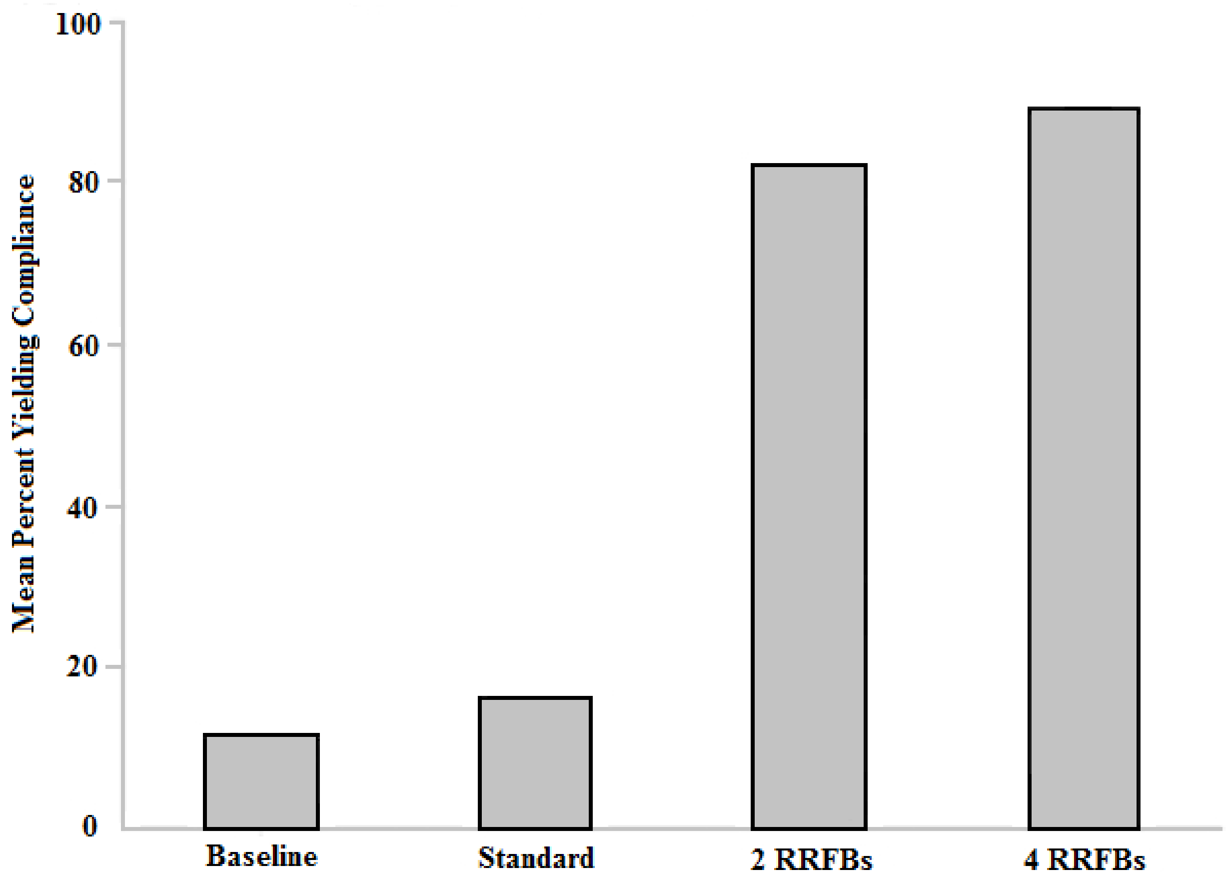

Figure 5. Graph. Driver yielding behavior at the 58th Street N site.

