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Driver Behavior in Yielding to Sighted and Blind Pedestrians at Roundabouts

Duane R. Geruschat and Shirin E. Hassan

Abstract: This study evaluated drivers' behavior in yielding the right-of-way to sighted and blind pedestrians who stood at different stopping distances from the crosswalk lines at entry and exit lanes at two different roundabouts. The findings demonstrate that drivers' willingness to yield to pedestrians is affected by whether they are attempting to cross at the entry or exit to the roundabout and, under some conditions, by the presence of a long cane.

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At roundabouts, where there are no traffic signals or stop signs, when the volume of traffic is low, sighted

pedestrians simply recognize the absence of traffic before they cross. When the volume of traffic is high, they must identify a gap in vehicular traffic that is of sufficient duration to allow them to cross safely or must cross in front of vehicles whose drivers have yielded to them.

Pedestrians who are blind or have low vision may find it challenging to acquire the necessary information to cross roundabouts safely. Blind pedestrians, who use their hearing to determine whether gaps in traffic are crossable, often have difficulty deciding when it is safe to cross at roundabouts. Guth, Ashmead, Long, Ponchillia, and Wall (2003) and Ashmead, Guth, Wall, Long, and Ponchillia (in press) found that blind pedestrians took significantly longer to detect crossable gaps than did sighted pedestrians. For roundabouts assessed in Baltimore (Guth, Ashmead, Long, Wall, & Ponchillia, in press) and in Tampa (Guth et al., 2003), blind pedestrians took, on average, 3 to 5 seconds more than did sighted pedestrians to indicate (by pushing a button) when it was safe to start crossing, and were likely to miss crossable gaps altogether. Furthermore, blind pedestrians were about 2.5 times less likely than were sighted pedestrians to make correct judgments. These findings suggest that blind pedestrians face greater challenges than do sighted pedestrians when crossing at roundabouts. However, if drivers yielded to blind pedestrians, and blind pedestrians could reliably determine that drivers had yielded, the need to detect crossable gaps would be eliminated, at least at single-

lane roundabouts.

In an attempt to increase the safety of pedestrians, states have introduced laws that grant pedestrians the right-of-way in marked crosswalks and at other locations, such as intersections without marked crosswalks. For example, in Maryland, where this study was conducted, Statute 21-602(a2) states:

The driver of a vehicle shall come to a stop when a pedestrian crossing the roadway in a crosswalk is: (i) On the half of the roadway on which the vehicle is traveling; or (ii) Approaching so closely from the other half of the roadway as to be in danger.

Furthermore, because of a specific incident in which a blind pedestrian was struck and killed, Maryland enhanced the right-of-way for blind or deaf pedestrians by eliminating the requirement to be in a crosswalk. Transportation Article 21-511 states:

The driver of a vehicle shall yield the right-of-way to:

(1) A blind or partially sighted pedestrian using a guide dog or carrying a cane predominantly white or metallic in color (with or without a red tip).

This Maryland law applies only when pedestrians are physically in a crosswalk or, in the case of blind pedestrians, in a crosswalk or a street. When a pedestrian is standing at the curb, the law does not require a driver to yield. We believe that the use of "in a crosswalk," rather than "at a crosswalk," places a heavy

burden on pedestrians who must step into the street to obligate drivers to yield. For the purposes of this study, *yielding* was defined as completely stopping a vehicle before the lines of a crosswalk to allow a pedestrian to cross in front of the vehicle.

Pedestrians should cross in the crosswalk if they expect drivers to yield in compliance with the law. However, it appears to be too much of an assumption that drivers will yield even then. Koepsell et al.'s (2002) retrospective analysis of crosswalk markings and motor vehicle collisions with pedestrians aged 65 and older found that the risk of a collision between a pedestrian and a motor vehicle increased at crosswalks that did not have traffic signals or stop signs. Varhelyi (1998) passively recorded 790 driver-pedestrian encounters at a crosswalk in Sweden to determine, among other things, the frequency of drivers giving way to pedestrians and concluded that drivers did not observe the law, since they yielded to pedestrians only 5% of the time.

