

Crosswalk Markings and the Risk of Pedestrian–Motor Vehicle Collisions in Older Pedestrians

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ON SEPTEMBER 14, 1899, AT the corner of 74th Street and Central Park West in Manhattan, a man named Henry Bliss stepped off a streetcar and was struck and killed by an electric taxicab. Mr Bliss, 68, became the first American to be fatally injured in a pedestrian–motor vehicle collision.^{1,2} A century later, pedestrian–motor vehicle collisions caused 4739 deaths in the United States in 2000, accounting for 11% of all motor vehicle deaths and 78000 reported injuries.

Adults aged 65 years and older accounted for 21% of pedestrian deaths in 2000 and had a pedestrian–motor vehicle collision mortality rate of 2.85 per 100000 person-years—higher than in any other age group.³⁻⁵ The excess of pedestrian deaths among older adults has been found to be even more marked after accounting for time spent as a pedestrian and the number of streets crossed.⁶ However, the most common mechanisms leading to pedestrian–motor vehicle collisions appear to dif-

Context Motor vehicles struck and killed 4739 pedestrians in the United States in the year 2000. Older pedestrians are at especially high risk.

Objective To determine whether crosswalk markings at urban intersections influence the risk of injury to older pedestrians.

Design Case-control study in which the units of study were crossing locations.

Setting Six cities in Washington and California, with case accrual from February 1995 through January 1999.

Participants A total of 282 case sites were street-crossing locations at an intersection where a pedestrian aged 65 years or older had been struck by a motor vehicle while crossing the street; 564 control sites were other nearby crossings that were matched to case sites based on street classification. Trained observers recorded environmental characteristics, vehicular traffic flow and speed, and pedestrian use at each site on the same day of the week and time of day as when the case event had occurred.

Main Outcome Measure Risk of pedestrian–motor vehicle collision involving an older pedestrian.

Results After adjusting for pedestrian flow, vehicle flow, crossing length, and signalization, risk of a pedestrian–motor vehicle collision was 2.1-fold greater (95% confidence interval, 1.1-4.0) at sites with a marked crosswalk. Almost all of the excess risk was due to 3.6-fold (95% confidence interval, 1.7-7.9) higher risk associated with marked crosswalks at sites with no traffic signal or stop sign.

Conclusions Crosswalk markings appear associated with increased risk of pedestrian–motor vehicle collision to older pedestrians at sites where no signal or stop sign is present to halt traffic.

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fer in older adults from those in younger age groups. Collisions in which the victim is an older pedestrian are less likely to involve an intoxicated pedestrian,^{7,8} are more likely to occur at an intersection rather than mid block,⁹ and are more likely to occur during daylight hours.^{8,10,11}

Because these collisions result from the interplay of pedestrian, vehicle-driver, and environment, any of these variables can be targeted for preven-

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tive interventions.^{10,12,13} Strategies aimed at maximizing the safety of the street crossing environment may be especially attractive because they may avoid the need to re-educate and to motivate millions of drivers and pedestrians to make long-lasting behavioral change. One such environmental factor is crosswalk markings, which are intended to guide pedestrians in a safe path across the street so that pedestrians can be seen by drivers, and to alert motorists that pedestrians may be encountered there. Whether crosswalk markings actually prevent pedestrian-motor vehicles remains unclear. Some studies have suggested that sites with marked crosswalks may be safer than sites without markings,¹⁴ but others have found marked crosswalks to be associated with higher injury rates,^{15,16} even after accounting for differences in pedestrian volume. After reviewing the evidence, the National Committee for Injury Prevention and Control recommended in 1989 that crosswalk marking be halted pending additional research into its safety effects.²

We wanted to determine whether marked crosswalks increase or decrease the risk of pedestrian-motor vehicle collision to an older person crossing the street at an urban intersection. We also investigated whether the risk of these collisions varies by type of marking pattern, the condition of the markings, and other environmental characteristics.