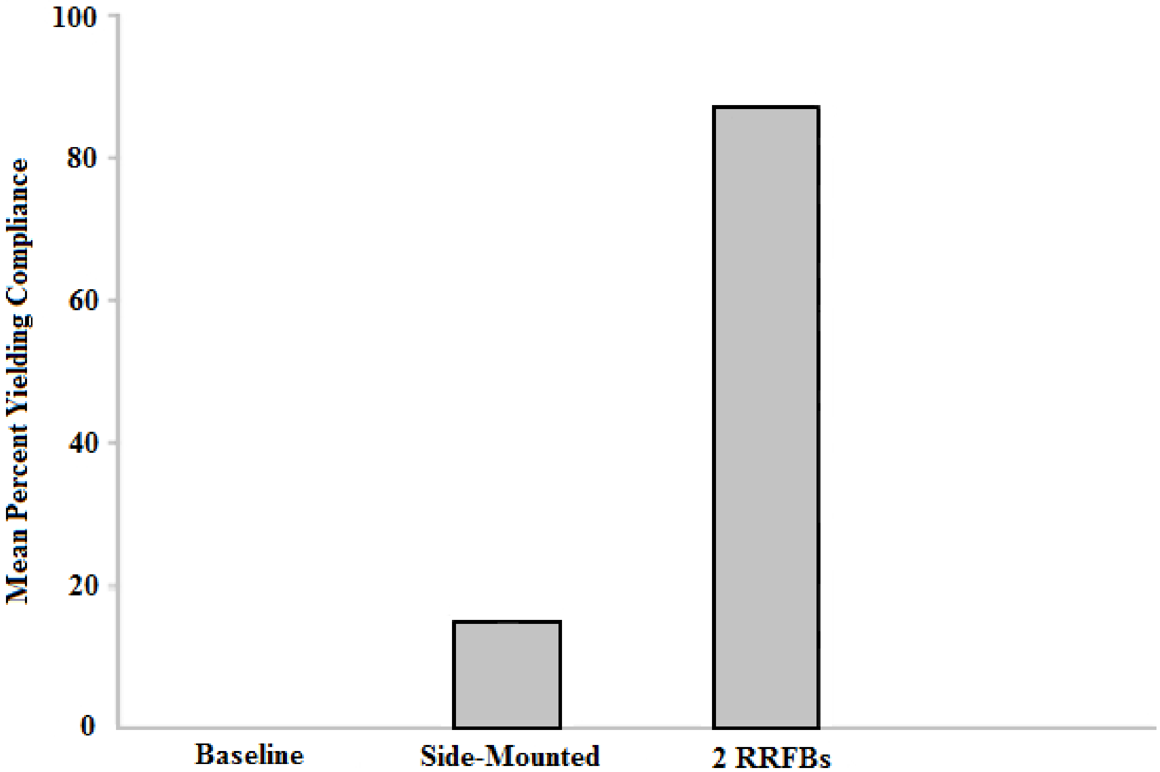

Figure 6. Graph. Relative efficacy of the side-mounted yellow beacon at the 4th Street S site.

The yielding distance improved in the absence of the standard flashing beacon than in its presence. When the standard flashing beacons were activated, a higher percentage (1 percent) of drivers yielded at less than 30 ft. However, there were more drivers yielding during treatment, and this produced a larger number of drivers who yielded at a closer distance than in the absence of the light. There were 48 drivers who yielded at less than 30 ft during the treatment compared with only 27 drivers who yielded during the baseline condition. In addition, 5.6 percent of drivers yielded at more than 100 ft during treatment as opposed to 8.4 percent who yielded at more than 100 ft during the baseline. The majority of yielding during both conditions occurred between 30 and 50 ft. During the baseline, 41 percent of drivers yielded at this distance, and 43 percent yielded during the standard beacon treatment. The majority of driver yielding when the RRFB was activated occurred between 30 and 50 ft (44 percent). During the four-beacon system, the majority of driver yielding was also between 30 and 50 ft (42 percent). The percentage of drivers who yielded at more than 100 ft more than doubled from the two-beacon system to the four-beacon system, with an increase from 6 to 12 percent.

Interobserver Agreement

Interobserver agreement on the occurrence of a yielding behavior averaged 92 percent with a range of 80 to 98 percent, averaged 100 percent on drivers who slammed on the brakes, and averaged 99 percent on stopping distance.

CHAPTER 5. EXPERIMENT 3

METHOD

Participants and Setting

Participants in experiment 3 consisted of drivers and pedestrians across 22 sites, with 19 sites in Florida, 2 sites in Illinois, and 1 site in Washington, DC. These sites, along with the ADT and posted speed limit at the crosswalk location, are presented in table 3.

Table 3. Characteristics at each of the treatment sites.

Location of Crosswalk	Number of Lanes	Median Present	Traffic Flow	ADT	Posted Speed Limit (mi/h)
Florida					
31st Street and 54th Avenue S	4	Yes	Two-way	9,600	35
4th Street and 18th Avenue S	4	Yes	Two-way	17,657	35
22d Avenue N and 7th Street	4	Yes	Two-way	13,524	35
9th Avenue N and 26th Street	4	No	Two-way	12,723	35
22d Avenue N and 5th Street	4	Yes	Two-way	18,367	35
Martin Luther King Street and 15th Avenue S	5	Yes	Two-way	12,025	35
Martin Luther King Street and 17th Avenue N	5	No	Two-way	14,336	35
1st Avenue N and 13th Street	3	No	One-way	9,715	30
9th Avenue N and 25th Street	4	No	Two-way	12,723	35
1st Street and 37th Avenue N	4	Yes	Two-way	6,216	35
58th Street and 3d Avenue N	4	Yes	Two-way	13,826	35
Central Avenue and 61st Street	4	No	Two-way	12,742	40
1st Avenue S and 61st Street	3	No	One-way	12,742	35
1st Avenue N and 61st Street	4	No	One-way	9,128	35
83d Avenue N and Macoma Drive	2	No	Two-way	4,774	35
9th Avenue N and 45th Street	4	No	Two-way	9,343	35
22d Avenue S and 23d Street	4	No	Two-way	9,343	35
62d Avenue S and 21st Street	3	No	Two-way	5,008	35
9th Avenue N and 31st Street	4	No	Two-way	11,982	35
Illinois					
Hawley Street and Atwater Drive	2	No	Two-way	N/A	35
Midlothian Road and Kilarny Pass Road	4	No	Two-way	N/A	35
Washington, DC					
Brentwood Road and 13th Street	4	No	Two-way	30,000	30

N/A = data not available.