The effect of a pedestrian with a disability on drivers' willingness to yield has also been studied. At a busy four-lane street in Edmonton, Alberta, Canada, with a striped crosswalk not regulated by a traffic signal, Harrell (1992) found that drivers were three times more likely to yield to an experimenter who was equipped with an orthopedic cane than to one who was not. Harrell (1994a) studied the factors that influenced drivers to stop for blind pedestrians at a non-signal-regulated pedestrian crossing, finding that drivers were

significantly more likely to yield to blind than to sighted pedestrians. Ashmead et al.'s (in press) study at a multilane roundabout in Nashville, Tennessee, reported that overall, drivers yielded to pedestrians 27% of the time at the entry lane, but only 4% of the time at the exit lane. Furthermore, drivers seemed to be more willing to yield at entry lanes and to yield more to blind pedestrians than to sighted pedestrians. They yielded to blind pedestrians 36% of the time at the entry lane and 9% of the time at the exit lane, but yielded to sighted pedestrians only 17% of the time at the entry lane and not at all at the exit lane.

To evaluate the yielding behavior of drivers for blind and sighted pedestrians at roundabouts, we presented drivers with a variety of pedestrian behaviors at two double-lane roundabouts. We hypothesized that the yielding behavior of drivers at roundabouts is affected primarily by the speed of the vehicle and whether the vehicle is entering or exiting the roundabout. We also wanted to assess whether a pedestrian's location relative to the curb altered the drivers' yielding behavior. In this regard, we hypothesized that the closer that pedestrians stood to the curb and crosswalk lines, the higher the percentage of drivers who would yield. Finally, we were interested in assessing the effect of the long cane that many blind persons use as a mobility aid on the willingness of drivers to yield. We hypothesized that the presence of a long cane would increase the yielding behavior of drivers.

Method

The roundabouts

We studied yielding by drivers at two roundabouts that were approximately two miles apart in Annapolis, Maryland. Both roundabouts met the primary characteristics of modern roundabouts: They had no traffic-control signals other than yield signs for entering traffic; circulating vehicles had the right of way; access by pedestrians was allowed only on the legs of the roundabouts (that is, the roads that connect to the roundabout); no parking was allowed on the roundabouts; and all vehicles circulated counterclockwise (U.S. Department of Transportation, 2000). Roundabout 1 (see [Figure 1](#)), in the center of Annapolis at the intersections of Main Street and Compromise Street, is an urban double-lane roundabout. Roundabout 2 (see [Figure 2](#)), on the edge of the downtown Annapolis business district at the intersection of West Street and Taylor Avenue, is also an urban double-lane roundabout.

Roundabout 1 is in a high-density business district with signal-controlled intersections, one of which was located one block from the leg of the roundabout that was used in this study. Roundabout 2 is in a less-dense business environment than is Roundabout 1. A cemetery and a park are on each side (north and south) of the road from the crosswalk, and businesses are to the east and west of the roundabout. The nearest signal-

controlled intersection is approximately one-third of a mile from the leg of the roundabout that was used in this study. We selected the entry lane and exit lane at one leg of each roundabout. The arrows in Figures 1 and 2 indicate the crosswalks where the study was conducted. For three of the four crossings, there were two lanes for vehicles. For the entry crossing at Roundabout 1, there was one lane for vehicles.

Recognizing that measures of speed are static values of a dynamic situation and are dependent on the location of the vehicle at the time that the speed was recorded, we measured speeds from a variety of locations to characterize the driving environment of each roundabout more accurately. To describe each roundabout, we recorded the speeds of 20 vehicles at three locations, for a total of 60 vehicle speeds per roundabout. Although these 60 vehicles met the criteria for inclusion in the study (they were the lead vehicles and were passenger cars, vans, or half-ton pickup trucks only; no queuing vehicles [line of vehicles]; and if a second vehicle was following the lead vehicle, it was not tailgating), data on these drivers' yielding behavior were not collected; these speeds were recorded on a separate day from the one on which data on yielding were collected. The three locations at each roundabout where measurements of speed were taken were the leading edge of the entry and exit crosswalks, respectively, and 50 feet after the exiting crosswalk used in the study. [Table 1](#) lists the means and standard deviations of the speeds that were measured at the three

locations at each roundabout. Significant differences in speed between the two roundabouts were found across the different locations $F(5, 19) = 33.2, p < .001$. Post hoc analyses (Tukey's HSD) showed that the speeds that were recorded at the exit crosswalk and 50 feet from the exit crosswalk of Roundabout 1 were significantly lower than those that were recorded at the same locations at Roundabout 2. No significant difference was found between Roundabouts 1 and 2 for speeds that were recorded at the entry crosswalks.