METHODS

We used a case-control study design in which the units of study were street-crossing locations ("crossings"). Case sites were crossings at which a collision involving an older pedestrian had occurred. Control sites were other crossings in the same neighborhood, matched to case sites on street type.

Setting

The study was conducted in 4 cities in western Washington and 2 in southern California, with case accrual from February 1995 through January 1999 (TABLE 1). Data collection began in Se-

Table 1. Dates of Participation and Number of Cases by City

City, State	Participation Dates	No. of Cases
Seattle, Wash	February 1995-January 1999	133
West Los Angeles, Calif	May 1995-January 1999	103
Tacoma, Wash	February 1995-January 1999	28
Everett, Wash	February 1996-January 1999	8
Bellevue, Wash	February 1996-January 1999	5
Long Beach, Calif	February 1995-April 1995	5
Total		282

attle and Tacoma, Wash, and in Long Beach, Calif, and later expanded to Everett and Bellevue, Wash, to boost case accrual. After the 3 months, an area encompassing 4 police jurisdictions in West Los Angeles, Calif, was substituted for Long Beach to reduce travel time and costs from the field center at the University of California at Los Angeles. Throughout the study, case sites were matched to control sites from the same city.

Selection of Cases and Controls

A case site was defined as a crossing location at which a pedestrian aged 65 years or older had been crossing the street when he/she was struck by a motor vehicle (with or without injury), resulting in a police report. Collisions involving an older pedestrian who was not in the process of crossing the street—those struck along the roadside or on the sidewalk or who fainted in the roadway—were excluded.

The street being crossed was termed the *index street*. To qualify for inclusion, it had to be a public thoroughfare other than an alleyway, driveway, or a parking lot and it could not be on private property. Copies of police reports of pedestrian-motor vehicle collisions were forwarded by traffic authorities in each city when a collision involving an older adult had occurred. Each report was then reviewed to verify eligibility under the study's case definition. Periodic checks of police report files were conducted to verify ascertainment of all qualifying cases. This article concerns crossings located within 30 feet of an intersection. (For an additional 70 mid block pedestrian-motor vehicle collision sites, the control-selection and data-

collection protocols were quite different, so they are excluded from this analysis.)

Two control sites were matched to each case site on the basis of neighborhood and the classifications of roadways meeting at the intersection. On maps provided by city traffic engineers, each street had been designated as a principal arterial, minor arterial, collector-arterial, or nonarterial, based chiefly on number of lanes, daily traffic volume, and speed limit. A crossing was deemed a potential control for a certain case if the street being crossed was in the same category as the index street at the case site and if the 2 next busiest streets radiating out from the intersection were also in the same classifications as the 2 next busiest streets at the case intersection. Overall, this produced an approximate match on traffic volume for the index street, as well as for the 2 next busiest intersecting streets.

From other maps we determined the US Census block group that contained the case site. A typical block group is an area of about 12 city blocks. Within it, we identified all potentially eligible control crossings, numbered them, and chose 2 at random using a random-number table. If the block group contained fewer than 2 potential control crossings, control sites were sought in the surrounding block groups using a random-selection scheme, working outward from the case's block group in concentric rings until 2 control sites had been identified.

Environmental conditions, traffic, and pedestrian flow at a given location can change over time. Using an incidence-density sampling scheme,¹⁷ a site that had already been studied as a case or

control could qualify again to serve as a case or control site at a different date and time. Among all 282 case and 564 control sites, 5 were studied twice as case sites, 17 were studied once as a case and once as a control sites and 18 were studied twice as control sites.

Data Collection

Two trained field workers conducted a standardized environmental assessment at each case and control site. To control for cyclical variation in such factors as pedestrian and vehicular traffic, signal phases and timing, and lighting conditions, all such time-critical observations were made on the same day of the week and at the same time of day as when the victim had been struck at the case site. This was called the *index time*. Field workers were kept blinded to the case and control status of sites they visited, and the ordering of visits to case and control sites within a set was randomized.