Additional participants consisted of drivers and pedestrians located at two school crosswalks in Illinois, one crosswalk in Washington, DC, and one of the sites in St. Petersburg, FL, equipped with an advance warning rapid-flash device similar to the one in Washington, DC. The first site is located at Hawley Street east of Atwater Drive in Illinois, the second site is located at Midlothian Road south of Kilarny Pass Road in Illinois, the third site is located at Brentwood Road and 13th Street NE in Washington, DC, and the fourth site is located at 1st Avenue N and 61st Street in St. Petersburg, FL (see table 3).

Apparatus

The treatment in this experiment is identical to that of experiment 1. The RRFB system as described previously was employed in this study. Exceptions are found at the third and fourth sites. These locations had a device similar to the previous locations with the exception of being equipped with an advance warning rapid-flash sign. The additional sign was a standard STOP FOR PEDESTRIANS AHEAD sign in Washington, DC, and a standard pedestrian silhouette sign at 1st Avenue in St. Petersburg, FL, equipped with an RRFB system similar to those used in the previous experiments. The advance warning sign in Washington, DC, was placed in the approximate area of the ITE threshold previously discussed. This location was designed so that upon activation of the pedestrian call button, the advance sign would activate immediately. After approximately 1.5 s, the devices located at the crosswalk would then become activated. However, the advance sign in St. Petersburg, FL, was located further away at 368 ft.

Experimental Design

This experiment used a before-after design. The baseline was collected for a series of 22 sites. Because these beacons were introduced at different times at each site, it is not likely that the resulting changes were due to any uncontrolled confounding variables such as the level of police enforcement or the occurrence of increased publicity that sometimes follows major pedestrian crashes. After the baseline data were collected, a treatment consisting of either two- or four-beacon RRFB systems was implemented. This treatment was extended in intervals of 7, 30, 60, 90, 180, 270, and 360 days, respectively. Not all sites were yet reporting data to 360 days. The site in Florida equipped with the advance warning sign was evaluated in an alternating treatment design. After a baseline period, the two treatment conditions, the rapid-flash device at the crosswalk sign and the rapid-flash device at the crosswalk sign plus the rapid flash device at the advance warning sign, were alternated in rapid succession (every other crossing).

Statistical Analysis

The general statistical methodology used in this study was based on the general time-series intervention regression modeling approach described in Huitema and McKean and McKnight et al. (See references 8–11.) However, the specific parameters included in the present model differ from those used in the earlier work.

The statistical model used here was developed to conform to the nature of traffic data collected in this study. Because it is well known that compliance with traffic-signal stimulus changes usually occurs rapidly but does not reach an asymptote immediately, the analysis was designed to model this expected change pattern.

Specifically, the change model contained five parameters. The first parameter measured the baseline level, the second measured the change from the baseline to day 7, the third measured the change from day 7 to day 30, the fourth measured the change from day 30 to day 60, and the fifth measured the slope during the remaining time points (days). This fifth parameter measured the general trend after the first month of observations through the final observation month (day 720). An additional parameter was also included to accommodate possible autoregressive patterns in the errors of the model. Because this parameter was of limited interest in this study, it is not described in detail here. The approach used to estimate the parameters of the model is based on a double bootstrap methodology that accommodates both independent and autocorrelated error structures encountered in time-series intervention designs of the type used in behavioral research.(11) Certain variants of this approach have been developed for the analysis of both simple and complex versions of single-case designs.(12)

RESULTS

The five main parameter estimates obtained in the study are shown in table 4. Alpha was set at 0.05 before the data were collected, and any *p*-value that is less than equal to or 0.05 is statistically significant. *P*-values are presented to allow the reader to decide whether the evidence is convincing. There is an immediate and large statistically significant level change from the baseline to day 7, a small but statistically significant additional increase from day 7 to day 30, a minor and not statistically significant level decrease at day 60, and a general trend after day 60 that has little slope across the remaining observation days. Hence, the evidence for change is overwhelming, and it is maintained for the duration of the study. There are 144 degrees of freedom for all tests shown in table 4.

Table 4. Florida data estimates of treatment effect parameters and associated *t*-ratios and *p*-values.

Treatment Effect Parameter	Parameter Estimate	*t*-Ratio	*p*-Value
Baseline level	1.79		
Level change day 7	77.25	29.22	0.001
Level change day 30	6.03	2.38	0.02
Level change day 60	–4.26	–1.75	0.08
Follow-up slope	0.0059	1.62	0.11

Note: Certain cells were left blank because only *t*-ratios and *p*-values that show a change from the baseline were included.

Driver Yielding Behavior

The average combined yielding percentage during the baseline of all 19 Florida sites was less than 1.7 percent. Follow-up data were available for all 19 sites at the 7-, 30-, and 60-day periods. The average yielding percentage of all combined sites was 79 percent after 7 days, 86 percent after 30 days, and 82 percent after 60 days. Yielding percentages for the 19 sites at 90, 180, 270, and 365 days were 80, 76, 86, and 83 percent, respectively. The 17 sites that were installed for 2 years showed a yielding compliance of 85 percent 730 days after installation.

Each of the two locations in Illinois has reported data during the baseline and again 7 and 30 days after installation. The first location, Hawley Street east of Atwater Drive, produced 19 percent yielding during the baseline, 71 percent 7 days after installation, and 68 percent 30 days after installation. The second location, Midlothian Road south of Kilarny Pass Road, produced a yielding percentage of 6.6 percent during the baseline. The device was activated 7 days after installation, and yielding compliance increased to 62 percent 30 days after installation. Both of the sites used only two of the rapid-flash devices.