Because of the close proximity of the two roundabouts, drivers were considered to come from the same driving culture in terms of their general willingness to yield to pedestrians. We sought to take advantage of the similarity in the driving culture to study drivers' yielding behavior at two dissimilar roundabouts.

Measurements of speed

A Bushnell Speedster speed gun was used to measure the speed of vehicles. According to the manufacturer's manual, the speed recording is exact when a vehicle is moving directly toward the speed gun (that is, it would hit the speed gun if it continued in a straight line). This criterion was true for three of the four crossing situations. The angle from the speed gun to the vehicle for the other condition was less than 10 degrees.

According to the manufacturer, at a distance of 50 feet and an angle of 10 degrees off center, the measurement error is 1.5%.

Procedures

The authors, both of whom are sighted, were the two pedestrians who participated in the study (hereafter referred to as "the pedestrians"). For all the trials, we wore blue jeans, sunglasses, and a navy blue Windbreaker, which was shared among the participants. We evaluated drivers' yielding behavior under six crossing conditions at each roundabout's entry and exit lanes. Three different pedestrian behaviors, which were related to the pedestrians' distance from the curb and the crosswalk, were presented with and without a standard long cane. Specifically, the three behaviors were (1) stopping 1 foot from the curb (see [Figure 3](#)), (2) stopping at the curb (see [Figure 4](#)), and (3) stopping with both feet in the crosswalk (see [Figure 5](#)). These behaviors represented relative increases in pedestrians' assertiveness. Standing 1 foot from the curb may be considered passive behavior, standing on the edge of the curb may be considered assertive behavior, and placing both feet in the crosswalk may be considered aggressive behavior. The latter position is specifically taught to blind pedestrians as one strategy for communicating to drivers the intention to cross the street. Standing in the crosswalk is more assertive than the other two conditions and is more assertive than is typical of blind or sighted pedestrians.

Each behavior was presented with and without the standard long cane. Walking to the curb, one pedestrian

swung the cane in a sweeping fashion in front of his body, known as the touch technique. Upon arriving at the curb, he stopped and extended the cane toward the crosswalk lines with the cane tip touching the crosswalk line. In all the conditions, the pedestrians exhibited the same overall speed of walking, with his or her head turned left toward the oncoming vehicles. These techniques, which are taught to blind pedestrians, are familiar to both authors and are taught by the first author, who is a certified orientation and mobility (O&M) instructor with many years of experience teaching pedestrians who are blind.

A total of six crossing conditions (three pedestrian behaviors, with and without the cane) were presented to drivers 40 times at both the entry and exit lanes of one leg of each roundabout. With two roundabouts, an entry and exit crossing for each roundabout, six crossing conditions, and 40 trials per condition, the entire experiment involved 960 trials.

To begin each trial, the pedestrian stood behind a pillar or against a building, hidden from the driver's line of sight. She then walked approximately 10-15 feet down the sidewalk, timing the placement of her foot in the curb area so that it coincided with the predetermined location of the vehicle as it approached the crosswalk. Thus, the only difference in the pedestrian's behavior across the trials was the location of the pedestrian's feet and the presence or absence of the long cane.

At each crossing, the pedestrian timed his or her arrival at the curb so it would coincide with the vehicle being a specific distance from the curb area. For Roundabout 1, this distance was 35 feet, and for Roundabout 2, it was 50 feet. These distances were selected to be sufficient for the drivers to see a pedestrian and to decide whether to yield. The specific distances were determined through trial and error by observing drivers' braking behavior for the entry lanes (determined with the speed gun), identifying the location of the drivers' lines of sight to the pedestrian crosswalk for the exit lanes, observation of other pedestrians, and the collection of pilot data. In addition, the timing of the pedestrian's arrival at the curb was selected so the pedestrian could not cross before the vehicle entered the crosswalk unless the driver yielded. In other words, unless the driver yielded, the pedestrian could not safely proceed to cross.

The pedestrian always crossed within the boundary of the crosswalk, near the line closest to the approaching driver. When a driver yielded, the pedestrian crossed the street. He did so to reinforce the driver for exhibiting the proper behavior and to avoid confusing the driver. If a driver did not yield, the pedestrian immediately turned and walked away.

During the time that the data were collected, the temperature ranged from 50 degrees to 60 degrees Fahrenheit, and the weather was clear. Data were collected during the time of day when the sun was

positioned behind or to the side of the drivers, so as not to impair the drivers' ability to see the pedestrian.