At each case and control site, the study crossing consisted of the zone in which a pedestrian would walk from one side of the index street to the other, whether or not any crosswalk markings were present. Some crossings consisted of multiple *segments* if the path across the street contained 1 or more refuges (such as a raised median) where a pedestrian could stop safely and wait for the next signal cycle or for traffic to clear before continuing. A segment was defined as a portion of a crossing between refuges.

Field workers recorded data on the geometry and dimensions of the intersection; system of traffic flow regulation (such as a traffic signal or stop sign), if any; presence or absence of crosswalk markings; and other environmental factors. If a marked crosswalk was present, they recorded its dimensions, the marking pattern, the number and width of marking stripes, and the extent to which markings had been worn away by traffic and weather. As a measure of the “dose” of crosswalk markings, a summary index of pigment density was calculated. It estimated the proportion of the area within a marked crosswalk’s bounding rect-

angle that was covered by pigment. The value of this index depended on the length and width of the marked area, the number and dimensions of pigmented stripes used to form the marking pattern, and the extent of wear, as judged by field workers as the approximate percentage of originally pigmented surface area still covered.

To characterize vehicular traffic at each site, a portable radar gun was used to measure the speed of 50 vehicles (or all vehicles for 10 minutes at low-volume sites) as they passed over the target crossing in either direction. Vehicular traffic was also videotaped for 10 minutes, centered around the index time. These videotapes were later viewed by research assistants, blinded to case and control status, who tabulated the number of vehicles of various types and the path each vehicle had taken through the intersection.

Pedestrian flow at each crossing was videotaped for 30 minutes, divided into two 15-minute periods, 1 before and 1 after the index time. In Washington, pilot testing indicated that an openly visible video camera and tripod stimulated pedestrians’ curiosity and altered their behavior, so the video camera was hidden in a plastic trash can with a hole cut in its side. In California, pedestrians seemed generally more oblivious to a video camera, which was usually left operating in an open location. These videotapes were later viewed by 2 research assistants who recorded the sex and estimated age of each pedestrian. A videotape showing people of known ages crossing the street was used as a training guide to estimate ages. Pilot testing had shown high correlation between estimated age and age as determined by asking the pedestrian (Pearson $r=0.92$, $n=44$). During the study, the intraclass correlation between observers on estimated pedestrian age was 0.91.

Data Analysis

The main analyses concerned the extent to which crosswalk marking characteristics were associated with a site’s case-control status, controlling for other site characteristics. The odds ratio (OR) was

used as the measure of association, and it is known to provide a good estimate of relative risk in case-control studies of rare outcomes.¹⁸ The OR can be interpreted herein as the risk of pedestrian-motor vehicle collision at a site with a certain characteristic, divided by the risk at a site without that characteristic.

To account for case-control matching, we used conditional logistic regression.¹⁹ For simplicity of presentation, tables that compare case and control sites show means and standard deviations or percentages for all cases and all controls combined. All ORs, confidence intervals (CIs), and *P* values were derived from conditional logistic regression models that accounted for matching. *P* values less than .05 were regarded as statistically significant.

Potential confounding factors included other environmental characteristics and the amount of pedestrian and vehicular traffic flow at each site. In addition to the number of older pedestrians observed on the videotape at each site, we also included the number of younger pedestrians (age <65 years) seen at each site as a covariate. This was because it provided useful information about average pedestrian flow at the site even if few older pedestrians were seen.

The relation between collision risk and pedestrian and vehicle flow was modeled using the fractional-polynomial approach described by Royston and Altman.²⁰ In general, a single logarithmic term fitted the data well for sites with any pedestrians seen. Because of the low number of pedestrians at some sites, dummy variables were also added to indicate whether any older or younger pedestrians were observed at the site.

All analyses were performed using STATA 6.0 (STATA Corp, College Station, Tex). The study protocol was approved by the University of Washington and University of California at Los Angeles institutional review boards.

