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The Effect of Right-Turn-on-Red on Pedestrian and Bicyclist Accidents

David F. Preusser, William A. Leaf, Karen B. DeBartolo, Richard D. Blomberg, and Marvin M. Levy

Right-Turn-on-Red (RTOR), in its "Western" version allows motorists to turn right on a red signal after stopping and yielding, unless specifically prohibited by a sign. The objective of this study was to determine the effect of Western RTOR on pedestrian and bicycle accidents in selected jurisdictions adopting the rule in the mid-1970s. The results showed significant increases in pedestrian and bicyclist accidents involving right-turning vehicles at signalized locations following the introduction of Western RTOR. These increases were: 43% for pedestrians and 82% for bicycles in New York State; 107% for pedestrians and 72% for bicycles in Wisconsin; 57% for pedestrians and 80% for bicycles in Ohio; and 82% for pedestrians in New Orleans. Analysis of police accident reports suggested that drivers stopped for a red light are looking left for a gap in traffic and do not see pedestrians and bicyclists coming from their right. Countermeasure research and development was recommended to deal with this well defined problem which involves between 1% and 3% of all pedestrian and bicycle accidents.

Right-Turn-on-Red (RTOR) in its "permissive" or "Western" version allows motorists to turn right on a red signal after they have stopped and searched for pedestrians, bicyclists, and oncoming vehicles. It is referred to as "permissive" since the maneuver is generally allowed except where specifically prohibited by a sign. It is referred to as "Western" since it has long been common in the western states. During the mid-1970s, many eastern states adopted Western RTOR as an energy conservation measure. It was reasoned that Western RTOR would reduce driver delay at intersections and thus save fuel. By 1980, Western RTOR was the law throughout the United States with the exception of New York City. The present study was conducted to assess the impact of Western RTOR on pedestrian and bicyclist accidents.

Past research has found somewhat conflicting findings as to changes in the occurrence of pedestrian accidents after RTOR adoption. McGee, Stimpson, Cohen, King,

This paper was based on a final report to the National Highway Traffic Safety Administration under Contract No. DOT-HS-6-01411. David F. Preusser and Karen B. DeBartolo are staff members with Dunlap and Associates East, Inc., Darien, Connecticut, and Richard D. Blomberg is President of the Company. William A. Leaf was formerly with Dunlap and is now at Applied Science Associates, Inc. Marvin M. Levy is with the Office of Driver and Pedestrian Research of the National Highway Traffic Safety Administration. The opinions, findings, and conclusions are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

and Morris (1976) reported a small increase in pedestrian accidents involving right-turning vehicles at selected intersections in Chicago following introduction of RTOR. The American Association of State Highway and Transportation Officials (1979) reported no increase in pedestrian accidents at signalized intersections following adoption of Western RTOR, but their study did not provide specific information on pedestrian accidents involving a right-turning vehicle. Zador, Moshman, and Marcus (1980) reported a 57% increase in pedestrian accidents involving a right-turning vehicle at a signalized intersection and concluded that this increase was most severe in urban areas and with elderly pedestrians. Accidents involving bicyclists were not specifically covered in any of these previous efforts, although Cross and Fisher (1977) did identify a bicycle accident type ("Motorist Turn-Merge: Intersection Controlled by Signal") that was characterized by motor vehicles making a right turn on red and striking a bicyclist.

This study was conducted in two parts. First, it was determined whether the mid-1970s implementation of Western RTOR was associated with any change in pedestrian and bicyclist accident rates. This question was addressed through pre vs. post analysis of state accident data computer tapes. Second, regardless of the direction or magnitude of any change in accident rates, it was important to understand the characteristics and dynamics of RTOR pedestrian and bicycle crashes. This question was addressed by analyzing police accident reports of crashes involving right-turning vehicles at signalized locations.

METHOD

Measures. The primary measure used in this study to assess any change in accidents following Western RTOR was the number of pedestrian and bicycle crashes in which the victim was struck by a right-turning motor vehicle at a signalized location. Prior to Western RTOR, it may be assumed that the vast majority of right turns were on green. Following adoption of Western RTOR, it may be presumed that many were still on green while others were made on red. Nevertheless, the vehicle maneuver that should have been most directly affected by Western RTOR was the right turn by a motor vehicle at a signalized location. Right-turn-on-green accidents may or may not have decreased following Western RTOR, and right-turn-on-red accidents may or may not have increased, but the primary measure was the total number of right-turning accidents including right-on-green and right-on-red. Pedestrian and bicycle accidents involving left-turning vehicles and other vehicle actions (primarily straight-through) at signalized locations were also of interest as a general measure of total signalized location activity and accident occurrence.

