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Exploratory Analysis of Driver Yielding at Low-Speed, Uncontrolled Crosswalks in Milwaukee, Wisconsin

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Abstract

One of the most common circumstances contributing to pedestrian crashes is drivers failing to yield to pedestrians in crosswalks. A better understanding of driver yielding behavior can help identify optimal safety treatments to improve driver yielding and prevent pedestrian injuries and fatalities. Recognizing this need, this study observed driver yielding behavior at 20 uncontrolled intersections along two-lane arterial and collector roadways with posted speed limits of 25 or 30 miles per hour in Milwaukee, Wisconsin during weekday afternoon peak travel periods in fall 2016. The naturalistic observations showed that drivers yielded 60 times out of 364 opportunities when the pedestrian wished to cross (16% driver yielding rate). Yielding rates differed between intersections, ranging from a high of 60% to a low of 0%. A binary logistic model showed that drivers were more likely to yield to pedestrians when the major roadway had a lower speed limit or less traffic; when the intersection had a shorter crossing distance or a bus stop; and when the pedestrian was White, standing in the street, or acting assertively. Finally, all else equal, intersections with no reported pedestrian crashes in the last 5 years had higher driver yielding rates than intersections with at least two reported pedestrian crashes. While this exploratory study is based on a small sample of observations, it supports several engineering, education, and enforcement strategies and provides suggestions for future studies of driver yielding behavior.

United States pedestrian fatalities have increased from approximately 4,100 in 2009 to approximately 6,000 in 2016 (a 46% increase) (*1*, *2*). The current number represents the highest level of annual fatalities in nearly three decades (*3*). Reversing this trend is critical, and it is supported by federal (*4*), state (*5*), and local (*6*) goals to move toward zero traffic fatalities.

Drivers failing to yield to pedestrians in crosswalks is a common factor contributing to pedestrian crashes. It was the top factor in California and Wisconsin pedestrian crashes (*7*) and was listed as the top common contributing factor (besides "hit-and-run," which is a post-crash characteristic) in a study of six states (*8*). Increasing driver yielding through education, enforcement, and engineering strategies may help improve pedestrian safety (*9*, *10*).

This study conducted naturalistic field observations in Milwaukee, Wisconsin to explore two questions related to driver yielding behavior: (1) How often do drivers yield to pedestrians in specific locations? (2) What characteristics of drivers, pedestrians, and crosswalk locations are associated with whether or not drivers yield to pedestrians?

This study focuses on pedestrians crossing at uncontrolled crosswalks—locations without a traffic signal or stop sign for the driver. These locations are particularly important because they often involve interactions between pedestrians crossing the roadway and drivers traveling straight. Vehicles going straight tend to travel at higher speeds than turning vehicles, leading to more severe pedestrian injuries when collisions occur. A sample of Wisconsin pedestrian crashes from 2011 to 2013 showed that 49% of non-severe crashes involved a vehicle going straight but 77% of fatal crashes involved a vehicle going straight (*11*).

This study is exploratory. Field data were collected in one community at 20 intersections with a relatively narrow range of characteristics. Still, the results are theoretically consistent with previous studies on driver yielding; support several specific education, enforcement, and engineering pedestrian safety strategies; and provide suggestions for future studies.

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Literature Review

Previous research suggests that a variety of factors influence whether or not drivers yield to pedestrians in crosswalks. For example, Schneider and Sanders developed a broad conceptual framework to explain driver yielding behavior (*7*). According to this framework, whether or not a driver yields to a pedestrian at a specific crosswalk depends on roadway design, land-use patterns, pedestrian safety education and enforcement, pedestrian and driver sociodemographic characteristics, and how drivers and pedestrians typically interact throughout a community.

Yet, with several exceptions (*12–15*), there are few driver yielding field studies that examine more than one set of factors. This exploratory study contributes to pedestrian safety research by examining the association between driver yielding and a broad set of roadway design and pedestrian and driver characteristics.

Two of the most common categories of driver yielding factors studied in the literature and evaluated in this study are roadway design characteristics and individual pedestrian and driver characteristics.

Roadway Design Characteristics

A survey of nearly 400 pedestrian safety professionals throughout North America suggested that lower speed limits and fewer roadway lanes were associated with higher driver yielding rates (*7*). These perceptions are supported by field data: lower posted speed limits were associated with higher driver yielding rates for several pedestrian crossing treatments (*16*), and lower actual motor vehicle approach speeds were associated with higher rates of driver yielding in Massachusetts (*17*) and at roundabouts in six states (*12*). Further, shorter crossing distances were associated with higher yielding rates in a multi-state study (*18*). In general, these studies suggest that roadways designed primarily to move large amounts of motor vehicle traffic quickly are less conducive to yielding than narrower, lower-speed roadways.

Many studies have tested how drivers respond to design treatments at specific crosswalk sites. Driver yielding rates tend to be higher at crossings with MUTCD R1-6 in-street pedestrian crossing signs (*13*, *19*), gateway treatments (i.e., MUTCD R1-6 in-street signs at the center of the roadway and on the curbs near either end of the crosswalk) (*20*), advance yield markings (*21*), median islands (*18*), rapid flashing beacons (*22–24*), pedestrian hybrid beacons (*25*), and leading pedestrian intervals at signalized intersections (*26*).