RESULTS

A total of 282 qualifying collisions involving an older pedestrian were iden-

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tified in study cities during the surveillance period (Table 1). Seattle and West Los Angeles contributed the largest share of sites. According to the police reports, all but 5 collisions resulted in injury to the pedestrian. In 20 cases the injury was fatal.

TABLE 2 compares case and control sites by factors other than crosswalk markings. Although the number of streets radiating from the intersection was not a matching factor, case and control sites proved to be similar in this respect. Most intersections had 4 radiating streets. The index street's width and number of traffic lanes were also similar between case and control sites. Because only about 6% of sites had more than 1 crossing segment, the remaining analyses were restricted to case and control crossings with only 1 segment.

Single-segment case and control crossings were also generally similar on segment length (along the pedestrian path), number of lanes crossed, type and condition of surface material, and width (perpendicular to the pedestrian path) of a marked crosswalk, if present (Table 2). Compared with control sites, traffic regulation on the index street at case sites more often involved a phased traffic signal, usually accompanied by a pedestrian signal.

Despite the matching on street classification, measured traffic flow was about 4% greater at case sites than at control sites. This difference was statistically significant for all vehicles combined, for automobiles, for sport-utility vehicles (SUVs), and for vans, but more vehicles of every type were observed at case sites than at control sites. However, mean vehicle speeds over the study crossing were slightly slower (0.4 miles per hour) at case sites.

A total of 17 105 pedestrians were videotaped crossing the street at single-segment sites, including 1154 whose estimated age was 65 years and older. Pedestrian flow was observed to be about 50% greater at case sites than at control sites (27.2 pedestrians per 1/2 hour at case sites vs 18.5 at control sites, $P < .001$). A similar ratio applied to older pedestrians (1.9 at case sites vs 1.2 at

Table 2. Intersection Geometry, Crossing Characteristics, Vehicular Traffic Flow and Pedestrian Flow at Case and Control Sites*

Characteristic	Case Sites	Control Sites	P Value†
Intersection geometry			
No. of radiating streets, No. (%)			
3	59 (21)	142 (25)	.19
4	215 (76)	406 (72)	
5	8 (3)	14 (2)	
6	0 (0)	2 (<1)	
Mean (SD)	3.8 (0.5)	3.8 (0.5)	.15
No. of crossing segments, No. (%)			
1	267 (95)	532 (94)	.64
2	12 (4)	28 (5)	
3	3 (1)	3 (1)	
4	0 (0)	1 (<1)	
Width of index street, ft			
No. of sites	282	564	.98
Mean (SD), ft	52.5 (16.4)	52.5 (20.3)	
No. of lanes crossed			
No. of sites	282	564	.13
Mean (SD)	4.3 (1.6)	4.2 (1.8)	
Crossing characteristics‡			
Segment length			
No. of sites	267	532	.03
Mean (SD), ft	58.7 (17.4)	57.1 (17.8)	
No. of lanes crossed			
No. of sites	267	532	.12
Mean (SD)	4.2 (1.5)	4.1 (1.7)	
Crosswalk surface, No. (%)			
Asphalt	205 (77)	395 (74)	.76
Concrete	36 (13)	81 (15)	
Other	26 (10)	56 (11)	
Surface condition, No. (%)			
Excellent	44 (16)	102 (19)	.63
Good	150 (56)	284 (53)	
Fair	58 (22)	125 (23)	
Poor	15 (6)	21 (4)	
Crosswalk width (if marked)			
No. of sites	181	262	.95
Mean (SD), ft	12.4 (3.2)	12.7 (3.1)	
Traffic regulation, No. (%)			
Phased signal	151 (57)	255 (48)	.001
Stop sign	39 (15)	95 (18)	
Unregulated	73 (27)	181 (34)	
Other	4 (2)	1 (<1)	
Pedestrian signalization, No. (%)			
Pedestrian signal	144 (54)	243 (46)	.02
Vehicle signal only	7 (3)	12 (2)	
Stop sign	39 (15)	95 (18)	
Unregulated	73 (27)	181 (34)	
Other	4 (2)	1 (<1)	
Vehicle flow, No. (%)‡			
No. of sites	267	529	
Total No. of vehicles, mean (SD)	174.2 (148.2)	167.9 (157.3)	.014
Automobiles	119.3 (107.1)	116.6 (114.8)	.04
Sports utility vehicles	18.0 (18.5)	17.1 (9.5)	.03
Pickup trucks	15.2 (14.2)	14.5 (4.2)	.19
Vans	14.3 (11.5)	12.9 (1.1)	<.001
Other vehicles	5.3 (5.6)	4.9 (5.4)	.12
Motorcycles	0.6 (1.3)	0.5 (0.9)	.14
Mean (SD) speed, mph	19.8 (7.7)	20.2 (7.9)	.13