This study also considered the characteristics of pedestrian and bicycle crashes that involved a vehicle turning right on a red signal. Accident counts and descriptive information from police accident reports for those crashes in which the presence of a red signal could be determined were the primary measure employed.

Data collection. Western RTOR was adopted by most eastern states during the period 1974 to 1978. Prior to 1974, most of these states had allowed RTOR under the "Eastern" or sign-permissive rule which allows RTOR only when specifically permitted by a sign. Some of these states had no RTOR provisions. Any eastern state changing during the 1974–1978 period could have been selected for this study. Contacts were initiated with several states to determine the availability of pedestrian and bicycle accident data. This and other preliminary work led to the selection of New York, Ohio, and Wisconsin as the primary study states. The City of New Orleans was added to this list since, through other ongoing NHTSA-sponsored work by the authors, police accident reports for pedestrians were available for the period surrounding Louisiana's adoption of Western RTOR.

The three selected states and New Orleans yielded seven data sets which were examined for accident rate changes associated with the introduction of Western RTOR. Four of these data sets covered pedestrian/motor vehicle accidents (New York, Ohio,

Wisconsin, and New Orleans), and three data sets covered bicycle/motor vehicle accidents (New York, Ohio, and Wisconsin). In addition, pedestrian accident data were available from Los Angeles for the period 1973–1978. Los Angeles has had Western RTOR for more than 30 years, and thus driver and pedestrian behaviors should be well established.

RESULTS

Right turn accidents as a proportion of all crashes. Table 1 shows overall accident distributions from New York, Wisconsin, and Ohio for pedestrians and bicyclists and from New Orleans and Los Angeles for pedestrians. These data show that only between 1 and 4% of all pedestrian and bicycle crashes

TABLE 1
PRE/POST CRASH DATA FOR NEW YORK, WISCONSIN, OHIO, AND NEW ORLEANS AND CRASH DATA FOR LOS ANGELES

	PEDESTRIAN				BICYCLE			
SITE AND YEAR	Vehicle Turn Right	Vehicle Turn Left	Other Vehicle Action	Total Crashes	Vehicle Turn Right	Vehicle Turn Left	Other Vehicle Action	Total Crashes
New York								
1974	1.3%	3.2%	9.8%	9072	1.5%	3.0%	8.6%	6139
1975	1.2	2.9	9.8	9300	1.8	2.6	9.5	5947
1976	1.3	2.9	9.8	8983	1.8	2.7	10.1	5457
1977[a]	1.5	3.3	10.0	8933	3.2	2.5	10.4	5700
1978	2.1	3.3	9.4	9004	3.2	3.4	10.7	5519
Wisconsin								
1973	1.5%	4.6%	6.4%	2614	1.4%	3.6%	6.3%	1854
1974	2.1	4.5	7.0	2402	1.3	3.5	5.8	2098
1975[a]	1.9	4.0	6.6	2418	1.8	3.2	5.3	2137
1976	4.0	3.8	7.6	2422	1.8	3.7	5.3	1930
1977	3.2	4.3	7.6	2512	2.6	4.1	6.5	1975
1978	3.8	3.1	7.2	2584	2.8	3.4	7.6	1849
1979	2.4	3.3	6.4	2698	3.0	4.2	6.9	1844
Ohio								
1974	1.5%	4.1%	9.3%	6049	1.0%	2.4%	6.5%	4120
1975[a]	2.3	4.1	9.4	6256	1.9	2.2	7.1	4208
1976[b]	2.3	3.4	9.8	4961	1.8	2.5	7.5	3244
1977	2.2	3.7	10.9	6544	2.1	2.5	7.9	3680
1978	2.5	3.7	10.6	6502	2.3	2.1	8.3	3410
1979	2.8	3.6	11.8	6105	2.4	3.0	7.8	3185
New Orleans								
1973	1.1%	0.7%	14.1%	877				
1974	1.8	0.7	13.0	895				
1975	1.4	0.7	12.4	868				
1976[a]	2.0	0.4	12.9	912				
1977	2.8	1.2	13.4	923				
1978 (Jan-Mar only)	2.8	0.0	14.6	213				
Los Angeles								
1973	4.9%	5.7%	9.6%	3062				
1974	4.6	5.3	10.5	3082				
1975	4.6	5.2	9.7	3141				
1976	4.7	5.9	11.5	3310				
1977	4.2	5.2	11.3	3239				
1978	5.9	6.1	11.3	3549				

Note. — Data are for signalized locations only, expressed as a percentage of all motor vehicle/pedestrian or all motor vehicle/bicycle accidents.

