TECHBRIEF

Pedestrian and Bicycle Safety

Impacts of LED Brightness, Flash Pattern, and Location for Illuminated Pedestrian Traffic Control Device

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Introduction

Illuminated traffic control devices, such as rectangular rapid-flashing beacons (RRFB), have been shown to increase the number of drivers yielding to crossing pedestrians. Evaluations of field installations of these devices have been conducted in several locations, including Florida, Texas, Oregon, Michigan, Arizona, Wisconsin, and Calgary, AB. (See references 1 through 10.) Before-after studies have shown a large increase in driver yielding between the before period (range of 1 to 83 percent) and the after period (range of 38 to 98 percent). While driver yielding has always increased after the RRFB installation, there are still examples of low yielding in some locations. Studies have shown a wide range in driver yielding to the RRFB, with values extending from a low of 22 percent to a high of 98 percent.

There is growing interest in adding the RRFB to the *Manual on Uniform Traffic Control Devices* (MUTCD).[11] The Signals Technical Committee of the National Committee on Uniform Traffic Control Devices, which assists in developing language for chapter 4 of the MUTCD, is interested in research to support proposed language for inclusion of RRFBs in the manual. To achieve the uniformity desired in the MUTCD and provide guidance that results in the best driver yielding behavior, several details require research. These details include beacon size, shape, color, placement location, brightness, and flash pattern. There is some concern that the brightness of flashes at or contained within signs at night may

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make it difficult for drivers to detect and observe the movements of pedestrians at the crossing. To prevent devices from being set at brightness levels that produce disability or discomfort glare, the profession needs to quantify the effect of illuminated traffic control devices on a driver's ability to detect pedestrians in and around the crosswalk.

This TechBrief describes the methodology and results from a closed-course study sponsored by the Federal Highway Administration (FHWA) that addressed brightness, flash patterns, and location of light-emitting diodes (LED). It examined driver detection of cutout pedestrian photographs in the presence of LEDs of various brightness levels and flash patterns, which are placed in different locations within the sign assembly.[12]

Study Approach

Study Method

The study enlisted 98 licensed drivers (aged 19 to 85). They were placed in a vehicle 200 ft from a crosswalk. Their basic task was to identify as quickly as possible which direction a pedestrian cutout photograph appeared to be walking. Life-sized photo cutouts of adult and child size pedestrians were used (figure 1). These cutout photographs were placed in one of three positions within the crosswalk. To control when the drivers could see the scene, the participants wore special glasses that blocked their view with an opaque film. With the press of a button, the film became transparent, and the subject could begin searching for the pedestrian. The amount of time needed to correctly identify the direction of travel of the pedestrian was the measure of performance. Following the driver's identification of the pedestrian's direction and the darkening of the glasses, the researcher asked the participant to rate the brightness of the sign as comfortable, irritating, or unbearable.

The pedestrian detection study was conducted on a closed course (a former taxiway at the Texas A&M University

Figure 1. Researcher removing short cutout pedestrian after placing tall cutout pedestrian.

Source: Texas A&M Transportation Institute.

Riverside campus) where edge line, center line, and transverse crosswalk markings were added to give the site a more urban feel and to simulate two vehicles approaching a pedestrian crossing on a multilane divided road. Each lane was approximately 12 ft wide, and the width of the paved surface was about 40 ft. The study was designed so that data would be collected from two participants simultaneously seated in separate vehicles (i.e., participants could not hear each other's responses). Street lighting—in the form of two work zone light towers—was present at the site for the nighttime testing, and drivers were instructed to keep the low-beam headlamps on during nighttime testing. Testing occurred during both daytime and nighttime.

The sign assemblies consisted of a pedestrian crossing sign with LEDs within the sign face and LEDs in rectangular beacons above and below the sign. The height to the middle of the sign was approximately 9.5 ft, with the height to the bottom edge of the bottom beacon at 7 ft and the bottom edge of the top beacon at 11.6 ft.