Pedestrian and Driver Demographic and Behavior Characteristics

Previous research has found pedestrian and driver characteristics to be associated with driver yielding. Drivers tend to yield more often to pedestrians holding a cane (*12*, *27*) and pedestrians wearing brighter clothing (*28*). Drivers may also yield more often to pedestrians who are White than to pedestrians of color (*29*, *30*). Drivers who are older (*31*), male (*31*), and drive less expensive automobiles (*32*) may yield more often to pedestrians. Yet, few studies have collected these demographic and socioeconomic characteristics, especially in combination with roadway characteristics.

Studies also suggest that there is a relationship between pedestrian behavior and driver yielding. More assertive pedestrians tend to produce higher driver yielding rates (*7*, *14*, *15*, *28*, *33*). However, researchers do not use a consistent measure of "assertiveness." For example, pedestrian assertiveness has been defined as waiting in the street (rather than on the curb) (*12*, *28*), walking quickly toward the crossing (*14*, *15*), or raising a hand or extending an arm in the direction of crossing (*33*). Overall, higher pedestrian volumes may be associated with higher rates of driver yielding (*13*, *31*). This may be attributable to heightened driver awareness or greater pedestrian assertiveness in areas with high pedestrian activity.

Driver Yielding Data Collection Approaches

Most field studies observe how drivers react to staged pedestrians (i.e., members of the research team) as they approach a crosswalk (*10*, *12*, *13*, *17*, *18*, *20*, *24*, *29*, *30*, *33*). This method has several advantages. First, researchers can collect a large sample of driver yielding opportunities relatively quickly. Second, researchers can control pedestrian demographic and assertiveness characteristics. In particular, pedestrians can be directed to behave similarly for each approaching vehicle (e.g., set one foot into the roadway and look at the approaching driver). Some staged pedestrian studies have also observed unstaged crossings of pedestrians who happened to pass through the study site (*10*).

This study focuses exclusively on unstaged crossings, following the approach used by Schroeder (*14*) and Schroeder and Rouphail (*15*) in Raleigh, NC. This approach was chosen to document naturally occurring interactions between drivers and pedestrians in the Milwaukee community.

Data Collection

Driver yielding data were collected at 20 uncontrolled intersections along two-lane arterial and collector roadways in Milwaukee during fall 2016. Ten of the intersections had experienced at least two reported daytime pedestrian crashes during a 5-year period (2010–2014). The other ten had similar characteristics but experienced one or zero reported crashes during this period (Figure 1). Data were collected in central Milwaukee because it tends to have moderate to high pedestrian activity as a result of its relatively high development density, neighborhood commercial streets, proximity to the central business district, and high-frequency bus lines. Regular pedestrian activity allowed observation of a

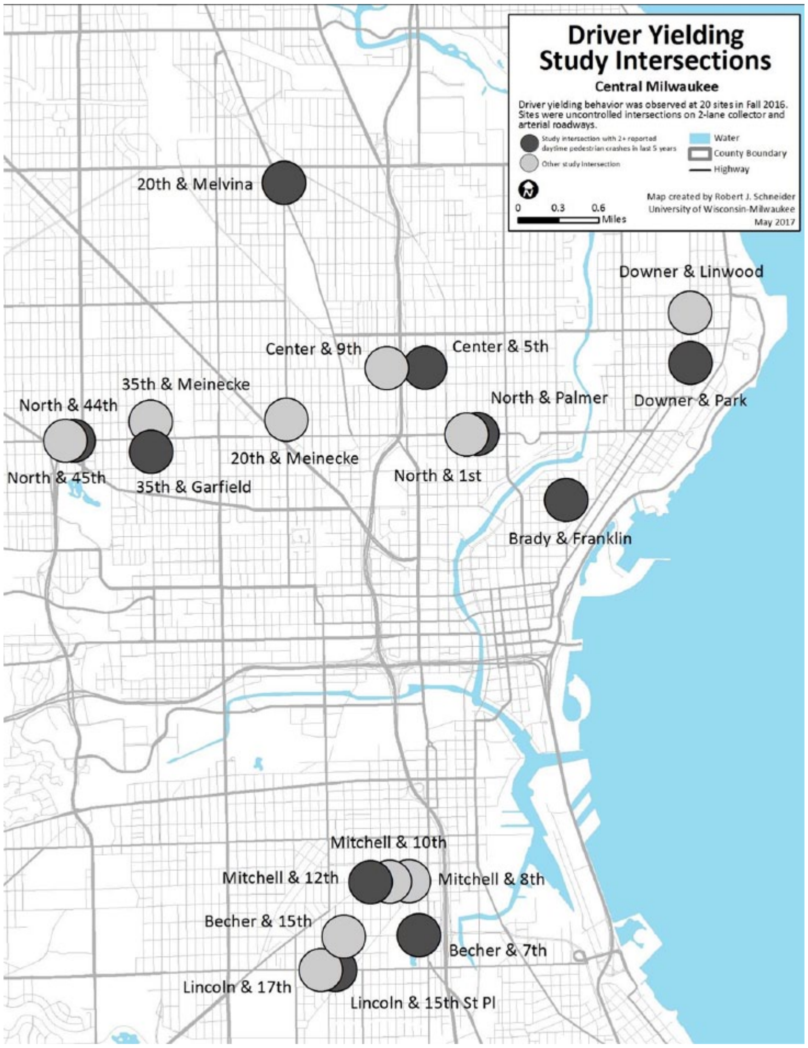

Figure 1. Milwaukee study intersection locations.

sufficient sample of pedestrian crossings during relatively short field data collection periods at each site.