The Washington, DC, location, which was equipped with an advance warning rapid-flash device, was evaluated during baseline conditions and again 7, 30, and 180 days after installation. Baseline yielding compliance at this location was 26 percent. Average yielding compliance increased for 7-, 30-, and 180-day evaluations to 62, 74, and 80 percent, respectively.

The St. Petersburg, FL, site that was equipped with the advance warning device at 1st Avenue North and 61st Street had an average yielding compliance of 8.6 percent during the baseline condition. During activation of the rapid-flash device, average yielding increased to 92 percent only at the crosswalk. The addition of the advance warning device had no effect on yielding, which remained at 92 percent (see table 5).

Distance of Driver Yielding Behavior

Data on the distance of yielding drivers were recorded for both of the Illinois sites, the Washington, DC, site, and the St. Petersburg, FL, site at 1st Avenue North and 61st Street that was equipped with the rapid-flash advance warning device. The total combined percentage of drivers yielding at 30 ft or more during the baseline for the two sites in Illinois was 83 percent. The introduction of the treatment device produced increases in the percentage of drivers yielding at 30 ft or more to 94 percent at the Atwater Drive site and 92 percent at the Kilarny Pass Road site. The Washington, DC, site had a baseline percentage of 41 percent for drivers yielding at 30 ft or more. Once the rapid-flash device, including the advance warning sign, was activated 7 days after installation, the percentage increased to 62 percent. Follow-up data collected at days 30 and 180 showed an additional yielding increase at 30 ft or more to 72 and 87 percent, respectively.

The St. Petersburg, FL, site had an average baseline yielding percentage of 50 percent for drivers who yielded at 30 ft or more. No drivers yielded at more than 100 ft during the baseline for this location. During the crosswalk alone condition, the average percentage of those yielding at 30 ft or more was 83 percent. The crosswalk plus advance warning condition saw a slight increase in yielding to 84 percent.

Table 5. Baseline and follow-up yielding data at sites in Florida, Illinois, and Washington, DC.

Site	Day (Percent)								
	Baseline (Percent)	7	30	60	90	180	270	365	730
Florida									
31st Street and 54th Avenue S	0	54	76	N/A	59	N/A	91	75	83
4th Street and 18th Avenue S	0	63	72	N/A	69	N/A	69	80	80
22d Avenue N and 7th Street	0	97	96	91	93	92	91	98	96
9th Avenue N and 26th Street	0	80	82	85	95	81	88	77	78
22d Avenue N and 5th Street	8	87	89	92	92	87	96	92	95
Martin Luther King Street and 15th Avenue S	1	86	84	85	82	N/A	89	88	88
Martin Luther King Street and 17th Avenue N	0	96	94	80	82	83	88	82	83
1st Avenue N and 13th Street	2	85	87	75	78	N/A	91	88	N/A
9th Avenue N and 25th Street	0	86	90	83	90	N/A	88	81	79
1st Street and 37th Avenue N	0	79	87	85	87	N/A	90	97	95
58th Street and 3d Avenue N	0	85	84	85	85	79	92	82	88
Central Avenue and 61st Street	0	94	95	77	73	72	79	67	72
1st Avenue S and 61st Street	5	68	72	73	75	72	90	72	78
1st Avenue N and 61st Street	0	75	75	68	82	42	76	79	83
83d Avenue N and Macoma Drive	0	86	93	91	73	88	84	80	90
9th Avenue N and 45th Street	0	54	91	89	90	80	83	77	78
22d Avenue S and 23d Street	0	89	86	78	77	60	75	81	82
62d Avenue S and 21st Street	0	77	76	77	53	78	81	84	80
9th Avenue N and 31st Street	16	93	95	89	88	82	82	89	N/A
Average	2	81	86	82	80	76	86	83	84
Illinois									
Hawley Street and Atwater Drive	19	71	68	N/A	N/A	N/A	N/A	N/A	N/A
Midlothian Road and Kilarny Pass Road	7	62	62	N/A	N/A	N/A	N/A	N/A	N/A
Average	13	67	65	N/A	N/A	N/A	N/A	N/A	N/A
Washington, DC									
Brentwood Road and 13th Street	26	62	74	80	N/A	80	N/A	N/A	N/A

N/A = data not available.

CHAPTER 6. EXPERIMENT 4

METHOD

Participants and Setting

Participants in experiment 4 drove through the crosswalk at 4th Street and 18th Avenue S in St. Petersburg, FL. This location has four through lanes at the crosswalk with a refuge island in the center median. The location has a posted speed limit of 35 mi/h and an ADT of 17,657.

Apparatus

The treatment in this experiment is identical to that of experiment 1. A standard pedestrian warning sign with two RRFBs with the same light positioning, timing, and sequence was used. Each unit was dual indicated, with LEDs on the front and back. Each side of the beacon flashed in a wig-wag sequence (left light on followed by the right light on). Combined, the two LEDs flashed 190 times in the wig-wag sequence during a 30-s cycle. The devices were updated with Direct Aim® lighting and the momentary light bar (MLB).