(continued)

control sites). At least 1 older pedestrian was observed at 48% of case sites vs 32% of control sites.

Crosswalk markings were more often present at case sites than at control sites (68% vs 49%, TABLE 3). Over-

all, presence of a marked crosswalk was associated with a 4.0-fold increase in risk of a collision involving an older pedestrian (95% CI, 2.5-6.2). However, among sites with a marked crosswalk, no significant differences were found by marking pattern or condition of markings. Using a summary index of pigment density as a measure of the “dose” of markings, the excess risk associated with marked crosswalks was greatest with relatively faint markings, although elevated risk was also found for marked crosswalks with medium or dense markings. A test for trend showed no significant difference in the effect of crosswalk markings in relation to pigment density.

An artifactual association between pedestrian–motor vehicle collision occurrence and presence of a marked crosswalk could arise if markings had been applied or refreshed after a pedestrian had been hit but before the study team visited the site. To check on this possibility, records of the Seattle Transportation Department were reviewed for all 39 case sites at which crosswalk markings in “good” or “excellent” condition were found by the field team. Crosswalk markings had not been newly applied or reapplied at any of the sites between the collision date and the data collection date.

The association between pedestrian–motor vehicle collision risk and presence of a marked crosswalk changed somewhat after adjusting for other characteristics that differed between case and control sites. TABLE 4 summarizes the adjusted OR for crosswalk marking in several multivariate models that adjusted for various combinations of potential confounding factors. The adjusted OR for presence of a marked crosswalk declined from 4.0 in the unadjusted base model to 2.1 in the model that controlled for 5 covariates, with similar levels of precision. The last model suggested about a 2.1-fold increase in risk associated with presence of a marked crosswalk, after controlling for pedestrian flow, vehicular traffic flow, crossing segment length, and type of traffic regulation.

Table 2. Intersection Geometry, Crossing Characteristics, Vehicular Traffic Flow and Pedestrian Flow at Case and Control Sites* (cont)

Characteristic	Case Sites	Control Sites	P Value†
Pedestrian flow, No. (%)‡			
No. of sites	267	531	
Pedestrians per 1/2 hour, mean (SD)	27.2 (64.9)	18.5 (47.2)	<.001
Older pedestrians	1.9 (3.7)	1.2 (2.8)	<.001
Younger pedestrians	25.3 (62.6)	17.3 (45.4)	<.001
Any pedestrians?			
Yes	234 (88)	387 (73)] <.001
No	33 (12)	144 (27)	
Any older pedestrians?			
Yes	129 (48)	172 (32)] <.001
No	138 (52)	359 (68)	

*The number of case sites is 282 and the number of control sites is 564 unless otherwise indicated.
 †P value for null hypothesis of no association with case or control status.
 ‡Restricted to sites with one crossing segment.