Driver Yielding Behavior

Three data collectors made field observations for 2 hours during weekday evening travel periods (Monday through Thursday, typically 5 pm to 7 pm). Unstaged pedestrian crossings were observed—pedestrians and drivers of all types of motor vehicles interacting naturally in public. Pedestrian crossings were only observed for the mainline roadway crosswalks and were only considered when pedestrians started within the crosswalk lines. Pedestrians were observed when crossing either from the driver's left or right. After a pedestrian arrived at the crossing, data collectors observed the first driver from either direction with an opportunity to yield. Drivers were considered as having an opportunity to yield if they were beyond a minimum distance away from the crosswalk when the pedestrian arrived at the curb (which is slightly different than state law: drivers must yield the right-of-way when a pedestrian puts at least one foot in the crosswalk). The method described by Van Houten et al. (*34*) was used to calculate the minimum safe stopping distance for drivers. For example, based on a driver reaction time of 2.5 s, the posted speed limit in feet per second, and a conservative deceleration rate of 11.2 feet (3.41 m) per second, the safe stopping distance for vehicles traveling at 30 mph (48 km/h) on a flat grade is 196 feet (59.7 m). Drivers within this distance when the pedestrian arrived were not considered to have an opportunity to yield. Overall, 473 pedestrian crossings were observed across the 20 study sites, and drivers had an opportunity to yield for 364 of these crossings.

Explanatory Variables

Several categories of explanatory variables were collected, including site characteristics, pedestrian and driver demographics, and pedestrian group size and behavior characteristics.

Roadway and crosswalk characteristics were measured at each intersection (Table 1). All of the study intersections were in corridors with on-street parking. Annualized average daily traffic (AADT) volumes in these corridors ranged from approximately 5,000 to 16,000, and posted speed limits were either 25 or 30 mph. Some corridors had bicycle lanes, while others did not. This feature was correlated with crossing distance, which ranged from 35 to 52 feet. All study intersections had four legs. Some intersections had both crosswalks marked across the major roadway, while others only had one of the two crosswalks marked. Some intersections had standard crosswalk warning signs (MUTCD W11-2 or W11-2A). None of the study intersections had designated left-turn lanes, designated right-turn lanes, far-side bus stops, in-street pedestrian crossing signs (MUTCD R1-6), curb extensions, or median islands.

The field data collectors also assessed pedestrian assertiveness, observed pedestrian crossing group size, and estimated pedestrian and driver demographic characteristics. Table 2 defines and summarizes the variables corresponding with each of the 364 driver yielding opportunities. How these variables may be related to driver yielding based on previous research was hypothesized. To the authors' knowledge, few previous studies have evaluated as broad of a combination of demographic, behavioral, and site variables. More details about the data collection protocol and specific variables are provided in the study report (*35*).

Binary Logistic Regression Model Structure

A series of binary logistic regression models was developed to identify explanatory variables that may be associated with drivers choosing to yield (or not yield) to pedestrians. The binary logistic regression model is specified as:

$$g(X) = Ln\left[\frac{P(x_i)}{1-P(x_i)}\right] = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \varepsilon_i \quad (1)$$

where $P(x_i)$ is the probability of a driver yielding to a pedestrian at any of the $i = 364$ pedestrian crossing opportunities, X_{ki} is a vector representing the kth explanatory variables (e.g., roadway features, pedestrian and driver demographic characteristics, pedestrian behaviors) for the ith observation, β_k is a vector of parameters that express the relationship between each explanatory variable in X_{ki} and the probability of a driver yielding to a pedestrian, and ε_i is the error term. The parameters β_k were estimated using maximum likelihood estimation. Using the equation specified above, the probability of driver yielding to pedestrian can be written as:

$$P(x_i) = \frac{1}{1 + exp\left[-\left(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki}\right)\right]} \quad (2)$$

Since observations were collected at 20 distinct intersections, it is possible that driver yielding behavior is correlated between drivers at a particular intersection as a result of some unmeasured factors. To evaluate the unobserved correlation in driver yielding at particular intersections (or any other unmeasured intersection-related characteristics contributing to the driver yielding decision), a random-effect logistic regression model was also developed and tested. This was done by introducing 20 intersection-specific indicator variables to the model. However, these indicator variables were not significant, and calculations of null deviance, residual deviance, and Akaike Information Criterion (AIC) showed that this model did not have better performance, so the final results from our binary logistic regression model are presented.

Modeling Process

All 23 explanatory variables were tested in a series of models, starting with only demographic and behavior variables, assuming that driver yielding behavior may depend on driver and pedestrian age, gender, and race/ethnicity, as well as pedestrian assertiveness. Then site-specific variables were added. Variables were selected for more refined models using random forest and step-wise procedures. Explanatory variables were removed that did not have a significant relationship (90% confidence level) with driver yielding, starting with the least significant variables. Theoretical relationships and practical expertise were used to prevent statistically correlated variables from being included in the same model.