Direct Aim® lighting angles the LED lights of preexisting units so that the lights, when activated, do not flash parallel to the roadway but rather flash at an angle that places oncoming traffic lanes in the direct path of the light (see figure 7). In the figure, the arrows on the left panel show perpendicular lighting, while the arrows on the right panel highlight Direct Aim®. This device was developed to accommodate the sensitive directivity of LED lights. That is, LED lights have a small angle of maximum visibility and effect. While new LED lighting systems mounted on emergency vehicles are parallel to the roadway and the vehicle, they remain effective in their purpose. The reason for this may be that their purpose is to alert all of those directly in front of them to pull off to the side of the roadway. However, it would seem impossible to place the RRFB lights directly in the path of oncoming traffic. The MLB device is an addition to Direct Aim® lighting. The MLB attaches below the Direct Aim® and is activated on a delay circuit. The delay allows any vehicles in close proximity to the activated crosswalk to clear the crosswalk. Once this has occurred, the MLB activates with a horizontal arrangement of intensely bright LEDs. After a moment, the MLB lights fade out.

Experimental Design

In this study, an alternating treatment design was employed to record driver yielding percentages in an evaluation of two devices in an effort to further increase driver yielding to pedestrians at a single midblock crossing. The alternating treatment design was chosen due to its ability to evaluate multiple treatments while offering experimental control. This is accomplished by rapidly alternating between two or more different treatments in succession after an initial stable baseline has been achieved. The design allows for the alleviation of any possible confounding or nuisance variables.[13] First, baseline data were collected by having staged pedestrians (researchers) cross as the drivers' yielding behavior was recorded for three datasheets, each consisting of 20 crossings. After this, data were collected on the preexisting RRFB device for a total of 70 crossings following the baseline at 7, 30, 270, and 365 days. The third stage involved the installation of Direct Aim® LED lights along with an MLB to the RRFB.

Figure 7. Photo. Perpendicular lighting (left panel) and Direct Aim® lighting (right panel).

The MLB device was installed with a cutoff switch to allow for a quick transition between Direct Aim® and Direct Aim® plus MLB. A coin flip was used to decide which device was to be evaluated first. After Direct Aim® was evaluated for 20 crossings, the switch was flipped, and the MLB was evaluated for 20 more crossings. This collection procedure was reproduced 5 times per condition, producing 100 crossings per condition.

RESULTS

Statistical Analysis

A z-test for proportions was used to test for differences. The percentage of drivers yielding in the RRFB with the Direct Aim® condition did not differ from the percentage yielding in the Direct Aim® plus MLB condition at the 0.05 level ($z = 0.43$ with 66.6 percent confidence level one tail test). However, the RRFB with Direct Aim® was associated with higher yielding than the parallel aim RRFB at the 0.05 level ($z = 1.74$ with 95.9 percent confidence level one tail test).

The percentage of drivers who yielded to pedestrians during the baseline condition was zero percent. The average yielding compliance 7 days after RRFB installation increased to 33 percent. Yielding compliance continued to increase to 72 percent 30 days after installation. Average yielding compliance was 69 percent after 180 days and remained unchanged 270 days after installation. Yielding compliance 365 days after installation averaged 80 percent (see figure 8). The average yielding compliance during the duration of the RRFB with perpendicular lighting was about 80 percent.

The change from perpendicular LEDs to Direct Aim® lighting produced an average increase of 89 percent. Sessions including the MLB produced an average of 86 percent. These averages included 100 crossings per condition.