Table 3. Pedestrian–Motor Vehicle–Collision Risk in Relation to Crosswalk Markings (Single-Segment Sites Only)

Characteristic	No. (%)		Estimated OR (95% CI)	P Value*
	Case Sites	Control Sites		
Crosswalk marked?				
No	86 (32)	270 (51)	1.0 (Referent)	
Yes	181 (68)	262 (49)	4.0 (2.5-6.2)	<.001
Marking pattern				
Unmarked	86 (32)	270 (51)	1.0 (Referent)	
	139 (52)	210 (39)	3.7 (2.3-6.0)] .39
	22 (8)	29 (5)	4.8 (2.0-11.5)	
	12 (4)	13 (2)	6.2 (2.0-19.4)	
Other	8 (3)	10 (2)	4.6 (1.1-18.9)	
Edge stripe condition				
Unmarked	86 (32)	270 (51)	1.0 (Referent)	
Excellent	50 (19)	70 (13)	4.8 (2.6-9.1)] .33†
Good	56 (21)	98 (18)	2.9 (1.7-5.0)	
Fair	28 (10)	36 (7)	4.6 (2.3-9.5)	
Poor	18 (7)	24 (5)	4.9 (2.2-11.3)	
No edge stripes	29 (11)	34 (6)	5.2 (2.3-11.5)	
Crosshatch condition				
Unmarked	86 (32)	270 (51)	1.0 (Referent)	
Excellent	18 (7)	24 (5)	5.7 (2.1-15.9)] .41†
Good	19 (7)	23 (4)	4.8 (1.8-12.5)	
Fair or poor	5 (2)	4 (1)	14.1 (2.3-87.2)	
No crosshatches	139 (52)	211 (40)	3.7 (2.3-6.0)	
Pigment density				
Unmarked	86 (32)	270 (51)	1.0 (Referent)	
Faint	20 (7)	24 (5)	5.4 (2.4-12.0)] .19†
Medium	58 (22)	81 (15)	4.4 (2.5-7.7)	
Dense	103 (29)	152 (29)	3.7 (2.3-6.0)	

*P value for null hypothesis of equal odds ratios (ORs) among categories indicated. CI indicates confidence interval.
 †Test for trend.

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Measurement error in a covariate can limit the ability to remove confounding from that source.²¹⁻²³ To help gauge the possible impact of residual confounding by pedestrian and vehicular traffic flow, a sensitivity analysis was carried out, based on methods described by Armstrong et al²⁴ Measurement errors in these factors were assumed to be independent of each other and of crosswalk-marking status. The model suggested that the observed association between crosswalk markings and pedestrian–motor vehicle collision risk could be explained fully by residual confounding from older-pedestrian flow only if the test-retest reliability of this measure were less than about 0.38. For vehicular traffic flow, the corresponding threshold reliability was about 0.50. In actuality, only 1 measurement of each variable was obtained per site, but a lower-bound estimate of reliability was obtained by treating the measurements at the 2 paired control sites for each case as replicate observations. By this method, the reliability (intraclass correlation coefficient) of older-pedestrian flow was estimated to be 0.54, and that of vehicle flow was estimated to be 0.89. Thus, neither source of imprecision appeared sufficient by itself to explain away the observed association. Using these lower-bound estimates of reliability, the adjusted OR for crosswalk markings, controlled for older-pedestrian and vehicle flow and corrected for measurement error, would still be about 1.50.

Lastly, we examined variation in the effect of crosswalk markings in relation to other characteristics of sites (TABLE 5). Most of the overall increase in risk was due to a 3.6-fold elevation at crossing sites where the flow of vehicles on the index street was unimpeded by a traffic signal or stop sign. In contrast, there was almost no association between risk and presence of crosswalk markings at locations with a traffic signal or stop sign. No significant variation in the adjusted OR for crosswalk markings was found among the 3 cities with the most cases, or according to whether any older pedestrians were observed during videotaping at the site.