Results

In total, 473 pedestrian crossings at 20 uncontrolled intersections in Milwaukee were documented (Table 1). Of these crossings, 364 had opportunities for drivers to yield to a pedestrian. Sixty of these drivers were observed to yield, producing an overall yielding rate of 16%. Yielding rates differed between intersections, ranging from a high of 60% to a low of 0%. Note that these results apply to the specific urban context of Milwaukee and are limited to the range of values available in this dataset (see Table 2).

Overall Model Fit

The final binary logistic regression model of driver yielding included eight explanatory variables (Table 3). It had the lowest AIC of all models tested (261), suggesting the best fit. All explanatory variables in the final model were significant at the 95% confidence level. Table 4 provides an example of how the model-estimated percentage of drivers who yield is

Table 1. Milwaukee Study Intersection Characteristics and Driver Yielding Rates

Study intersection	Major road AADT	Major road posted speed limit (miles per hour)	Crossing distance[a] (feet)	Distance to on-street parking[b] (feet)	Bus stop (1 = Yes, 0 = No)	Both crosswalks marked (1 = Yes, 0 = No)	Crosswalk sign (MUTCD W11-2 or W11-2A) (1 = Yes, 0 = No)	Adjacent commercial land use (1 = Yes, 0 = No)	Intersection had 2+ reported crashes in 5-year period (1 = Yes, 0 = No)	Field data collection date	Field data collection time period (pm)	Pedestrian crossings	Driver yielding opportunities	Number of drivers who yielded	Percent of drivers who yielded
E North Ave & N Palmer St	16400	30	51	100	0	1	1	0	1	8/15/16	5:00–7:00	17	17	0	0%
W North Ave & N 1st St	16400	30	52	200	1	1	0	0	0	11/1/16	4:30–6:30	14	10	2	20%
N 35th St & W Garfield Ave	14500	30	56	500	1	1	0	1	1	8/24/16	5:15–7:15	31	28	1	4%
W Lincoln Ave & S 15th St Pl	14200	30	55	20	0	0	0	1	1	8/25/16	5:00–7:00	38	34	0	0%
N 35th St & W Meinecke Ave	13800	30	51	400	0	1	1	1	0	9/13/16	4:45–6:45	26	22	1	5%
W North Ave & N 44th St	13200	30	56	25	0	0	0	1	1	8/18/16	5:15–7:15	17	16	0	0%
W Lincoln Ave & S 17th St	13000	30	51	25	0	0	0	0	0	10/18/16	5:00–7:00	19	13	5	38%
W North Ave & N 45th St	11000	30	56	200	1	1	0	1	0	9/6/16	4:30–6:30	30	27	8	30%
E Brady St & N Franklin Pl	10100	25	40	18	0	1	1	1	1	8/10/16	5:00–7:00	38	27	14	52%
W Center St & N 5th St	10000	30	54	80	1	0	0	1	1	8/16/16	5:00–7:00	32	29	1	3%
W Becher St & S 7th St	9600	30	49	300	0	0	1	0	1	8/29/16	5:00–7:00	24	11	1	9%
W Center St & N 9th St	9100	30	59	400	0	0	1	0	0	8/31/16	4:30–6:30	16	16	0	0%
W Mitchell St & S 8th St	9000	25	56	25	0	1	0	1	0	10/19/16	4:30–6:30	16	10	1	10%
W Mitchell St & S 10th St	8400	25	54	30	0	1	0	1	0	9/1/16	5:00–7:00	20	18	6	33%
N Downer Ave & E Park Pl	7200	30	50	30	1	1	1	1	1	8/11/16	5:00–7:00	58	29	6	21%
N 20th St & W Meinecke Ave	6800	30	50	120	0	1	0	0	0	10/25/16	4:30–6:30	23	18	4	22%
W Becher St & S 15th St	6600	30	46	200	0	0	0	0	0	10/11/16	4:30–6:30	15	7	0	0%
W Mitchell St & S 12th St	6300	25	5w1	30	0	1	0	1	1	8/24/16	5:00–7:00	18	16	4	25%
N Downer Ave & E Linnwood Ave	5100	30	58	200	1	0	0	0	0	8/30/16	5:00–7:00	15	10	6	60%
N 20th St & W Melvina St	4900	30	49	90	0	0	0	0	1	8/17/16	5:00–7:00	6	6	0	0%
Average of 20 Study Sites	10280	29	52	150	0.30	0.55	0.30	0.55	0.50			473	364	60	16%

Note: 10 miles per hour = 16.1 kilometers per hour; 1 foot = 0.305 meters.

[a]The crosswalk crossing distance was the shortest curb-to-curb distance within the crosswalk. The distance shown is the average of the two major road crosswalks.

[b]Distance from the crosswalk to street parking was the distance to the closest car parked on the street in advance of the crossing. The distance shown is the average of the two mainline crosswalks. All of the study intersections were two lanes with on-street parking during most times of day. However, two intersections (N. 35th Street and W. Meinecke Avenue and N. 35th Street and W. Garfield Avenue) had peak-hour parking restrictions on between 3:30 pm and 5:30 pm, so they had four operating traffic lanes and no on-street parking for part of the time when data were collected (approximately 45 minutes at N. 35th Street and W. Meinecke Avenue and approximately 15 minutes at N. 35th Street and W. Garfield Avenue).