The criteria for the selection of vehicles, mentioned earlier, were established to minimize the influence of neighboring vehicles and to ensure the drivers' safety when braking. These criteria were established to provide an evaluation of the interaction of one pedestrian and one driver. Although the roundabouts had two lanes, we restricted data collection to drivers in the near lane only. The study followed the tenets of the World Medical Association Declaration of Helsinki of 1964 that guides biomedical research involving human subjects and was approved by the Johns Hopkins institution's committee on human experimentation.

Results

Behaving in as similar a manner as possible and wearing similar clothing (dark sunglasses, blue jeans, and the same blue jacket), we, the pedestrians, evaluated the data for the possibility of a difference in drivers' yielding behavior that was due to differences in the pedestrians. The percentage of drivers yielding for Pedestrian 1 at Roundabout 1 (70%) was not significantly different from that for Pedestrian 2 (73%), $\chi^2(1, N = 480) = 0.10, p > .05$. Similarly, at Roundabout 2, the percentage of drivers yielding for Pedestrian 1 (40%) was not significantly different from that for Pedestrian 2 (47%) $\chi^2(1, N = 480) = 0.73, p > .05$. Since the analysis of the drivers' willingness to

yield to the two pedestrians was similar, the data were combined within the experiments for the initial analysis. In addition, the data were rounded to the nearest whole number, and analyses were performed after the data from Roundabouts 1 and 2 were combined.

Speed of vehicles and drivers' yielding behavior

One objective of this study was to examine whether vehicular speed affects the percentage of drivers who yield. [Figure 6](#) shows a significant relationship between the speed of vehicles and drivers' yielding behavior, accounting for 56% of the variability. As vehicular speed decreases, yielding behavior increases; conversely, as vehicle speed increases, yielding behavior decreases. Specifically, at low speeds (less than 15 miles per hour (mph), drivers yield approximately 75% of the time, whereas at higher speeds (greater than 20 miles per hour), they typically yield less than 50% of the time. [Figure 7](#) shows the relationship between vehicular speed and yielding for entry and exit lanes. We found that 52% of the variability in drivers' yielding behavior at the entry lane across all speeds was accounted for by vehicular speed (the triangles in Figure 7). With an entry speed of 15 mph or slower, drivers yielded over 80% of the time. At higher entry speeds (more than 20 mph), they yielded 55%-65% of the time, except that at 25 mph, they yielded only about 18% of the time. At the exit lanes (the circles in Figure 7), 72% of the variability in drivers' yielding behavior was accounted for by the

speed of the vehicles. Slower exiting speeds were associated with higher percentages of yielding, whereas higher exiting speeds were associated with lower percentages of yielding.

A comparison of the percentages of drivers who yielded and the vehicles' speeds indicates the willingness of drivers to yield when entering and exiting a roundabout. For example, at speeds of 10-11 mph, 99% of the drivers yielded when entering the roundabout, but only 60% yielded when exiting the roundabout. At speeds of more than 20 mph, approximately 65% of the drivers yielded on entering the roundabout, but only 10%-15% did so when exiting the roundabout. Thus, a significantly higher percentage of drivers yielded to pedestrians when entering the roundabout than when exiting it, $F(1, 30) = 99.7, p < .001$.

These findings suggest that a driver's willingness to yield to a pedestrian is related to the speed of the vehicle and whether the vehicle is entering or exiting the roundabout. However, we found no interaction between vehicular speed and the type of lane (entry versus exit), since the slopes of the entry and exit vehicle-yield percentages (see Figure 7) were not significantly different from each other, $F(1, 29) = 4.2, p > .05$.

Viewed from another perspective, the data indicate that drivers yielded 79% of the time for the entry lanes compared to 37% of the time for the exit lanes, $\chi^2(1, N$

= 960) = 34.3, $p < .001$. Drivers who were entering the roundabouts were 6.4 times (confidence interval [C.I.] 4.8-8.4) more likely to yield to pedestrians than were drivers who were exiting the roundabouts. (For an explanation of how these data were derived, please see the [Research Sidebar](#).) Expressed in functional terms, for every one driver who yields while exiting a roundabout, six drivers will yield when entering a roundabout.