Table 4. Multivariate Analysis of Association Between Risk of Pedestrian–Motor-Vehicle Collision and Presence of a Marked Crosswalk (Single-Segment Sites Only)

Variables	Covariates	Adjusted Odds Ratio for Crosswalk Marking (95% CI)*
Unadjusted Base Model	None	4.0 (2.5-6.2)
Model 1	Older pedestrian flow	3.1 (1.9-5.0)
Model 2	Younger pedestrian flow	2.4 (1.5-3.9)
Model 3	Older and younger pedestrian flow	2.2 (1.3-3.7)
Model 4	Vehicle flow	3.4 (2.1-5.5)
Model 5	Older and younger pedestrian and vehicle flow	1.8 (1.0-3.0)
Model 6	Segment length	3.9 (2.5-6.1)
Model 7	Traffic regulation	4.0 (2.3-7.0)
Model 8	All	2.1 (1.1-4.0)

*Adjusted for matching factors and covariates as listed. CI indicates confidence interval.

Table 5. Association Between Risk of Pedestrian–Motor Vehicle Collision and Presence of a Marked Crosswalk in Subgroups of Sites (Single-Segment Sites Only)

Subgroup	Adjusted Odds Ratio for Marked Crosswalk (95% CI)	P Value*
All sites†	2.1 (1.1-4.0)	
By traffic regulation‡		.03
Phased signal or stop sign	1.2 (0.6-2.5)	
No stop required	3.6 (1.7-7.9)	
By city†		.71
Seattle, Wash	2.5 (1.1-5.6)	
Tacoma, Wash	1.1 (0.2-6.6)	
West Los Angeles, Calif	2.4 (0.9-6.1)	
By older pedestrian flow§		.63
≥ 1 Older pedestrians seen	1.8 (0.8-4.5)	
No older pedestrians seen	2.3 (1.2-4.5)	

*P value for null hypothesis of equal odds ratios among subgroups. CI indicates confidence interval.

†Adjusted for pedestrian flow, vehicle flow, signal type, segment length.

‡Adjusted for pedestrian flow, vehicle flow, segment length.

§Adjusted for younger pedestrian flow, vehicle flow, signal type, segment length.

COMMENT

The results of this study suggest that, contrary to the good intentions of traffic engineers, crosswalk markings alone may do little to protect older pedestrians from being struck by a motor vehicle as they cross the street at an urban intersection. In fact, we found that the presence of crosswalk markings was associated with increased risk overall, even after controlling for the amount of pedestrian traffic, vehicular traffic, and other site characteristics. However, this association varied significantly according to the system of traffic regulation on the street being crossed. When no traffic signal or stop sign was present to control traffic flow, marked crosswalks were associated with a 3.6-fold increase in risk. At intersections with a stop sign or traffic signal,

there was virtually no association between presence of markings and pedestrian–motor vehicle collision risk.

Several study limitations should be borne in mind. First, this was an observational study, not a controlled experiment. We attempted to measure and control for several relevant factors, but confounding by other unmeasured site characteristics cannot be ruled out. Moreover, despite the matching on neighborhood and street classifications, pedestrian flow and vehicular traffic flow emerged in the analysis as important confounding factors, and both characteristics are subject to measurement error. Pedestrian and vehicle counts observed during a limited time interval on the same weekday and time of day as the pedestrian–motor vehicle collision may be impre-

cise as indicators of long-term use levels. However, a sensitivity analysis suggested that measurement error in pedestrian and vehicular traffic flow is unlikely to explain fully the observed association between pedestrian–motor-vehicle collision risk and presence of crosswalk markings.

A second limitation is that the study was restricted to pedestrian–motor-vehicle collisions involving a pedestrian aged 65 years or older, and the findings may not necessarily apply to other age groups. Nonetheless, older pedestrians are a known high-risk group, and it is plausible that similar mechanisms may apply to other vulnerable groups. Third, the study had limited statistical power to detect differences in the effects of specific crosswalk marking patterns or effects confined to subgroups of sites. Fourth, the study involved 6 cities in Washington and California, and generalizability to other urban areas is uncertain.