Features Studied

The study focused on the following three features of illuminated pedestrian traffic control devices:

- Location of LEDs in the sign assembly (above sign, below sign, or embedded within the sign border).
- LED brightness (intensity) levels.
- Flash patterns.

Table 1 lists the variable combinations studied. The total number of all possible combinations was too large to evaluate for any one driver. Therefore, each driver was presented with a sample of 105 combinations in the 1-h testing period. The order of the combinations was randomized and balanced across driver groups to avoid biasing results due to presentation order, fatigue, or practice.

Table 1. Variable combinations studied.

Group	Variable combinations
Participant characteristics	• Gender (2): male or female. • Age (2): young (less than 55 yr) or old (55 yr or older)—used during participant recruitment; however, actual age was used in analysis.
Site characteristics	• Time of day (2): day (natural light) or night (with street light at 25 to 27 lux). • Lane (2): left lane or right lane. • Viewing position (1): 200 ft upstream from assemblies.
Study assemblies characteristics	• LED location (4): LEDs in rectangular beacon below sign active, LEDs in rectangular beacon above sign active, LEDs within sign active, or no LEDs active (i.e., LEDs are not illuminated). • Flash patterns (7): 3 for rectangular beacons, 3 for LEDs within, no flash pattern (i.e., LEDs are not illuminated), see figure 4 for illustrations of flash patterns. • Target intensity (a measure of brightness) (4): 0, 600, 1,400, and 2,200 cd.
Cutout pedestrian characteristics	• Pedestrian position (4): none, right side, center, or left side. • Pedestrian height, when present (2): tall (5.75 ft) or short (4.5 ft). • Pedestrian direction, when present (2): left or right.

cd = Candelas.
LED = Light-emitting diode.

Location of LEDs

In accordance with the Interim Approval (IA-11), the RRFB light bars are to be located below the sign face.[13] However, placing the bars above the sign may offer some advantages. The devices tested are shown in figure 2 and figure 3.

Brightness of LEDs

The brightness characteristics of the LEDs may affect the detection of pedestrians, particularly at night. In this study, researchers measured brightness using intensity, which is a method for quantifying brightness defined by Society of Automotive Engineers (SAE) Standard J595.[14] To quantify the brightness of the pulsing lights, a researcher measured the 95th-percentile peak intensity. The researchers took the measurements at a vertical angle of 0 degrees and a horizontal angle of 0 degrees. Three levels of intensity were selected for the study. The minimum value was 600 candelas (cd), which is the minimum value for an RRFB within the interim approval. The maximum brightness value of 2,200 cd reflected the value researchers could consistently obtain during study development for the range of equipment available. A midpoint value of 1,400 cd was also used.

Flash Patterns

Six flash patterns were tested, and each was compared with a control condition of no illumination (see figure 4). The 2-5 flash pattern was selected based on FHWA official interpretation 4(09)-21 (I).[15] The other flash patterns reflected either patterns available within the controllers