The average speed for the entry lane at Roundabout 1 during the study (15 mph) was significantly slower than the average speed for the entry lane at Roundabout 2 (24 mph), $F(1, 479) = 949, p < .0001$. The corresponding percentages of drivers who yielded at the entry lanes of Roundabouts 1 and 2 were 90% and 68%, respectively. We found that drivers yielded significantly more times to pedestrians at the entry of Roundabout 1 than at the entry of Roundabout 2, $\chi^2(1, N = 480) = 33.8, p < .005$. Expressed in functional terms, drivers were 4.3 times more likely to yield (C.I. 2.6-6.9) at the entry of Roundabout 1 than at the entry of Roundabout 2. These findings suggest that slower speeds of entry were associated with higher percentages of drivers' yielding.

At the average speeds for the exit lanes of Roundabout 1 (16 mph) and Roundabout 2 (17 mph) drivers yielded 53% and 20%, respectively, of the time. The difference between driver yields at the exit lanes of Roundabouts 1 and 2 was significant, $\chi^2(1, N = 480) = 38.2, p < .005$.

Drivers were 3.6 times more likely to yield at the exit lane of Roundabout 1 than at the exit lane of Roundabout 2 (C.I. 2.4-5.3).

Pedestrians' behavior and drivers' yielding behavior

With regard to the assessment of whether the pedestrians' behavior influenced the drivers' yielding behavior, we analyzed two types of pedestrian behavior: location relative to the curb and the use or nonuse of a long cane. The first analysis was of the pedestrian's location relative to the curb. Across all the trials without the use of the long cane, when the pedestrian stood 1 foot from the curb, drivers yielded 45% of the time; when the pedestrian displayed assertive behavior by standing at the curb, drivers yielded 52% of the time; and when the pedestrian displayed aggressive behavior by standing in the crosswalk, drivers yielded 60% of the time. There was a significant difference in the yield percentages, $\chi^2(1, N = 360) = 7.2, p < .005$, specifically between standing 1 foot from the curb (45%) and standing in the crosswalk (60%). The odds ratio between these conditions was 1.89, (C.I. 1.2-3.0). Thus, drivers were almost twice as likely to yield to a pedestrian who exhibited aggressive behavior (standing in the crosswalk) than to one who exhibited passive behavior (standing 1 foot from the curb). The reader is reminded that in Maryland, the law requires drivers to yield only when a pedestrian is in the crosswalk, defined in this study as aggressive behavior.

In the second analysis, we evaluated the presence or absence of the long cane on drivers' yielding behavior at roundabouts. When the long cane was present, drivers yielded 63% of the time, whereas when the long cane was not present, they yielded 52% of the time. A significant difference in yielding was found between the use and nonuse of the long cane, $\chi^2 (1, N = 960) = 12.0$, $p < .05$, which led us to conclude that the long cane did make a difference. Drivers were 1.6 times more likely to yield to a pedestrian with a long cane (C.I. = 1.2-2.1) than to a pedestrian without one. Although the long cane provided a significant and beneficial effect, the reader is reminded that only 63% of the drivers yielded to pedestrians with a long cane, and 52% yielded to pedestrians without a long cane.

[Table 2](#) presents the mean percentages of drivers who yielded for all 24 conditions. In 4 of the 12 conditions without the long cane 70% or more of the drivers yielded and, in 3 of these 80% or more yielded, while in 3 conditions 30% or fewer drivers yielded. All the highest percentages of yielding occurred at entry lanes, while all the lowest percentages occurred at exit lanes. In 6 of the 12 conditions with the long cane 70% or more of the drivers yielded, and in 4 of these conditions 80% or more yielded, while in 3 conditions 40% or fewer drivers yielded.

Comparing the yield results obtained across the different pedestrian behaviors, we found that a

pedestrian's behavior can influence a driver's willingness to yield. Specifically, drivers yielded more when the pedestrian behaved aggressively than when the pedestrian behaved passively. However, additional analyses showed that this was not equally the case across both roundabouts and pedestrian locations. In the no-cane condition, there was no effect for pedestrian location at the entry lane of Roundabout 1 because of a ceiling effect, $\chi^2(2, N = 120) = 4.0, p > .05$. That is, because the percentage of drivers yielding at the entry lane of Roundabout 1 was more than 80% for all pedestrian conditions, there was no significant increase in yielding with aggressive behavior, since the percentage of drivers yielding was already so high. Nor was there an effect for the low percentages of drivers yielding at the exit lane of Roundabout 2 because of a floor effect, with all conditions showing 12% or less of drivers yielding, $\chi^2(2, N = 120) = 1.42, p > .05$. The effect for pedestrian location occurred at the exit lane of Roundabout 1, $\chi^2(2, N = 120) = 11.7, p < .05$, and at the entry lane of Roundabout 2, $\chi^2(2, N = 120) = 9.2, p < .05$. We found that at the exit lane of Roundabout 1, yielding behavior was affected when we compared the pedestrian behavior of stopping 1 foot from the curb to that of being in the crosswalk (38% and 65% of drivers, respectively). At the entry lane of Roundabout 2, yielding increased from 48% of drivers when the pedestrian stood 1 foot from the curb to 73% when the pedestrian stood in the crosswalk.