[a]Year in which RTOR initiated.

[b]Data for 1976 are incomplete.

involved a right-turning vehicle at a signalized location.

The first set of data shown in Table 1 is for pedestrian crashes in New York State excluding New York City. For the 1974–1976 baseline period, approximately 1.25% of all pedestrian crashes involved a right-turning vehicle at a signalized location. For 1977 and 1978 when Western RTOR was the law, approximately 1.82% involved a right-turning vehicle at a signalized location. The second set of data covers bicycle/motor vehicle crashes in New York over the same period, again excluding New York City. During the 1974–1976 baseline period, approximately 1.69% of these events involved a vehicle turning right at a signalized location. For the 1977–1978 RTOR period, the figure was 3.20%.

The next sets of data are for Wisconsin. In 1973–1974, which was prior to Western RTOR, approximately 1.81% of all Wisconsin pedestrian crashes involved a vehicle turning right at a signalized location. Western RTOR was adopted in mid-1975, and for the period 1976–1979 approximately 3.36% of all Wisconsin pedestrian crashes involved a right-turning vehicle at a signalized location. Of the bicycle/motor vehicle crashes in Wisconsin during 1973–1974, approximately 1.37% involved a right-turning vehicle at a signalized location. The comparable figure for the RTOR period was 2.53%.

In Ohio in 1974, which was prior to Western RTOR, approximately 1.50% of all pedestrian crashes involved a vehicle turning right at a signalized location. Western RTOR was implemented in mid-1975. Since there were missing data for several months in late 1976, however, only 1977–1979 data were used for the RTOR period. During this abbreviated post period, approximately 2.50% of the pedestrian accidents involved a vehicle turning right at a signalized location. For bicycle crashes in Ohio, approximately 1.02% in 1974 involved a vehicle turning right at a signalized location. During 1977–1979, the comparable figure was 2.27%.

The next data set covers pedestrian crashes in New Orleans. During the period 1973–1975, which was prior to Western RTOR, approximately 1.44% of all pedestrian crashes involved a vehicle turning right at a signalized location. Western RTOR was adopted in October 1976. During 1977, the only full year for which data were available following Western RTOR, the comparable figure was 2.82%.

Also shown in Table 1 are pedestrian crashes in Los Angeles for the years 1973–1978. These data should be relatively stable since Los Angeles has had Western RTOR since 1947. The percentage of crashes with the vehicle turning right at a signalized location is relatively high–4.81% of all pedestrian accidents.

Overall, the data in Table 1 show a large increase in both pedestrian and bicycle accidents involving right-turning vehicles at signalized locations. In each data set the baseline years had fewer such accidents than every year following Western RTOR. The accident rate increases persisted for as long after Western RTOR as the data were studied – up to 4½ years in Ohio and Wisconsin and for lesser periods in New York and New Orleans.

Analysis of first 12 months. Separate analyses were also conducted examining the 12 months immediately before and immediately after the implementation of Western RTOR. These deal with fewer data than the overall analysis above, but examine time periods closer together, reducing the effect of long-term trends and focusing on the effect of Western RTOR immediately after implementation. These data, shown in Table 2, indicate that increases in pedestrian and bicycle crashes involving a right-turning vehicle at a signalized location began within the first 12 months following implementation of Western RTOR.