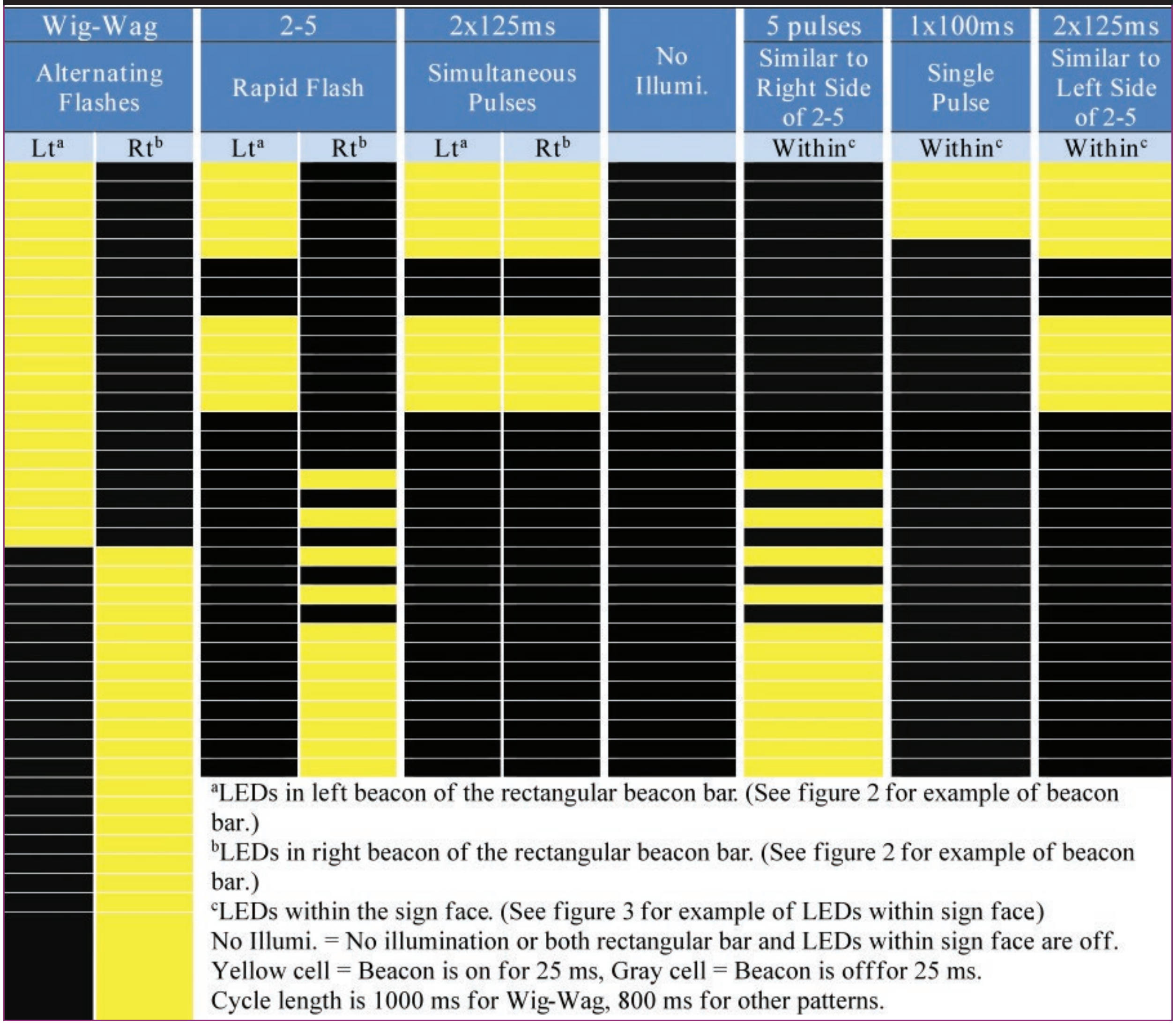
Figure 2. RRFB bar locations tested. (Note that only one bar unit was activated at a time.)

Source: Texas A&M Transportation Institute.

Figure 3. Embedded LED sign tested.

Source: Texas A&M Transportation Institute.

Figure 4. Flash patterns tested.



Source: Texas A&M Transportation Institute.

Table 2. Characteristics of flash patterns.

Flash pattern[a]	Pulse rate[b] (number of pulses/cycle duration)	On ratio[c] (percent)
Wig-wag	2.00	100
2-5	8.75	69
2x125 ms	2.50	31
5 pulses	6.25	38
1x100 ms	1.00	10

[a]See figure 4 for illustrations of flash patterns.

[b]Pulse rate is determined as the number of pulses divided by the cycle duration. For example, the 2-5 pattern has seven pulses within the 0.8-s cycle for a pulse rate of 8.75, while the rapid-flashing LEDs within a sign have five pulses within the 0.8-s cycle for a pulse rate of 6.25.

[c]On-ratio is the percent of the 25 ms increments within a cycle in which the LEDs within the beacon or sign are illuminated. For example, in the wig-wag pattern, there are no dark periods; thus, it has an on-ratio of 100 percent.

donated for the study or portions of an available pattern determined to be viable alternatives for comparison. Because the amount of time the LEDs are on within each cycle may influence a driver's ability to detect a pedestrian, researchers also considered the percent of cycle time when the LEDs were illuminated. (See table 2 for calculated values.)