Additional analyses were conducted to understand the specific conditions in which the presence or absence of the long cane made a difference in drivers' yielding. No effect was found for the long cane at Roundabout 1, most likely because the entry lane of Roundabout 1 had high percentages of drivers yielding to pedestrians (more than 80%) across all the cane and no-cane conditions, $\chi^2(1, N = 240) = 0.43, p > .05$. Presentation of the long cane at the exit lane of Roundabout 1 also did not change the percentage of drivers who yielded, $\chi^2(1, N = 240) = 1.6, p > .05$. The effect of the long cane occurred at the entry and exit lanes of Roundabout 2.

When we combined the percentages of drivers yielding across all pedestrian behaviors, we found that 60% of the drivers yielded to the pedestrian without the long cane at the entry lane, while 76% of the drivers yielded to the pedestrian with the long cane, $\chi^2(1, N = 240) = 6.2, p < .05$. Thus, drivers at the entry lane were 2.1 times (C.I. 1.2-3.7) more likely to yield to a pedestrian using a long cane.

At the exit lane of Roundabout 2, 9% of the drivers yielded to the pedestrian without the long cane and 31% did so for the pedestrian with the long cane--a significant difference: $\chi^2(1, N = 240) = 16.2, p < .05$. Hence, drivers at the exit lane were 4.4 times (C.I. 2.1-9.1) more likely to yield to a pedestrian who used a long cane.

Discussion

This study found a relationship between speed of the vehicle and whether it was entering or exiting the roundabout with whether or not drivers yielded to the pedestrian. However, speed does not always explain the findings. While differences in speed at the entry lanes of Roundabouts 1 and 2 could explain the significantly different percentages of drivers yielding, we are left to reconcile the similarity of speeds at the exit lanes with the significant difference in these percentages. Vehicle speeds were similar (16 mph and 17 mph) as the vehicles traveled in both roundabouts, but the recorded speed of a vehicle in the roundabout may not provide a full understanding of a driver's experience. As we described in the Methods section, the exit lanes of Roundabout 1 lead into a light-controlled intersection one block from the roundabout, whereas Roundabout 2 flows to a potentially higher-speed environment. This difference between the roundabouts is reflected in the dissimilar speeds of vehicles 50 feet after the roundabouts, where the average speeds were 15 mph at Roundabout 1 and 23 mph at Roundabout 2 (see Table 1). We speculate that drivers' expectation to, and the opportunity to, accelerate to over 20 mph while leaving Roundabout 2 explain the low percentages of drivers who yielded that we observed at the exit lane of Roundabout 2. Speed in the roundabout cannot explain the difference in the percentages of drivers who yielded between the exit lanes of Roundabouts 1 and 2, but the speed 50 feet after the roundabout exit can explain this

difference. We postulate that to gain a fuller understanding of the factors that influence drivers' yields, one should consider the contribution of the larger roadway environment. The expectations of drivers about being able to accelerate as they leave the roundabout may have an effect on their willingness to yield, independent of their speed while in the roundabout. Thus, the larger context in which the roundabout exists may be an important factor in understanding the willingness of drivers to yield. This possibility requires further study.

Support for our suggestion that drivers' expectation plays a role in drivers' yielding behavior can be found in the yielding behavior at the entry and exit lanes of Roundabout 2. We found that at the entry lane of Roundabout 2, drivers yielded 68% of the time with speeds averaging 24 mph versus 20% of the time with speeds of 17 mph at the exit lane of Roundabout 2. We postulate that drivers are more willing to yield to pedestrians when they are entering a roundabout, since they may be forced to decelerate (a design feature) or even stop to yield to other vehicles in the roundabout, irrespective of whether a pedestrian wants to cross. Thus, if a pedestrian is present when the driver is approaching the roundabout, the driver may be more willing to yield because he or she expects to have to reduce the vehicle's speed. More data are needed to determine if the environment surrounding the roundabout and the expected slowing of vehicles entering the roundabout influence drivers' yielding

behavior.