Time-series statistical testing. While the raw data in Tables 1 and 2 indicate striking differences in pre/post accidents rates, these changes needed to be tested for statistical significance. The analyses followed two steps. First, accident results were displayed as numbers of accidents per month with monthly (i.e., seasonal) mean differences removed. Second, Box-Jenkins analysis procedures (Box & Jenkins, 1976) were used on the raw accident data to isolate specific

TABLE 2
PEDESTRIAN AND BICYCLE CRASHES INVOLVING RIGHT-TURNING VEHICLES AT SIGNALIZED LOCATIONS 12 MONTHS BEFORE AND 12 MONTHS AFTER RTOR

	PEDESTRIAN		BICYCLE	
SITE	12 Mos. Pre	12 Mos. Post	12 Mos. Pre	12 Mos. Post
New York	116	137	98	182
Wisconsin	42	92	26	39
Ohio	109	181	41	94
New Orleans	17	26		
Total	284	436	165	315
% change		+54%		+91%

Note.—Data are numbers of crashes. Ohio data are complete, since 1976 data loss occurred after the 12-month post period.

time-sequence components of variation, such as trends and seasonal swings, and to determine simultaneously the size and statistical significance of changes due to Western RTOR.

Table 3 presents data for the mean number of accidents per month for all seven test data sets. While these results are similar to those in Table 1, there are some important differences. First, the data were seasonally adjusted; second, the missing data for Ohio (last 4 months of 1976) were replaced with "estimated" figures based on average "same month" data from prior and subsequent years. The far right columns show mean crashes for the pre- and post-RTOR periods expressed as differences from the overall mean. Since the data have been seasonally adjusted, these results may be interpreted as the change in number of crashes per month. For instance, the overall monthly mean for New York pedestrian crashes involving a vehicle turning right at a signalized location was 11.13. This consisted of a pre-RTOR mean of 9.50 crashes per month (11.13 − 1.63) and a post-RTOR mean of 13.58 crashes per month (11.13 + 2.45). The difference was 4.08 crashes per month or 49.0 crashes per year. The monthly accident frequencies summarized in Table 3 were the basic input data for the time series analyses.

The application of the Box-Jenkins time series procedure involved developing a best-fitting time series model using a parallel "transfer function" time series representing the absence or presence of the Western RTOR rule. In each model, coefficients related the time-dependent components and

TABLE 3
PEDESTRIAN AND BICYCLE CRASHES INVOLVING RIGHT-TURNING VEHICLES AT SIGNALIZED LOCATIONS: MEAN ACCIDENTS PER MONTH AND DIFFERENCES FROM MEAN

		DIFFERENCE FROM MEAN									
SITE AND CRASH TYPE	Mean	1973	1974	1975	1976	1977	1978	1979	Pre-RTOR	Post-RTOR	% Change
New York[a]											
Pedestrian	11.133		−1.55	−1.88	−1.47	.28[b]	4.62		−1.63	2.45	43
Bicyclist	10.883		−3.30	−2.05	−2.72	4.28[b]	3.78		−2.69	4.03	82
Wisconsin											
Pedestrian	5.679	−2.43	−1.43	−1.85[c]	2.40	.99	2.57	−.26	−2.32	1.29	107
Bicyclist	3.393	−1.23	−1.06	−.14[c]	−.56	.94	.86	1.19	−1.08	.60	72
Ohio											
Pedestrian	12.306		−4.72	−.14[d]	1.94[e]	−.22	1.11	2.03	−3.70	1.24	57
Bicyclist	5.986		−2.49	.51[d]	.51[e]	.60	.51	.35	−2.24	.75	80
New Orleans											
Pedestrian	1.333	−.50	0.00	−.33	−.08[f]	.75	.33[g]		−.25	.63	82

Note.—All data (means and differences) are per month.
[a]New York data exclude New York City.
[b]Western RTOR began January 1, 1977—36 months pre-RTOR, 24 months post-RTOR.
[c]Western RTOR began July 1975—30 months pre-RTOR, 54 months post-RTOR.
[d]Western RTOR began July 1975—18 months pre-RTOR, 54 months post-RTOR.
[e]September-December 1976 data missing and estimated.
[f]Western RTOR began October 1976—45 months pre-RTOR, 18 months post-RTOR.
[g]January-March only.

the transfer function to the data series. The statistical significance of the effect of Western RTOR on crashes was assessed by calculating a confidence interval associated with the transfer function coefficient. If this confidence interval included the value 0.0, then it could not be concluded that the transfer series was related to crash occurrence. The value of 0.0 was not included in the 95% confidence interval for the six data set models tested. This showed that the transfer series (i.e., presence or absence of Western RTOR) was a statistically significant model parameter. Moreover, since the coefficients were positive, these results demonstrated that right-turning accidents at signalized locations increased. For the seventh data set, New Orleans pedestrian accidents, there were no significant cyclic trends so a time series model was not required. The New Orleans data showed a significant increase in crashes from about 1.1 per month pre-RTOR to 2.0 per month post-RTOR.