RESULTS

Pedestrian Detection Time

Table 3 provides calculated median detection times to aid in illustrating the effects of a variable. Note that these values are based on several assumptions, such as age of the participant or beacon intensity, as listed in the table. They do not represent all possible combinations of statistical comparisons and are provided as examples.

On average, drivers took longer to detect the pedestrian cutout photographs in the nighttime (1,404 ms) than in the daytime (1,137 ms), with a difference of 267 ms.

For this study, brightness intensity did not have a significant impact on driver detection time for daytime conditions but was significant for nighttime conditions. Nighttime detection time increased by 8.5 percent at 2,200 cd (the maximum used in the study), compared with when the LEDs were off. The brighter the LEDs, the longer it took for the participants to determine which direction the pedestrian was facing.

Only two flash patterns produced significantly longer detection times when compared with the control condition of no LED illumination: the 2-5 pattern (during the day and at night) and the wig-wag pattern (only at night). These detection times were produced when the light bar was both above the sign face and below the sign face. Compared with the control condition (i.e., LEDs are not illuminated), the 2-5 pattern caused an increase in median detection time of 5.2 percent during day and 6.0 percent at night. The wig-wag pattern caused an increase of 13.7 percent in median nighttime detection time. For example, nighttime median detection was significantly faster when LEDs were dark (1,730 ms) compared with flashing the wig-wag pattern at 2,200 cd (2,108 ms), with a difference of 378 ms. This 22-percent increase in median detection time reflects an additional 13.7 percent because of the wig-wag pattern and 8.5 percent because of the intensity of 2,200 cd (i.e., 1.22 is approximately equal to 1.137 times 1.085).

LED location had a significant impact at night but not during the day. At night, detection was fastest when the LEDs were above the sign face, after controlling for other factors such as intensity. Compared with the LED location above the sign, the median detection time increased 6.0 percent when the LEDs were within the sign, and it increased an additional 6.0 percent when the LEDs were below the sign for a total of a 12.3-percent increase when the below location was compared with the above location. As an example, to detect a short pedestrian under the assembly with LEDs at 2,200 cd and the wig-wag flash pattern, the expected (i.e., by statistical analysis) nighttime median detection times for the three LED positions are as follows: 1,877 ms for LEDs above, 1,989 ms for LEDs within, and 2,108 ms for LEDs below. The difference between below and above is 231 ms.

Some of the other variables tested showed small differences in detection time (< 5 percent) but statistically significant differences between conditions. These variables included pedestrian height, with shorter pedestrians detected slightly more slowly; pedestrian position, with pedestrians in the center of the crosswalk detected slightly more quickly than those on the sides; and age, with average daytime detection time being slower for the older participants than the younger ones.

Table 3. Examples of median detection times for a given set of assumptions.

Variable	Combinations	Daytime (ms)	Nighttime (ms)
Flash pattern	None	925[a]	1,361[a]
	2-5	**989**[a,b]	**1,519**[a,b]
	Wig-wag	961[a]	**1,629**[a,b]
	1x100 ms	982[a]	1,387[a]
	2x125 ms	940[a]	1,422[a]
	5 pulses	981[a]	1,409[a]
LED location	Below	989[c]	1,519[c]
	Within	978[c]	**1,433**[c,d]
	Above	982[c]	**1,352**[c,d]
Brightness level (cd)	0	925[e,f]	**1,361**[e,g]
	600	980[e,f]	**1,475**[e,g]
	1,400	989[e,f]	**1,519**[e,g]
	2,200	998[e,f]	**1,564**[e,g]
Pedestrian position	Under assembly	989[h]	1,519[h]
	Center crosswalk	**934**[h,i]	**1,270**[h,i]

[a]Median detection times represent the following conditions: beacon intensity of 1,400 cd, LED located below the assembly, short pedestrian under the assembly, and 50-yr-old participant.