Our findings agree with those of Herms,¹⁵ who studied 400 unsignalized San Diego intersections at which 1 marked and 1 unmarked crosswalk extended across the same street. During a 5-year period, nearly 6 times as many pedestrian–motor vehicle collisions occurred at marked crosswalks. Pedestrian volume was measured at a 10% sample of sites and was about 3-fold greater at marked crosswalks, suggesting that differences in pedestrian use could not account fully for the difference in risk. Zegeer et al¹⁶ used a study design involving 2000 unsignalized sites and found that pedestrian–motor vehicle collision rates, while generally low, were higher at marked than at unmarked crosswalks, particularly on wider and busier streets.

In contrast, Knoblauch et al^{14,25} compared 762 intersections and mid block locations at which a pedestrian–motor-vehicle collision had occurred with a stratified sample of 495 control locations in the same 5 cities. They found that unmarked crosswalks were associated with increased risk of pedestrian–motor vehicle collision when site comparisons were based on a “hazard score”

calculated from pedestrian and vehicle flow. That study combined intersection and mid block locations as well as signalized and unsignalized intersections, it was not restricted to older pedestrians, it used entire intersections or mid block locations (rather than specific crossings) as the units of analysis, and it used no matching or multivariate analysis to control for other confounding factors. These methodological differences may have contributed to the discrepant results.

A possible explanation for the association we found is that marked crosswalks may give older pedestrians a false sense of security, based on their questionable assumptions about driver behavior. Tidwell and Doyle²⁶ found that nearly 40% of pedestrians incorrectly believed that traffic must stop for a pedestrian who is on the curb waiting to cross at a marked crosswalk. Washington and California laws require vehicles to stop when a pedestrian is actually present in a marked crosswalk, but even then many drivers fail to comply.^{27,28} Baker et al²⁹ found that drivers involved in a sample of Maryland pedestrian–motor-vehicle collisions had worse-than-average driving records. Saibel and colleagues²⁸ found that driver compliance was actually somewhat worse when the pedestrian was an older adult, and there were more “near misses” at marked than at unmarked crossings. The limited information available suggests that pedestrians are no less vigilant at marked crossings than at unmarked locations.^{14,30} Oxley et al³¹ found that older pedestrians tended to be more cautious than younger ones by waiting for longer gaps in traffic, but that this safety advantage was more than offset by their slower walking speeds.

We found that the association between presence of a marked crosswalk and increased pedestrian–motor-vehicle collision risk was essentially confined to sites where no traffic-control device was present to restrict the flow of vehicles. This result emerged from subgroup analyses and was not hypothesized in advance, so it should be interpreted with caution. Nonethe-

less, older pedestrians, who have slower walking speeds,³² may be more vulnerable at crossing locations where vehicles can normally proceed unimpeded. The pedestrian may venture into the street at a sanctioned location and have the legal right of way, but drivers may be accustomed to proceeding through such an intersection without stopping. The pedestrian’s safety depends heavily on driver alertness and compliance. In contrast, when a traffic signal or stop sign is present, pedestrians have a much stronger guarantee that traffic will stop and allow them safe passage.

Traffic engineers have been found to hold widely varying opinions about the effectiveness of crosswalk markings, resulting in considerable variation in policies and practices among jurisdictions.^{33,34} Additional research may be needed to eliminate uncertainty about the safety and effectiveness of crosswalk markings as a preventive measure. Findings from our study suggest that measuring and controlling for pedestrian flow, vehicle flow, and signalization pattern are important in future studies. Ultimately, controlled intervention studies may be needed to establish causes beyond reasonable doubt.

In sum, we found that marked crosswalks at urban street crossings without a traffic signal or stop sign were associated with elevated risk of pedestrian–motor vehicle collision to older pedestrians. This information may be useful to traffic engineers for setting policies on the placement and maintenance of crosswalk markings. Older pedestrians may wish to be especially cautious when crossing the street at high-risk locations.

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CROSSWALK MARKINGS AND COLLISIONS

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