Many other time series models covering geographic areas in New York, left turns in New York, etc., were developed. These results reinforced the basic findings presented above and suggested that increases in right-turning crashes were not associated with any concomitant decreases in other types of pedestrian or bicycle crashes. They did, however, suggest that the effects of Western RTOR were more pronounced in urban and suburban areas than rural areas which have fewer signalized locations. The developed time series models and accident distributions are shown in the full report of this study (Preusser, Leaf, DeBartolo, & Blomberg, 1981).

Dynamics of RTOR pedestrian crashes. Los Angeles has had Western RTOR since 1947. Pedestrian accident reports from Los Angeles (City only) were being researched by Dunlap staff as part of an ongoing evaluation effort in that City. These data comprised 19,383 police-reported pedestrian crashes within the Los Angeles Police Department's jurisdiction for the period 1973 to 1978. (Freeway events covered by the California Highway Patrol and five events for which year was unknown were excluded.) Of these crashes, 933 (4.81%) involved a vehicle turning right at a signalized location, and for 526 of these (2.71%), it was clear that the maneuver was performed on a red signal. The coding procedures in this research (Blomberg, Preusser, Hale, & Leaf, in process) were not specifically designed for RTOR but nevertheless included the following RTOR "accident types":

RTOR left – Pedestrian crossing from left to right in front of a driver turning right on red;

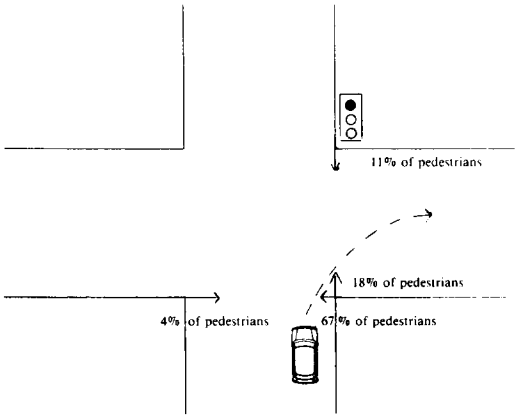
RTOR right – Pedestrian crossing right to left in front of a driver turning right on red;

RTOR across – Pedestrian crossing parallel to driver's original path before he made a right on red, i.e., pedestrian struck crossing street driver turned into.

Of the three types, RTOR-right was by far the most prevalent, accounting for 361 (69%) of the identified right-on-red events. These three types are diagramed in Figure 1. For both RTOR-left and RTOR-right, the pedestrian is crossing on a green signal and may even have a "walk" light. RTOR-across involves a pedestrian crossing against the traffic signal, and its incidence is relatively low (20%). RTOR-left is also an infrequent crash event (11%). This may be partly because the vehicle is turning away from pedestrians on the left and partly because the driver is looking to the left for a gap in traffic and thus has a greater opportunity to see any pedestrians.

While the dynamics of the situation suggest that RTOR-left and RTOR-across should be of low incidence, they also suggest that RTOR-right should be of greater incidence. A driver stopped at a red light and preparing to make a right turn is looking *left* to find a gap in traffic, and he may not see a pedestrian crossing from the right directly in front of the vehicle. When later asked about the accident, drivers will typically say "I never saw her." Pedestrians typically say "He was there, stopped for the light, and he just pulled out and hit me." In other words, the pedestrian is crossing on the green signal, sees the car, and doesn't believe it will just pull out. The driver, looking left, never sees the pedestrian about to cross from his right.

FIGURE 1
THREE TYPES OF PEDESTRIAN ACCIDENTS INVOLVING A VEHICLE TURNING RIGHT ON RED



Accident reports from New York, Wisconsin, and Ohio were studied by project staff. Each report was identified, through computer codes, as involving a vehicle turning right at a signalized location. As a general rule, the police accident reports from the three states did not provide the level of detailed crash information contained in the Los Angeles reports. Therefore, many data points were coded as "other," "unknown," and "not available." In addition, for New York, Wisconsin, and Ohio, the RTOR accident types were expanded, and RTOR-across was separated into "up" and "down." For up, the pedestrian (or bicyclist) was moving away from the vehicle (north in Figure 1), and for down the pedestrian (or bicyclist) was moving toward the vehicle (south in Figure 1).