Another possible explanation is related to the different demands placed on a driver when entering or exiting a roundabout. Entering these two roundabouts involves straight-line driving, while exiting them involves turning while in the roundabout and changing direction again during the exit. These differences in driving requirements may alter the demands on the driver's attention, limiting the driver's ability to notice and respond to a pedestrian.

Still another possible explanation is the different sight lines on entering and exiting the roundabouts. On entering the roundabouts, drivers were on straight roads and so had an unimpeded view of the pedestrian, but when they exited the roundabouts, a small (knee-high) chain fence in one roundabout and knee-high shrubs in the other roundabout impeded their view of the pedestrian.

While the overall result is that a pedestrian's location can influence a driver's willingness to yield, this finding is not universal. From the pedestrian viewpoint, it may not be worth the risk of standing in the crosswalk under circumstances in which this behavior will not increase a driver's willingness to yield. For the pedestrian who is familiar with the roundabout and knows that drivers are likely to yield (over 80% of the time) or unlikely to yield (less than 20% of the time), there is no advantage to standing in the crosswalk (aggressive behavior), and

there may be an increased risk of being injured. When the pedestrian knows that drivers are likely to yield or not to yield, standing 1 foot from the curb will be just as successful as standing in the crosswalk and is potentially safer.

[Figure 8](#) illustrates the effect of the long cane across the entries and exits of Roundabouts 1 and 2. It shows that the presence of the long cane had an effect on altering a driver's willingness to yield at both the entry and exit lanes of Roundabout 2, where the percentage of drivers yielding is the lower. The presence of a long cane resulted in a positive response among some drivers where yielding was unlikely (the exit of Roundabout 2), but the percentage of drivers yielding for pedestrians with the long cane remained low (31%).

The findings for Roundabout 2 at the exit lane show that while the location of the pedestrian relative to the curb does not influence a driver to yield, the presence of a long cane does. By comparison, at the entry lane of Roundabout 2, the pedestrian's behavior did influence the driver's willingness to yield. When assertive or aggressive behavior was combined with the use of the long cane, at least 70% of drivers yielded at the entry lane of Roundabout 2. Unfortunately, the more aggressive behavior exhibited by the two pedestrians is not recommended, especially for pedestrians who are blind, because of safety concerns. It can be more difficult for pedestrians who are blind to recognize the need for avoidance behavior than for pedestrians who

are sighted, which makes it more difficult for them to move quickly and safely to avoid a possible crash.

Limitations

There are a number of limitations that the reader should consider in evaluating these findings. While the relationship of speed and yielding is compelling, it is also true that the drivers' sight lines for the exit lanes were more impeded than they were for the entry lanes of both roundabouts. There were no specific obstacles at the exit lanes, but the natural turn of the roundabout placed the pedestrian at the right side of the driver's peripheral vision. By comparison, as the driver approached the roundabouts' entry lanes, the road was straight (possibly easier to navigate), with the pedestrian still on the right but potentially easier to see.

There may also be unidentified mitigating factors that caused the apparent relationship between vehicular speed and drivers' yielding behavior. Roundabout 1 is in a downtown area that generally has a high volume of pedestrian traffic, whereas Roundabout 2 has a lower volume of pedestrian traffic. Although the experiment was conducted only when no other pedestrians were present, it may be that drivers in the downtown area expected to see pedestrians and were thus habituated to the need to stop to give a pedestrian the right of way.

This study is also limited in that it did not address the issue of yielding for both lanes. The roundabouts we

assessed had two lanes, but we studied the behavior only of drivers in the near lane. In fact, for a blind pedestrian, a single-lane roundabout is much more manageable than is a two-lane roundabout because the sound of the motor of a vehicle in the near lane masks the sound of a vehicle in the far lane.

The findings associated with the effect of the long cane on the percentages of drivers who yielded represent the best possible scenario. Although we attempted to simulate blind pedestrians (by wearing dark sunglasses and moving the long cane in a sweeping fashion), we were able to monitor the drivers' behavior visually. Some drivers flashed their lights, waved their hands, or honked their horns to indicate their willingness to yield to us. For the purposes of this study, these behaviors were accepted as yields. Obviously, a blind traveler would be unaware of the first two of these behaviors and would sometimes be unsure of the meaning of a honking horn. In addition, we did not take into account ambient noise (masking) of other traffic in the roundabout or on the opposite side of the street. The importance of ambient noise was described by Ashmead et al. (in press), who found that blind pedestrians accepted only 9 of 27 yields by drivers, whereas sighted pedestrians accepted all 12 yields. Thus, a blind traveler could expect to perceive a lower percentage of yields than were obtained in this study. Clearly, this is an area that requires further research.