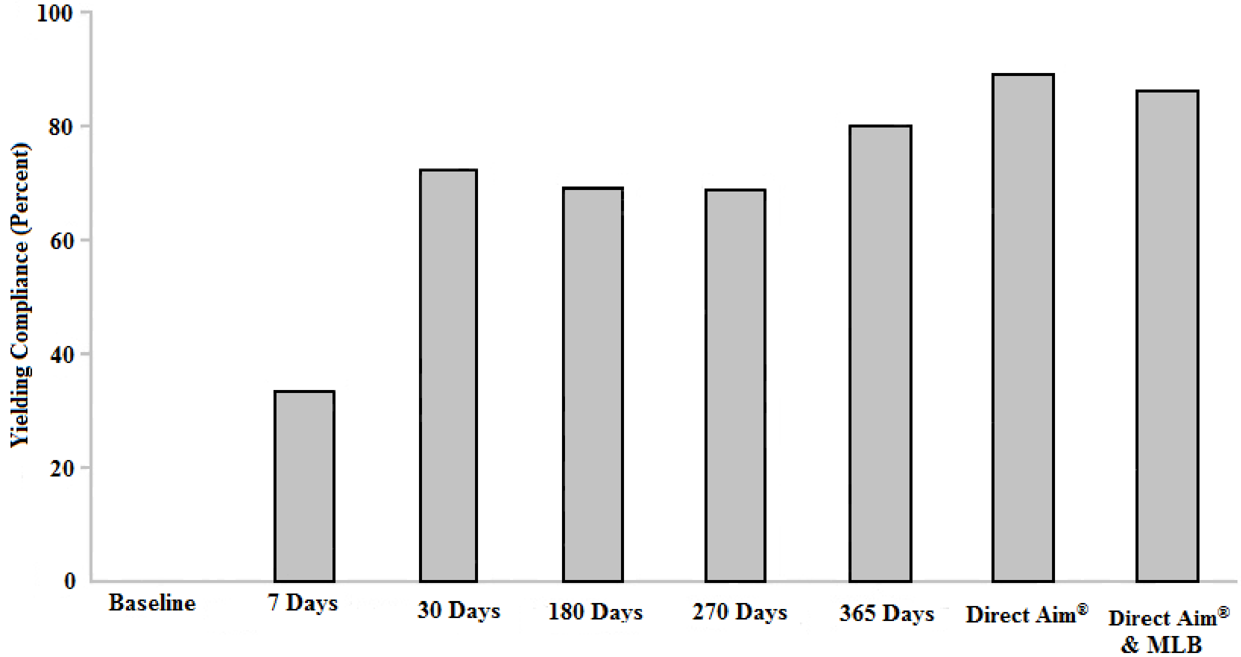

Figure 8. Graph. Yielding compliance for experiment 4 located at 4th Street and 18th Avenue S in St. Petersburg, FL.

CHAPTER 7. EXPERIMENT 5

METHOD

Participants and Setting

In experiment 5, participants consisted of drivers who traveled on 1st Avenue N and 61st Street and pedestrians who crossed the street. This site is a one-way avenue where the crosswalk traverses three lanes and has a posted speed limit of 35 mi/h and an ADT of 12,245. This site does not provide a median for crossing pedestrians.

Apparatus

The treatment in this experiment was the standard RRFB described in experiment 4. A standard pedestrian warning sign with two LED flashers with the same light positioning, timing, and sequence was used. Additional RRFB advance warning units were also placed on each side of the roadway 2 $^{1}/_{2}$ times the distance of the dilemma zone for this location. These advance warning devices did not have any call buttons and were attached to a PEDESTRIAN CROSSWALK AHEAD sign. The advance warning devices were activated when the call button at the crosswalk was depressed. The RRFB unit at the crosswalk would not activate when the advance warning devices were turned on until 2.5 s had elapsed.

Experimental Design

This experiment was conducted at 1st Avenue N and 61st Street to compare the efficacy of RRFB units with the addition of an advance warning LED unit. It used an alternating treatment design similar to the one used in experiment 4. During the baseline condition, driver yielding compliance and the distance of yielding were collected for 6 sessions, each consisting of 20 crossings. Following the baseline condition, each treatment condition was then evaluated for 20 crossings per session. Each session was alternated with the other in rapid succession. The RRFB units alone were evaluated first for 20 crossings. Following this phase, the advance warning devices were turned on and evaluated in addition to the RRFB units at the crosswalk for 20 crossings. This method was repeated until each of the treatment conditions had been evaluated five times. Following data collection of the treatment conditions, a return to the baseline was observed for 20 crossings.

RESULTS

Statistical Analysis

A z-test for proportions was used to test whether the RRFB alone or the RRFB plus advance warning sign produced more yielding. The results were not significant at the 0.01 level ($z = 0.26$ with 39.7 percent confidence level).

Driver Yielding Behavior

The average yielding compliance at the site during the initial baseline recording was 8.6 percent. The yielding compliance during the initial baseline ranged from 0.8 to 17 percent. The RRFB unit alone produced yielding averages of 95, 85, 83, 100, and 95 percent per session. The average yielding compliance during the RRFB at the crosswalk alone was 92 percent. The RRFB plus advance warning device had yielding averages of 93, 92, 98, 79, and 96 percent, respectively. The average yielding compliance during the RRFB plus advance warning condition was 92 percent (see figure 9). A return to baseline conditions for 20 consecutive crossings produced a yielding compliance of zero percent. The number of vehicles observed as not yielding during the return to baseline conditions was 344.