In all, 326, 376, and 676 pedestrian reports were tabulated from New York, Wisconsin, and Ohio, respectively. The percentages of these reports from which it could be determined that the vehicle turned right on red were 39% in New York and Wisconsin and 42% in Ohio. The distribution of these right-on-red crashes by accident type is shown in Table 4. Los Angeles events are also shown, and it can be seen that the Los Angeles distribution and the distributions from New York, Wisconsin, and Ohio are very similar. Additional analyses of these RTOR crashes showed that they typically involved a male driver about 30 years old striking a female pedestrian and that most crashes occurred in the afternoon and resulted in low to moderate pedestrian injury severity.

The proportion of crashes that could definitely be determined to involve vehicles turning right on red was not a valid estimator of the true proportion of such events, because the color of the traffic light could not be determined for many of the studied reports (36% in New York, 49% in Wisconsin, and 41% in Ohio). To arrive at a realistic estimate of the percentage of all pedestrian accidents involving a right-turning motor vehicle at a signalized location, the unknowns were distributed proportionately into the known categories. This resulted in estimates of 61% of crashes involving RTOR in New York, 69% in Wisconsin, and 64% in Ohio.

Dynamics of RTOR bicycle crashes. Police reports of bicycle/motor vehicle accidents from New York, Wisconsin, and Ohio were studied using the same procedures as for pedestrians. As with pedestrians, "light phase facing driver" and "directional analysis" were the most important items. Also, with bicyclists, it was important to know whether the bicycle collision course originated from the sidewalk or from the roadway.

A total of 359 post-RTOR bicycle reports was tabulated for New York, 217 for Wisconsin, and 355 for Ohio. The percentages of these reports from which it could be determined that the vehicle turned right on red were 18% in New York, 28% in Wisconsin, and 37% in Ohio. These identified

TABLE 4
DISTRIBUTION BY TYPE OF PEDESTRIAN ACCIDENTS INVOLVING A VEHICLE TURNING RIGHT ON RED

RTOR ACCIDENT TYPE	NEW YORK		WISCONSIN		OHIO		LOS ANGELES	
	N	%	*N*	%	*N*	%	*N*	%
right	61	59	106	76	175	67	361	69
left	11	11	4	3	4	2	59	11
up	18	17	21	15	51	20	106	20[a]
down	13	13	9	6	31	12		
Total	103	100	140	100	261	100	526	100

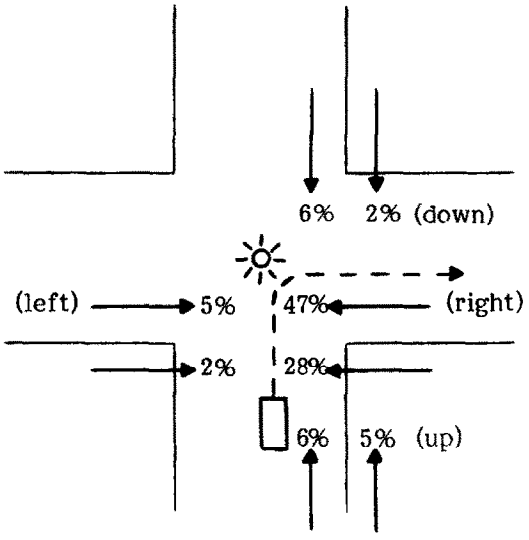
Note. — "Atypical" and "unknown" are excluded.
[a]"up" plus "down" equals "across" in Los Angeles.

right-on-red events, summed across all three states and separated by bicycle course origin (sidewalk or street), are diagrammed in Figure 2. As shown Figure 2, 75% of these crashes were of the RTOR-right type. In all cases (right, left, up, and down), more bicyclists began their collision course from the roadway than from the sidewalk. The 75% RTOR-right was composed of 47% from the roadway and 28% from the sidewalk. This greater incidence of roadway origins occurred only in New York and Ohio, however. In Wisconsin, only 5 of 40 RTOR-right events originated from the roadway.