Table 2. Explanatory Variables Tested in Binary Logistic Regression Models

	Mean	Std. dev.	Min	Max	Expected relationship with yielding
Demographic variables[a]					
Pedestrian race/ethnicity = White (1 = yes; 0 = no)	0.291	0.455	0	1	+
Pedestrian gender = Male (1 = yes; 0 = no)	0.632	0.483	0	1	+
Pedestrian age <25 years (1 = yes; 0 = no)	0.179	0.384	0	1	+
Driver race/ethnicity = White (1 = yes; 0 = no)	0.368	0.483	0	1	+
Driver gender = Male (1 = yes; 0 = no)	0.640	0.481	0	1	–
Driver age <25 years (1 = yes; 0 = no)	0.440	0.497	0	1	–
Behavior variables					
Pedestrian standing in the street (1 = yes; 0 = no)[b]	0.819	0.386	0	1	+
Pedestrian acting assertively (1 = yes; 0 = no)[c]	0.431	0.496	0	1	+
Pedestrian group size = 1 (1 = yes; 0 = no)[d]	0.731	0.444	0	1	–
Site variables					
Traffic volume (AADT)	10800	3260	4900	16400	–
Posted speed limit (miles per hour)	29.0	1.98	25	30	–
Average crossing distance (feet)[e]	52.3	4.53	40	59	–
Bus stop present (1 = yes; 0 = no)	0.365	0.482	0	1	+
Distance from upstream signal (feet)[f]	720	421	253	2000	–
Distance to downstream signal (feet)[f]	779	452	253	2000	+
Distance from crosswalk to street parking (feet)[g]	148	157	18	500	+
Both crosswalks marked (1 = yes; 0 = no)	0.610	0.488	0	1	+
Crosswalk sign present (1 = yes; 0 = no)[h]	0.335	0.473	0	1	+
Right-turn area present (1 = yes; 0 = no)[i]	0.508	0.501	0	1	–
Adjacent commercial land use (1 = yes; 0 = no)[j]	0.703	0.457	0	1	+
Majority of pedestrians are White (1 = yes; 0 = no)	0.228	0.420	0	1	+
Majority of drivers are White (1 = yes; 0 = no)	0.302	0.460	0	1	+
Intersection had 2+ pedestrian crashes (1 = yes; 0 = no)[k]	0.585	0.493	0	1	–

Note: 10 miles per hour = 16.1 kilometers per hour; 1 foot = 0.305 meters.
[a]The demographic characteristics of pedestrians and drivers were estimated by field data collectors.
[b]"Standing in the street" indicates that pedestrians waited in the crosswalk with at least one foot in the street.
[c]"Acting assertively" indicates that pedestrians exhibited any one of the following characteristics: (1) the pedestrian actively leaned toward the opposite side of the roadway when in the crosswalk, (2) the pedestrian directed his or her eyes toward approaching drivers for more than 3 seconds, or (3) the pedestrian pointed his or her arms or fingers toward the crosswalk.
[d]Group size was the total number of pedestrians waiting to cross at one time. The group was defined by waiting together; they did not all need to end up crossing at the same time.
[e]The crosswalk crossing distance was the shortest distance from the curb on one side of the street to the curb on the other side of the street within the crosswalk. Average crossing distance for each intersection was the average of the two crosswalks.
[f]Distance from upstream signal is the distance from the upstream signal to the center of the intersection, and distance to downstream signal is the distance from the downstream signal to the center of the intersection. These variables were calculated for the direction of travel of each individual approaching vehicle.
[g]Distance from the crosswalk to street parking was the distance from the crosswalk at the edge of the intersection to the closest car parked on the street in advance of the crossing (average distance from both mainline crosswalks).
[h]Intersection had a crosswalk sign (MUTCD W11-2 or W11-2A). No site had warning signs in advance of the crosswalks.
[i]A right-turn area was noted if there was a separate area to the right of the travel lane that was commonly used by right-turning cars to move out of the traffic stream prior to turning right. This operated like a right-turn lane but was not designated.
[j]Adjacent commercial land use indicates that the intersection was in a downtown or neighborhood commercial district.
[k]Intersection experienced at least two reported daytime pedestrian crashes during the 5-year period, 2010–2014.

associated with changes in each individual variable. These associations between each variable and driver yielding behavior are discussed below.

Demographic Variables Associated with Driver Yielding

The final model showed that drivers were more likely to yield to pedestrians who were White than pedestrians of other racial and ethnic backgrounds. This supports the findings of Goddard et al. (*29*). However, this result should be interpreted with caution. There were notable differences in the percentage of White pedestrians among the study intersections (12 intersections had 15% or fewer White pedestrians; three intersections had 85% or more White pedestrians). Therefore, the variable indicating that the pedestrian was White could be capturing other unmeasured characteristics that were different among the intersections (e.g., neighborhood income