[b]Statistically different from "None."

[c]Median detection times represent the following conditions: beacon intensity of 1,400 cd, 2-5 flash pattern, short pedestrian under the assembly, and 50-yr-old participant.

[d]Statistically different from "Below."

[e]Median detection times represent the following conditions: LED location below, 2-5 flash pattern, short pedestrian under the assembly, and 50-yr-old participant.

[f]An exponential increase of 0.11 percent in median detection time for an additional 100 cd of intensity was identified; however, it was found not to be statistically significant.

[g]An exponential increase in median detection time across all brightness levels was found statistically significant. This effect corresponds to an increase of 0.37 percent in median detection time for an additional 100 cd of intensity.

[h]Median detection times represent the following conditions: beacon intensity of 1,400 cd, LED located below the assembly, 2-5 flash pattern, short pedestrian, and 50-yr-old participant.

[i]Statistically different from "Under Assembly."

Bold numbers are statistically significant.

LED = Light-emitting diode.

Discomfort Glare

Participants rated their discomfort with the glare from the assemblies as comfortable, irritating, or unbearable. As expected, there were clear differences in the ratings between daytime and nighttime. Table 4 provides the distribution for comfort levels for nighttime conditions to aid in discussions. Note that these values represent the assumption discussed in the table and not all possible combinations.

Not surprisingly, LED intensity was correlated with nighttime discomfort level; as brightness levels increased, the percent of drivers saying unbearable increased (statistically significant). Similarly, there is convincing evidence of lower discomfort levels for the short pedestrian compared with the tall pedestrian. For nighttime only, LED location had a significant impact on discomfort levels. This analysis found evidence of higher

Table 4. Examples of nighttime discomfort glare distributions for a given set of assumptions.

Variable	Combinations	Comfortable (percent)	Irritating (percent)	Unbearable (percent)
Flash pattern	None	98[a]	2[a]	0[a]
	2-5	**48**[a,b]	**45**[a,b]	**7**[a,b]
	Wig-wag	**56**[a,b]	**39**[a,b]	**5**[a,b]
	1x100 ms	**77**[a,b]	**21**[a,b]	**2**[a,b]
	2x125 ms	**57**[a,b]	**38**[a,b]	**5**[a,b]
	5 pulses	**60**[a,b]	**35**[a,b]	**5**[a,b]
LED location	Below	48[c]	45[c]	7[c]
	Within	47[c]	45[c]	8[c]
	Above	**63**[c,d]	**33**[c,d]	**4**[c,d]
Brightness level (cd)	0	98[e]	2[e]	0[e]
	600	**68**[e,f]	**29**[e,f]	**3**[e,f]
	1,400	**48**[e,f]	**45**[e,f]	**7**[e,f]
	2,200	**29**[e,f]	**56**[e,f]	**15**[e,f]
Pedestrian position	Under assembly	48[g]	45[g]	7[g]
	Center crosswalk	**63**[g,h]	**33**[g,h]	**4**[g,h]

[a]Discomfort glare proportions represent the following conditions: beacon intensity of 1,400 cd, LEDs below the assembly, short pedestrian under the assembly, and 50-yr-old participant.

[b]All flash patterns produced discomfort glare levels statistically different from no flash pattern at all.

[c]Discomfort glare proportions represent the following conditions: beacon intensity of 1,400 cd, 2-5 flash pattern, short pedestrian under the assembly, and 50-yr-old participant.

[d]Statistically different from “Below.”

[e]Discomfort glare proportions represent the following conditions: LED location below, 2-5 flash pattern, short pedestrian under the assembly, and 50-yr-old participant.

[f]A continuous logistic effect across all brightness levels was found statistically significant, corresponding to a 9.3-percent increase in the odds of higher discomfort levels per additional 100 cd of intensity.

[g]Median detection times represent the following conditions: beacon intensity of 1,400 cd, LED located below the assembly, 2-5 flash pattern, short pedestrian, and 50-yr-old participant.