As with pedestrians, the proportion of bicycle crashes that could be determined to be RTOR was not a valid estimate of the number of RTOR accidents, because light color could not be determined for many of the studied reports (66% in New York, 58% in Wisconsin, and 46% in Ohio). Distributing the unknowns proportionately across the known categories resulted in estimates of 53% of crashes involving RTOR in New York and 61% in Wisconsin and Ohio.

Conceptually, the RTOR-right problem for bicyclists is similar to that for pedestrians. The driver is looking left for a gap in traffic and the bicyclist doesn't believe that the driver will just pull out against the light. There are some important differences, however. First, the bicyclist is typically moving faster than a pedestrian in the same situation. This is particularly true for a bicyclist coming from the roadway. Second, the bicyclist coming from the roadway is "wrong-way riding" illegally on the left side of the street against the flow of traffic. Additional analyses of these RTOR bicycle crashes showed that they typically involved a male motorist about 35 years old striking a male bicyclist about 15 years old. More than half of the crashes occurred between noon and 6:00 p.m., and bicyclist injury severity was low to moderate.

FIGURE 2
PROPORTIONS OF REPORTED BICYCLE CRASHES INVOLVING A VEHICLE TURNING RIGHT ON RED BY BICYCLE DIRECTION AND CRASH LOCATION



DISCUSSION

Prior to the mid 1970's, only a few states had RTOR in its Western or permissive version. From about 1974 to 1977, many more states initiated Western RTOR, so that by 1980 the maneuver was generally permitted everywhere in the United States except in New York City. The first question addressed by this study was whether or not this change to Western RTOR was associated with a change in the number of pedestrian and bicyclist accidents. The answer was clearly yes. Four pedestrian and three bicycle accident data sets all showed statistically significant *increases* in the number of crashes involving a right-turning vehicle at a signalized location. In terms of pedestrian accidents, the increases were .88, 3.61, 4.08, and 4.94 per month in New Orleans, Wisconsin, New York, and Ohio, respectively. Together, these increases total 13.51 accidents per month or 162.12 accidents per year across these four jurisdictions with a population of about 26 million. For bicyclists, the equivalent monthly increases were 1.68, 2.99, and 6.72 for Wisconsin, Ohio, and New York, respectively. Together, these increases total 11.39 accidents per month or 136.68 accidents per year with a population of about 25 million across the three jurisdictions.

Experimental considerations. This study of RTOR focused on right turns at signalized

locations. Right turns are intuitively the most proximate measure, since it is the right turn maneuver that is directly affected by the law. All intersection activity is a much more global measure, of which right turns are only one component. Nevertheless, it was possible that Western RTOR produced some changes in pedestrian and bicycle accidents not involving right-turning motor vehicles. Signalized intersections are complex and interactive, and permitting one maneuver could influence drivers engaged in some other maneuver. For this reason, the New York data in this study were analyzed in several different ways looking for other pedestrian and bicycle accident changes that might have been associated with Western RTOR. No systematic changes were found. Thus, it appears that focusing on right turns provides the best estimate of the impact of Western RTOR for pedestrians and bicyclists.

It is possible that the availability of RTOR might prompt some drivers to alter their routes so that they now make more right turns at signalized locations than they made prior to Western RTOR. In other words, increases in the absolute number of right turns at signalized locations could have contributed to the observed accident increases. It is not likely, however, that changes in route selection influenced the findings to any significant degree. First, it seems unrealistic to expect driver route planning changes to occur just after Western RTOR implementation which could lead to 50 to 100% increases in right-turn accidents at signalized locations. Such route changes would have to have been that large and that rapid to account for the observed changes in the accident data. Second, if such driver route changes had occurred and were accounting for the reported RTOR effects, they should have affected all road users equally. All road users were not affected equally, however. Zador et al. (1980) reported vehicle-only crashes to have increased by about 20%, whereas estimated accident increases for pedestrians and bicyclists ranged between 43% and 107% in this study and were reported at 57% by Zador et al. for pedestrians. Thus, pedestrians and bicyclists seem to have been affected much more than vehicles. Nevertheless, there remains the possibility that some of the observed increases could be accounted for by driver route changes. Unfortunately, in the absence of pre/post on-street observational (exposure) data, it is impossible to estimate the influence of this factor. Further, even if some route changes did occur, it is impossible to estimate whether the changes merely aggravated the RTOR problem or whether they were also associated with decreases in pedestrian and bicycle crashes at locations that were not signalized.