Table 3. Final Driver Yielding Model

Variables	Coefficient estimate	Std. error	Z-value	Pr(>|z|)
Intercept	15.580	3.751	4.155	0.000
Demographic variables				
Pedestrian race/ethnicity = White	1.005	0.423	2.376	0.017
Behavior variables				
Pedestrian standing in the street	1.284	0.548	2.341	0.019
Pedestrian acting assertively	0.946	0.405	2.330	0.019
Site variables				
Traffic volume (AADT)	–0.000125	0.000062	–2.071	0.038
Posted speed limit (miles per hour)	–0.384	0.099	–3.869	0.000
Average crossing distance (feet)	–0.129	0.052	–2.482	0.013
Bus stop present	1.669	0.520	3.208	0.001
Intersection had 2+ pedestrian crashes	–1.928	0.462	–4.168	0.000
Sample size (*n*)			364	
Null deviance			325.85 on 363 degrees of freedom	
Residual deviance			242.52 on 355 degrees of freedom	
AIC			260.52	

Note: 10 miles per hour = 16.1 kilometers per hour; 1 foot = 0.305 meters.

levels, which may relate to pedestrian clothing type and appearance; neighborhood driver behavioral norms, including acceptance of speeding; neighborhood enforcement of traffic laws). The data cannot determine whether specific drivers are less likely to yield because a pedestrian is a person of color or whether drivers in neighborhoods where there are more people of color crossing the street are less likely to yield in general. Nonetheless, this finding points to the importance of equity in pedestrian safety efforts.

Pedestrian age and gender were not significant. No driver demographic variables (age, gender, or race/ethnicity) were significant in the final model.

Behavior Variables Associated with Driver Yielding

Two pedestrian behaviors were significant in the final model. Pedestrians who waited in the street rather than on the curb were more likely to have drivers yield to them. In addition, pedestrians who indicated their intent to cross the street assertively were more likely to have drivers yield. Waiting in the street and taking an assertive stance in the crosswalk may make drivers more aware of pedestrians and may also more clearly indicate an intent to cross. Pedestrian group size was not significant in the model.

Site Variables Associated with Driver Yielding

Within this study context of two-lane roadways with speed limits of 25 to 30 mph, all else equal, drivers were less likely to yield at intersections with higher traffic volumes and higher posted speed limits. Streets with these design characteristics may be perceived by drivers and pedestrians as thoroughfares for automobiles, so drivers may be less aware of pedestrians and be less concerned about yielding to pedestrians at a crosswalk. In addition, it is more difficult to yield to a pedestrian when traveling at a higher speed, since it requires seeing the pedestrian sooner and decelerating more quickly than when traveling more slowly. Plus, on streets with more traffic and higher speeds, drivers may be more concerned about being rear-ended by other cars or about being passed recklessly on the right or left when the pedestrian is in the crosswalk.

Drivers were less likely to yield when the pedestrian crossing distance was longer. While this study focused on two-lane roadways, there was still some variation in road width. Wider roads generally make it easier for other drivers to pass on the right, especially when they think that a car stopped in front of them for a pedestrian is turning left. In addition, wider roads may be associated with higher travel speeds, regardless of speed limit, making it more difficult for drivers to yield.

There was evidence that intersections with bus stops tend to have a higher likelihood of driver yielding. This could be as a result of higher pedestrian volumes (pedestrians crossing to catch the bus), buses slowing traffic near the intersection as they exit and enter the traffic stream, or other factors. All of the bus stops were on the near side of the study intersections (far-side stops are rare in Milwaukee). This does not suggest that near-side bus stops are safer for pedestrians than far-side bus stops. To the contrary, the Federal Highway Administration recommends placing bus stops on the far side of intersections when possible to reduce the chances of multiple-threat pedestrian crashes (*36*). Future studies should examine the relationship between bus stop placement and driver yielding.

Drivers were less likely to yield to pedestrians who were crossing at intersections that had experienced two or more

Table 4. Model Sensitivity Example Using Hypothetical Site Values

Model variables	Hypothetical site variable initial value[a]	Hypothetical site variable changed value	Percent change in driver yielding associated with hypothetical variable change[b]
Pedestrian race/ethnicity = White (1 = yes; 0 = no)	0	1	+2.0%
Pedestrian standing in the street (1 = yes; 0 = no)	0	1	+3.0%
Pedestrian acting assertively (1 = yes; 0 = no)	0	1	+1.8%
Traffic volume (AADT)	6,000	5,000	+0.2%
Posted speed limit (miles per hour)	30	25	+6.4%
Average crossing distance (feet)	45	40	+1.1%
Bus stop present (1 = yes; 0 = no)	0	1	+4.8%
Intersection had 2+ pedestrian crashes (1 = yes; 0 = no)	1	0	+6.4%

[a]Hypothetical site variable initial values were chosen to produce a low model-estimated probability of driver yielding. This made it easier to change each individual variable in the same direction (i.e., to increase the model-estimated probability).
[b]The model-estimated probability of a driver yielding at a site with the hypothetical initial values for all variables is 1.2%. For example, changing the base value of White = no to White = yes is associated with a 2.0% increase in the model-estimated driver yielding percentage (from 1.2% to 3.2%).

daytime pedestrian crashes in the last 5 years. Given that factors such as traffic volume, speed limit, and crossing distance are already captured in the model, this variable may be capturing other unmeasured roadway or behavior characteristics that are associated with higher pedestrian risk at these particular crossings (i.e., driving while intoxicated or distracted; speeding; walking while intoxicated). This result also suggests an important relationship between higher driver yielding rates and enhanced pedestrian safety.