Implications for blind and sighted pedestrians

Vehicular speed is an important issue when evaluating interactions between drivers and pedestrians at roundabouts. The relationship between the speed of a vehicle and the severity of a pedestrian's injury in the case of an accident is compelling. As Leaf and Preusser (1999) noted, models suggest that 5% of pedestrians would die if they were struck by a vehicle traveling 20 mph, approximately 40% would die if they were struck by a vehicle traveling 30 mph, about 80% would die if they were struck by a vehicle traveling 40 mph, and nearly 100% would die if they were struck by a vehicle traveling more than 50 mph. Although no vehicles in this study were traveling more than 30 mph, some were traveling between 20 mph and 30 mph.

Of equal importance is the avoidance of crashes. Pasanen (1993), as reported in Leaf and Preusser (1999), documented that reducing vehicular speed could eliminate some crashes because drivers' and pedestrians' reaction times would increase and reduce the severity of injuries. Retting, Ferguson, and McCartt (2003), in a review of engineering measures to reduce pedestrian-vehicle crashes, proposed three categories of strategies: speed control, separation of pedestrians from vehicles (for example, by constructing a pedestrian bridge), and increasing the visibility of pedestrians. The greater visibility of pedestrians was also found to be effective in increasing the percentage of drivers who yielded to pedestrians (Harrell, 1994b). Van Houten and Malenfant (1992) found that signs and amber flashing

lights also increased the yielding behavior of drivers to pedestrians in the crosswalk. These two studies highlighted the mutual responsibility of pedestrians and drivers.

We calculated positive predictive values at each vehicular speed. The positive predictive value is an estimate of the probability that a driver who is traveling at a given speed or less will yield. A crossing environment that forced vehicles to travel at a speed with a high positive predictive value would be a relatively safer pedestrian crossing, since a high proportion of drivers traveling at that speed would yield to a pedestrian. Thus, the positive predictive value can be used to estimate a vehicular "cutoff" speed that would distinguish safe from less-safe pedestrian environments. Selecting a yield of 90% and the entry-lane data from both roundabouts, we calculated that vehicles traveling at 18 mph had a positive predictive value of 0.89. Thus, using 18 mph as a cutoff speed for roundabout entry lanes, a pedestrian could expect that approximately 9 out of 10 drivers would yield. By comparison, at the exit lane, the highest calculated predictive value of 0.6 was associated with a vehicular speed of 10-11 mph. Unfortunately, even at this relatively low speed, the pedestrian has only a 60% chance that a driver will yield.

Understanding the relative challenges of the various conditions can improve pedestrians' safety. It includes recognizing that to get drivers to yield may require

aggressive behavior. Just as drivers plan routes to avoid crossing multiple lanes of traffic by choosing to drive around the block, pedestrians may choose to avoid certain situations by planning routes that avoid particular roundabout crossings unless the crossing environment is made pedestrian friendly.

Conclusion

In conclusion, the major findings of this study demonstrate that the type of lane (entry versus exit) and the speed of vehicles affect the yielding behavior of drivers at roundabouts. Pedestrian behavior, especially assertive behavior, can influence a driver's willingness to yield. The presence of a long cane did have an effect on the yielding behavior of drivers, but not at the entry of Roundabout 1, with a high percentage of yields, or at the exit of Roundabout 2, with a low percentage of yields. The long cane did increase the percentages of drivers who yielded at the entry and exit lanes of Roundabout 2, although the overall percentage was still low at the exit lane (just 31%).

To increase pedestrians' safety and the accessibility of roundabouts, especially for pedestrians who are blind or have low vision, O&M instructors could use the positive predictive values of different street environments when they teach clients to cross roundabouts safely and independently. For the roundabouts that were assessed in this study, we found that a vehicular speed of 18 mph at an entry lane offers

a 9 in 10 chance that a driver will yield, whereas a vehicular speed of 10 mph at an exit lane offers a 6 in 10 chance that a driver will yield.

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