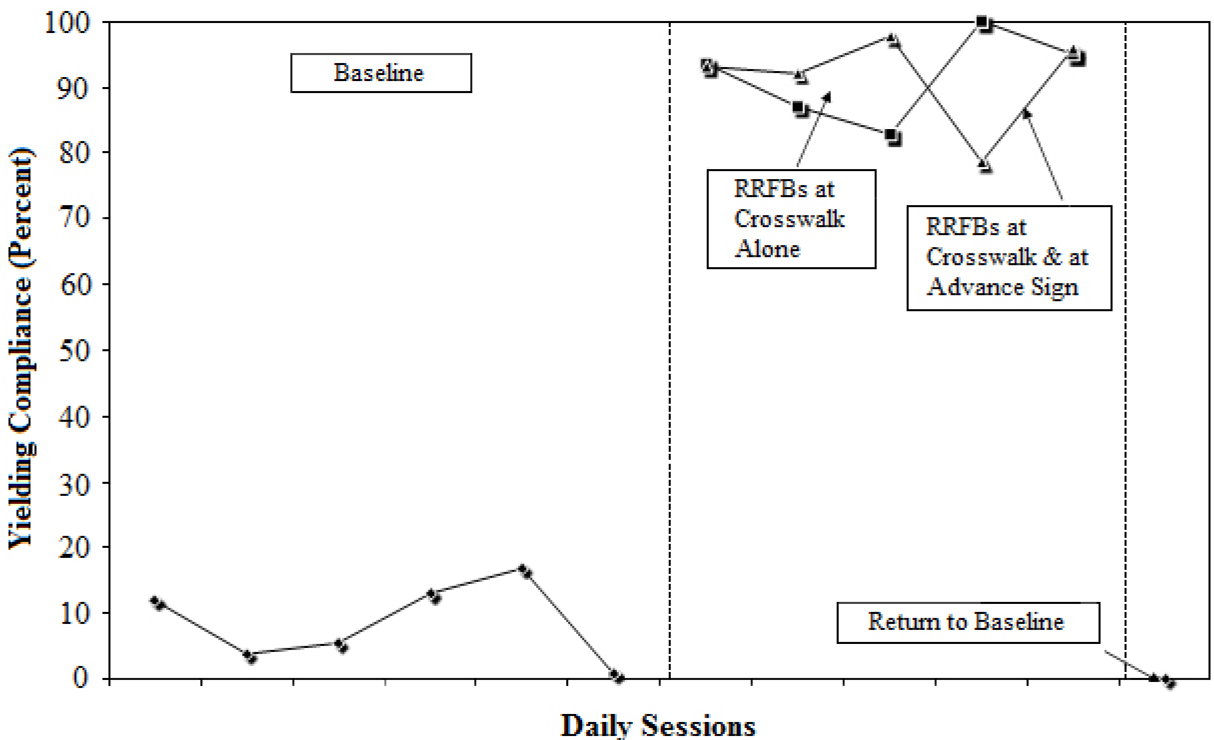

Figure 9. Graph. Yielding compliance during the baseline and the RRFBs at the crosswalk alone versus the RRFB at the crosswalk plus the RRFB at the advance sign.

Driver Yielding Distance Behavior

The absence of LED devices at this site was associated with a large proportion of driver yielding at 30–50-ft, with a yielding compliance of 37 percent. The second and third highest yielding distances during the baseline were the 20–30-ft and 10–20-ft intervals, with yielding compliances of 30 and 13 percent. During the RRFB at crosswalk alone condition, the largest proportion of drivers (39 percent) yielding more than 100 ft in advance of the crosswalk. The second and third highest percentages of yielding occurred at the 30–50-ft and 50–70-ft intervals, with 18 and 16 percent yielding compliance. The RRFB on the crosswalk and advance warning sign condition produced the highest proportion of drivers (49 percent) yielding over 100 ft from the crosswalk. Drivers yielding farther in advance of the crosswalk can be expected to improve the safety of pedestrians (see figure 10).

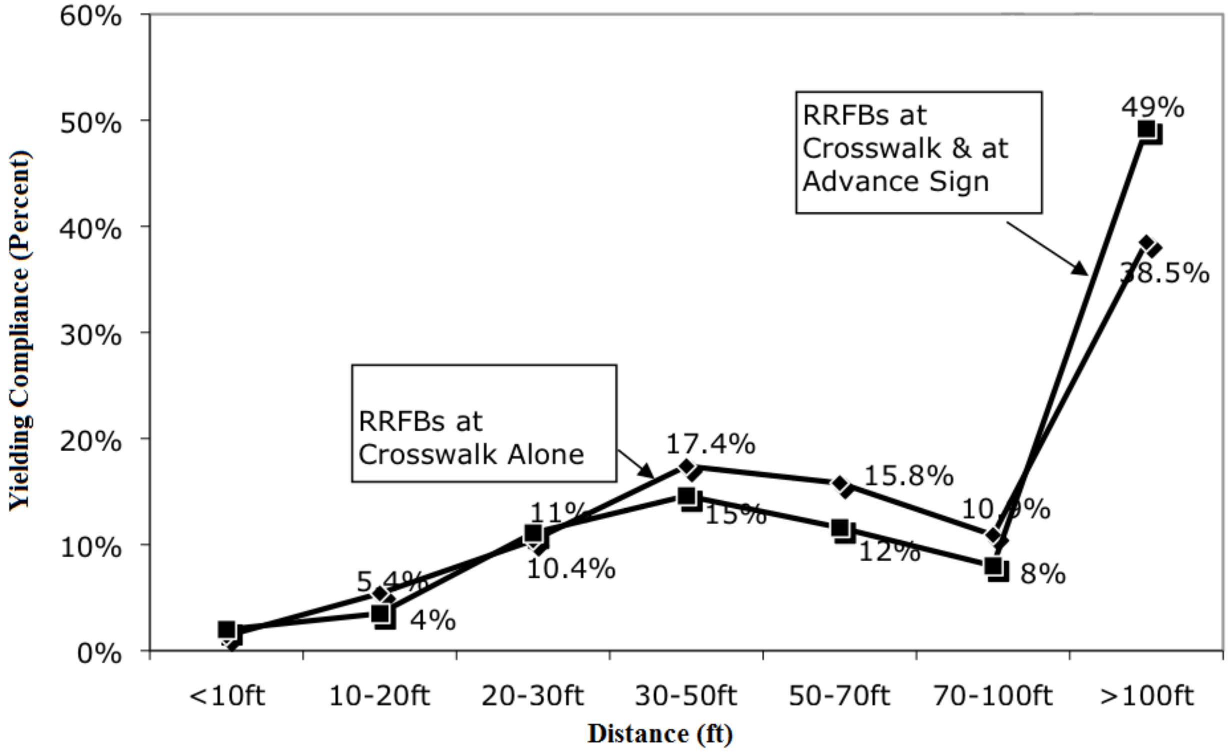

Figure 10. Graph. Average yielding percentage during the RRFBs at the crosswalk alone and the RRFBs at the crosswalk and on the advance sign.