Several other site characteristics were tested but not significant in the final model, including marked crosswalks, crosswalk signs, right-turn areas, the majority of drivers and pedestrians at the intersection being White, and adjacent commercial land use. While these variables were not significant in this particular model of behavior at a limited set of crosswalks in Milwaukee, they may still have a relationship with driver yielding and pedestrian safety.

Implications for Practice

This model identifies associations between driver yielding and specific roadway and behavior characteristics. While these results do not imply direct causation, they provide support for several strategies to increase driver yielding to pedestrians in uncontrolled crosswalks.

Reduce Roadway Design Speeds and Reduce Posted Speed Limits

Lower speed limits were associated with a higher likelihood of drivers yielding to pedestrians. This finding complements other research that finds actual approach speeds are inversely related to driver yielding rates (*17*). As higher speeds are also associated with higher pedestrian injury severity (*37*), reducing motor vehicle speeds is an important pedestrian safety strategy. Design strategies to discourage speeding along roadway corridors may include:

- Minimize the total number of automobile lanes.
- Minimize automobile lane widths.
- Introduce on-street parking or other features that provide visual cues to travel slowly.

Reduce Pedestrian Crossing Distances

Shorter pedestrian crossing distances were associated with a higher likelihood of drivers yielding to pedestrians. Shorter crossings also reduce the amount of time that pedestrians are in the roadway and exposed to traffic. Several design treatments can be used to shorten pedestrian crossing distances:

- Install curb extensions on roadways with on-street parking. In addition to reducing the crossing distance, this treatment helps keep sight lines between pedestrians and drivers from being blocked by parked cars. Curb extensions can also reduce vehicle turning speeds.
- Install raised median islands. Median islands divide the crosswalk into two distinct crossings, each shorter than the original crossing. This also provides a refuge for pedestrians, allowing them to cross one direction of traffic at a time.
- Reduce the number of automobile lanes and reduce lane widths. Reducing the roadway width allocated to automobile travel will reduce the distance that pedestrians will be exposed to potential conflicts with motor vehicles. Reducing the number of automobile lanes has been shown to benefit pedestrian, bicyclist, and motorist safety (*38*). This also provides additional space for bicycle lanes, shoulders, landscaped buffers, sidewalks, or other street features.

Help Pedestrians Communicate Intent to Cross

Drivers were more likely to yield to pedestrians who acted assertively. One simple strategy to increase assertiveness is to encourage pedestrians to point across the roadway after arriving at a crosswalk and make eye contact with approaching drivers. Pointing has been shown to increase driver yielding rates (*33*). However, increasing pedestrian assertiveness in a community is challenging because it involves modifying social norms that may have been established over decades and because pedestrian assertiveness is likely tied to expectations of driver yielding behavior (*7*). Helping pedestrians feel safe enough (and trust drivers enough) to act assertively is likely to require a comprehensive approach that includes:

- Education (e.g., emphasize that drivers should anticipate pedestrians and must yield the right-of-way to pedestrians who enter uncontrolled crosswalks; emphasize that pedestrians should make eye contact with drivers and confidently assert their right-of-way in crosswalks).
- Enforcement (e.g., implement high-visibility enforcement [HVE] programs that combine enforcement of pedestrian right-of-way laws with public messaging and media outreach [*10*, *34*]).
- Engineering (e.g., use roadway design principles supported by this study and other promising treatments described in the literature review).

These types of comprehensive pedestrian safety programs have increased driver yielding (*9*, *39*). Further, given that these findings suggest that drivers may be more likely to yield to White pedestrians, local leaders and agency staff should ensure that comprehensive education, enforcement, and engineering strategies are applied throughout a jurisdiction, including neighborhoods with many people of color. Additional focus may be needed to ensure that pedestrians of color experience crossing the street as comfortably and safely as all other community members.

Considerations and Future Research

This research studied driver yielding behavior at uncontrolled crossings of two-lane arterial and collector roadways. Although several significant demographic, behavior, and site variables were identified, there are other variables that should be included in future studies, such as actual vehicle speeds, pedestrian clothing type and brightness, and a wider range roadway design characteristics (e.g., number of travel lanes, designated turn lanes, median islands, curb extensions, and different combinations of signs, markings, and beacons). In addition, there are other contexts where driver yielding behavior at uncontrolled crossings should be documented, such as on urban residential streets and on suburban and rural roadways. A related line of research should also be undertaken to study driver yielding behavior when turning at controlled and uncontrolled intersections.

Data were collected at 20 study sites in Milwaukee. Although the multiple data collection sites allowed analysis of several different roadway features, the sample of sites is small. Therefore, data should be collected at more locations in Milwaukee as well as sites in other communities to examine the consistency of these results and to explore additional variables that may be related to driver yielding behavior. In particular, more study sites would help provide more data to explore the association between pedestrian and driver race/ethnicity and driver yielding and better understand the underlying reasons for any inequities.

Like most other driver yielding studies, this study collected data during daylight hours. However, 31% of the pedestrian crashes in Wisconsin between 2011 and 2015 where driver failure to yield was a contributing circumstance occurred during darkness (*35*). Lighting and visibility are likely to influence pedestrian and driver behaviors at uncontrolled crosswalks, so more research is needed to identify the potentially different factors associated with driver yielding at night.