[h]Statistically different from “Under Assembly.”

Bold numbers are statistically significant.

LED = Light-emitting diode.

discomfort levels when the LEDs were located below the sign, compared with LEDs above the signs, after controlling for other factors such as intensity.

For nighttime only, pedestrian position had an impact on driver discomfort level. Locating the pedestrian near the beacons on either side of the crosswalk yielded higher discomfort compared with when the cutout was located at the center of the crosswalk. This effect is probably associated with the proximity to the active LEDs. No evidence of higher driver discomfort was found when the pedestrian cutout was placed on the right side compared with when it was placed on the left side.

For nighttime only, there is convincing evidence that the flash pattern has an impact on discomfort levels. Not surprisingly, the analysis found a significant increase in discomfort ratings associated with any flash pattern when compared with no flash pattern (i.e., LEDs are not illuminated).

Discussion

The flash pattern, along with the brightness of LEDs, whether used within a light bar above or below the sign or embedded in a sign, can help draw drivers' attention to a device and the area around the device. Field studies have shown improvements in drivers' yielding to pedestrians at locations where these devices have been deployed. However, characteristics of the LEDs, such as brightness, location, or flash pattern, can also make it more difficult for drivers to see objects at or near a device or may result in drivers looking away from a device. This study used several measures to gain an understanding of how brightness, flash pattern, and location of LEDs affect drivers' ability to detect a pedestrian cutout within a crosswalk equipped with an RRFB. These measures included the time to correctly identify pedestrian walking direction and the participant's rating of discomfort glare.

The brighter the LEDs, the longer it took for the participants to determine which direction the pedestrian was facing. In other words, lower brightness is associated with reduced disability glare. The brightness intensities of the LEDs used in this study was 0 cd (i.e., the LEDs were not illuminated), 600 cd, 1,400 cd, and 2,200 cd. In another FHWA study, devices installed in the field were measured with higher brightness intensity (up to 3,000 cd), so the brightness levels used in this closed-course study do not exceed the values being used for some on-road RRFB installations.[7] The brightness of LEDs in the field appears to be highly variable. Part of the reason for the variability could be that current requirements only specify a minimum intensity. The minimum intensity is defined within SAE Standard J595; the minimum is 600 cd measured at a horizontal angle of 0 and a vertical angle of 0 for Class I yellow peak luminous intensity.[14]

The findings for pedestrian position and LED location indicate that the distance between the pedestrian and the light source affect the ability to quickly detect the pedestrian. When the pedestrians were located at the edge of the crosswalk (i.e., next to the assembly) and when the LEDs were located below the sign (i.e., closer to the pedestrian), detection time was longer. These findings support the idea of placing the LEDs above rather than below the sign. Another area of potential investigation is locating the LEDs over the roadway rather than on the roadside. Such a study would need to consider whether changes are needed in the LED designs (e.g., aiming the LEDs to flash downward toward the drivers).

The shorter-height pedestrian required more time to detect, which is an expected finding. Child-sized pedestrians are a known concern for pedestrian detection in crosswalks.

Some of the flash patterns used with the devices were associated with longer pedestrian detection times. Of the six flash patterns tested, only two flash patterns—the 2-5 and the wig-wag—were associated with statistically significantly longer detection times when compared with the control no illumination condition. Both of these patterns have longer on times (the 2-5 is on 69 percent of the cycle, and the wig-wag is on 100 percent of the cycle) compared with the other patterns (range of 10 to 38 percent on time). The LEDs being constantly "on" may cause the participants to look away from them. In addition, the lack of sufficient dark periods between the flashes may be limiting the participant's ability to adequately search for the pedestrian. A better flash pattern than the current 2-5 pattern should retain multiple pulses (because survey results found that participants felt patterns with multiple pulses are associated with greater urgency), more or longer dark periods (because this study found longer detection time for patterns with fewer dark periods), and a maximum intensity that limits discomfort when attempting to detect objects while still commanding driver attention (i.e., resulting in high driver yielding).[16]

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