CHAPTER 8. SUMMARY, CONCLUSION, AND DISCUSSION

SUMMARY

The results of the first experiment showed that the RRFB produced an increase in yielding behavior at multilane uncontrolled crosswalk locations. In addition, installing additional beacons on the median island further improved the efficacy of the system.

The second experiment compared the RRFB with a traditional overhead yellow flashing beacon and a side-mounted traditional yellow flashing beacon. The results showed that the RRFB system was more effective at increasing driver yielding behavior than the traditional beacon system.

The third experiment showed that the RRFB was highly effective in increasing yielding behavior at a large number of sites located in three cities in the United States and that these effects were maintained over time at each location.

The fourth experiment showed that while the use of Direct Aim® lighting increased yielding compliance, further increases in yielding were not achieved by implementing MLB.

The fifth experiment showed that the use of RRFB devices, with the addition of advance warning devices placed before the crosswalk, did not increase yielding compliance but may have increased the distance that drivers yielded in advance of the crosswalk.

CONCLUSION

In conclusion, the study found the following:

- The installation of the two-beacon system in experiment 1 increased yielding compliance from 18 to 81 percent, which was statistically significant.

- Yielding compliance increased from 81 to 88 percent following the installation of the four-beacon system at these sites, which was statistically significant.

- The percentage of drivers yielding at more than 100 ft doubled over the baseline condition during the four-system treatment. Many of the drivers yielded at distances much greater than 100 ft after the RRFB system was installed. This outcome reduced the chance that a pedestrian may have been struck by drivers due to the inability to see the pedestrian when a yielding vehicle blocked the view of the driver in the passing vehicle.

- The installation of a standard yellow overhead beacon increased yielding compliance from 11 to 16 percent. When side-mounted RRFBs replaced the overhead beacon, yielding compliance increased to 78 percent. Adding the RRFB to the median island increased yielding compliance to 88 percent. The installation of standard yellow side-mounted beacons increased yielding compliance from zero to 16 percent. The installation of side-mounted RRFBs increased yielding compliance to 72 percent. The increases produced by the RRFB system were statistically significant.

- The effects of the RRFB on driver yielding persisted for 2 years, and there was no tendency for them to decrease in effectiveness. These effects were statistically significant.

DISCUSSION

All comparisons of different systems or variations of the same system were conducted at the same sites, eliminating site characteristics as a confounding variable. Another strong point of this study was the large number of systems installed and evaluated.

The increased effectiveness of the four-beacon system over the two-beacon system may have been due to better visibility of the median island rapid-flash beacons for drivers occupying the inside lanes. This effect would be expected to be most pronounced when there were large vehicles in the outside lane that could block drivers' views.

Another important finding from this study was the increased percentage of drivers yielding well in advance of the crosswalk. The increases in yielding percentages and the yielding distances should be associated with a marked decrease in the number of vehicle passes or attempts to pass. This effect should be expected because of the signs' visibility to all drivers and not only those in the direct field of vision of the pedestrian.

One possible explanation of why the RRFB system produced a larger increase in driver yielding over the baseline is that it produced a novelty effect where an unfamiliar stimulus that had not been encountered by the drivers in the past was more likely to get their attention (similar to a unusual sound getting someone's attention). If this was the case, there should be a large decrease in yielding behavior over time; however, this was not found. The follow-up data (experiments 1 and 3) showed that the systems were still associated with high yielding behavior 1 and 2 years after installation. It appears that the lights on the system were such a salient stimulus that they obtained drivers' attention over the other competing stimuli and distractions they were exposed to when driving.

One problem that may arise is promoting the activation of the devices (i.e., pushing the devices' activation buttons). If a device is not activated, it is not effective. Some RRFBs contain sensors that detect pedestrians in the immediate area of the crosswalk and deliver an audible voice prompt that encourages pedestrians to activate the before crossing the street. No systematic data were collected to evaluate the efficacy of this feature.

The current device was not designed specifically for visually impaired pedestrians. It does not have a locator tone, but it does have a proximity sensor that provides an audible message when a pedestrian is in proximity to the device. When the button is pressed, another audible message confirms the button press and asks the pedestrian to wait for cars to stop before crossing. No other accessibility feature is included. Research should determine whether marked crosswalks at uncontrolled locations fitted with an RRFB are suitable or can be made suitable for use by visually impaired pedestrians.

These results show that the rectangular LED yellow rapid-flashing beacon appeared to be an effective tool for producing a large increase in the percentage of drivers yielding right-of-way to pedestrians in crosswalks at sites where drivers rarely yielded to pedestrians. Therefore, it should be a valuable tool for improving the pedestrian level of service at marked uncontrolled crosswalks. When used in conjunction with advance yield marking, it may also greatly increase the safety at uncontrolled crosswalks at high ADT multilane sites. As more sites are installed, a crash study should be conducted to determine if RRFBs increase the safety of crossings at high ADT multilane sites.

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