Demographic and behavior data were collected in the field, so observation, judgment, and recording errors made by field data collectors were accepted. Other researchers have addressed this challenge by conducting training to improve inter-observer agreement (*10*) or using video in driver yielding studies (*13–15*, *31*). However, given available resources, field observations were the only method available that allowed observation of pedestrian and driver demographic characteristics as well as behaviors at 20 different sites. By comparison, a previous study of unstaged pedestrian crossings in Raleigh used video to observe driver and pedestrian demographic characteristics and behaviors but only included two sites (*14*, *15*). Collecting data at multiple sites allowed testing of the relationship between several roadway design variables and driver yielding.

The definition of driver yielding opportunities did not match state law precisely. If the study had specified that driver yielding opportunities only existed when pedestrians placed at least one foot in the crosswalk, as defined by state law, it would have found that 54 of 298 drivers yielded (18% of the total rather than 16%). Yet, narrowing the definition of driver yielding opportunity to the state law would have excluded 66 pedestrians (18% of all observed yielding opportunities) who were hesitant to step in the roadway but still intended to cross the street. Of these 66 people, 17 (26%) assertively indicated their intention to cross from the curb. The broader definition of driver yielding opportunity allowed the authors to account for all people who wanted to cross and all people exhibiting assertive and non-assertive behavior so that pedestrian crossing behavior could be analyzed more completely.

This study points to several lines of additional research. In particular, future studies should:

- Develop a consistent definition of pedestrian assertiveness. Previous studies have used different definitions, but the important relationship between this behavior and driver yielding underscores the need for a similar measure across multiple studies.

- Collect additional data on driver yielding to pedestrians with disabilities. There were only four driver yielding opportunities to people who used wheelchairs or walkers or had other visible physical disabilities, so a separate analysis for this group was not conducted. However, people with disabilities are particularly important because they may cross at slower speeds (they may only find a sufficient gap in traffic to cross at an uncontrolled location if drivers yield) and may be less able to take evasive maneuvers if drivers do not yield.
- Count total pedestrian crossing volumes. While it was noted whether or not pedestrians crossed in groups, the overall intersection pedestrian volume could also be associated with the general level of driver awareness of pedestrians at a crossing location. Higher pedestrian volumes may help drivers anticipate yielding opportunities, even for a single pedestrian.
- Explore the association between bus stops and driver yielding behavior. Pedestrians may be more assertive when hurrying to board approaching buses, and drivers may be more cautious when approaching buses that are dropping passengers off at the intersection, but these behaviors were not observed in this study.
- Record vehicles traveling in platoons. Cars traveling in groups may influence driver yielding (*15*). The study attempted to observe the total number of cars that did not yield after the pedestrian arrived as proxy for the effect of platooning. Yet, the data collectors did not have sufficient capacity to observe this characteristic while documenting other important behaviors.
- Use staged pedestrian crossings to complement naturalistic observations. Staged pedestrian crossings could help address the issues in the bullets above and control for characteristics such as pedestrian attire and pedestrian skin color.
- Incorporate video-based observations at more sites. This would help produce more reliable measurements of driver yielding and pedestrian assertiveness while still capturing data at multiple sites with a variety of roadway characteristics.
- Collect complementary survey data on local social norms related to driver yielding behavior. Some drivers may follow how the majority of other drivers behave in their local community, despite pedestrian behavior, roadway design, or other site characteristics. Therefore, as future studies begin to collect and analyze driver yielding data from multiple communities, it will be important to control for social norms as a model variable.

Importantly, although only ten sites with reported crashes and ten sites without were analyzed, it was found that intersections with higher yielding rates were associated with fewer pedestrian crashes. This contributes to a growing body of research showing similar results: a pedestrian enforcement campaign led to higher yielding and fewer pedestrian crashes in St. Johns, Newfoundland and Fredericton, New Brunswick (*9*), and the Gainesville HVE study found that higher driver yielding rates were associated with significant decreases in pedestrian crashes across the city (*10*). However, there is a need for additional studies to explore the relationship between driver yielding rates and pedestrian crash rates at specific locations in a variety of communities and roadway environments.

Conclusion

This exploratory study adds to the knowledge about factors affecting driver yielding behavior. Data were collected at 20 uncontrolled intersections along two-lane arterial and collector roadways in Milwaukee to examine how often drivers yield to pedestrians, and to identify characteristics of drivers, pedestrians, and crosswalk locations that are associated with this behavior. The binary logistic model suggested that drivers were more likely to yield when the major roadway had a lower speed limit or less traffic; when the intersection had a shorter crossing distance or a bus stop; and when the pedestrian was White, standing in the street, or acting assertively. These results support roadway design strategies such as reducing roadway design speeds and narrowing roadway crossing distances to increase the probability of drivers yielding to pedestrians. They also suggest the importance of educating pedestrians and drivers so that pedestrians can carefully and confidently assert their right-of-way in uncontrolled crosswalks. Additional driver yielding research at a wider range of sites is recommended, in more communities, and at different times of day, especially at night. Ultimately, it is hoped that this study will help improve pedestrian safety programs and reduce pedestrian injuries and fatalities.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: Schneider, Qin; data collection: Sanatizadeh, Shaon, He; analysis and interpretation of results: Schneider, Sanatizadeh, Shaon; draft manuscript preparation: Schneider, Sanatizadeh. All authors reviewed the results and approved the final version of the manuscript.

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