Time factor. One surprising finding in this study was that the onset of the accident increases was rapid. It was as if the number of right-turning accidents shifted to a new level – 50 to 100% higher than the old level – soon after Western RTOR became effective and stayed at that level throughout the data collection period. This was indicated because the best-fitting time series models tended to be simple step functions in which accident frequency increased markedly immediately following Western RTOR adoption. This was contrary to expectations from learning theory which might predict an initial implementation period as drivers began using the maneuver, followed by a learning period as drivers, pedestrians, and bicyclists became familiar with it, followed by a plateau level of performance. While all of these stages may have occurred, they must have happened very quickly since the accident data showed an immediate increase and remained relatively constant thereafter. The one exception was for pedestrian accidents in New York which rose only slightly in the first year and increased sharply in the second year after Western RTOR implementation. The relatively high incidence of RTOR accidents in the Los Angeles data provided further evidence that such accidents continue well beyond the 2-, 3-, and 4-year periods covered in this study.

Nature of the problem. The secondary objective of this study was to describe pedestrian and bicycle RTOR accident events, especially any new accident types or situations associated with the RTOR maneuver. The results clearly showed RTOR-right to

be a special accident situation with inherent dangers for both pedestrians and bicyclists. Drivers looking left for a gap in traffic simply do not see pedestrians and bicyclists coming from their right. Pedestrians, in particular, are lulled into a false sense of security when they see the stopped vehicle and begin crossing with a green light and, perhaps, a "Walk" signal. They do not realize that the driver is looking left and could move forward at any moment.

Countermeasures. The present results suggest certain areas where countermeasures could profitably be considered. One possibility, of course, would be to repeal the RTOR statutes. This is not likely, however, now that Western RTOR is in place in all 50 states and drivers have become accustomed to it. Further, pedestrians and bicyclists are only one part of the overall situation. Any repeal effort must consider the total societal cost or benefit of RTOR including fuel savings, lowered air pollution, and reduced driver delay, as well as single- and multiple-vehicle crashes. Also, it may be possible to solve some of the pedestrian and bicycle RTOR problems through countermeasures short of outright repeal. Countermeasures in the following four areas appear reasonable for further analysis and development:

1. *Bicyclist Education* – The RTOR bicycle problem begins with wrong-way riding. Many bicyclists do not understand the problems inherent in wrong-way riding and, hence, the need to ride on the right side of the roadway. Right-side riding could be fostered through public education, in-school training, and/or enforcement of existing rules of the road.
2. *Pedestrian Education* – The pedestrian about to enter an RTOR-right situation is often provided with a variety of cues. The vehicle may be oriented towards a right turn, the vehicle's right directional signal may be flashing, or the driver may be looking left. Pedestrians could be taught to look for these cues and, if any are present, to delay crossing until the vehicle has gone or they are sure that the driver has seen them.
3. *Warrants* – Western RTOR specifically provides for sign prohibitions on certain intersection approaches. Further research could strengthen these warrants with respect to pedestrian and bicycle traffic.
4. *Traffic Engineering* – While several engineering concepts could be considered, two appear particularly promising. First, there could be an exclusive pedestrian light phase in which no vehicular movement, including RTOR, would be permitted. Second, an RTOR "box" forward of the stop line could be considered. Pedestrians would cross behind vehicles in this box.

It is noteworthy that countermeasures directed at the motorist do not appear cost-effective for initial consideration. The failure of motorists to stop prior to a right-on-red, an often cited theoretical cause, was not identified as significant in these pedestrian and bicycle accidents. Therefore, more complex behavioral remedies are indicated. These will require further research on the ability of motorists to cope with the cognitive load inherent in the RTOR situation.

CONCLUSIONS

The results of this study clearly show that Western RTOR has created a significant problem for pedestrians and bicyclists. While the associated crashes result in few fatalities and generally low injury severities, they may constitute up to 3% of a state or city's total pedestrian or bicyclist accidents. The vast majority of the crashes can be categorized as RTOR-right, a situation in which the victim, coming from the driver's right, is not seen because the driver is looking to his left for a gap in traffic. Initial countermeasure efforts should therefore be directed at this predominant subtype and should concentrate on bicyclist and pedestrian education, as well as traffic engineering solutions.

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