A Matched Case–Control Study Evaluating the Effectiveness of Speed Humps in Reducing Child Pedestrian Injuries

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Objectives. We evaluated the protective effectiveness of speed humps in reducing child pedestrian injuries in residential neighborhoods.

Methods. We conducted a matched case–control study over a 5-year period among children seen in a pediatric emergency department after being struck by an automobile.

Results. A multivariate conditional logistic regression analysis showed that speed humps were associated with lower odds of children being injured within their neighborhood (adjusted odds ratio [OR]=0.47) and being struck in front of their home (adjusted OR=0.40). Ethnicity (but not socioeconomic status) was independently associated with child pedestrian injuries and was adjusted for in the regression model.

Conclusions. Our findings suggest that speed humps make children's living environments safer. (*Am J Public Health.* 2004;94:646–650)

Pedestrian injuries caused by automobile collisions are a leading cause of death among children aged 5 to 14 years.[1] The demographic characteristics of children injured by automobiles have remained the same over the past 20 years, with boys, children between the ages of 5 and 9 years, and children living in neighborhoods of low socioeconomic status (SES) at highest risk.[2–4]

Children en route to school or at play in front of their homes are exposed to roads and street traffic. Modifying traffic patterns is a passive and sustainable public health intervention that may make children's living environments safer.[5] Traffic patterns can be modified with a number of engineering strategies that fall under the rubric of "traffic calming." Distinct from speed limit signs or stop signs, traffic calming measures such as speed humps, street closures, median barriers, and traffic circles are successful in providing long-term safety for pedestrians and motorists because they are physical structures with designs that are self-enforcing rather than requiring police enforcement.[6–8]

For years, European countries such as Denmark, the Netherlands, and Great Britain, as well as Australia and New Zealand, have implemented and tested the effects of traffic calming.[6] A report published in British Columbia summarized 43 international studies that demonstrated reductions in collision frequency rates ranging from 8% to 100% after implementation of traffic calming measures.[6] A Danish study showed that, in comparison with control streets, 72% fewer injuries occurred on experimental streets incorporating a variety of traffic calming measures in addition to new speed zoning requirements.[9]

As a result of the successful efforts in other countries, there is developing interest in traffic calming in the United States, and the Federal Highway Administration, in cooperation with the Institute of Transportation Engineers, has initiated a national traffic calming technical assistance project.[6] However, the majority of safety studies focusing on traffic calming measures have assessed accident statistics before and after installation, and there is no available hospital-based information on the specific effects of these interventions on childhood pedestrian injury.

Oakland has historically been one of the most dangerous cities in California in which to be a pedestrian, exhibiting, for example, the highest rate of pedestrian fatalities among the state's cities in 1995.[10] In that year, after a series of child pedestrian deaths, the Oakland Pedestrian Safety Project was formed. This multidisciplinary alliance addressed child and senior pedestrian injuries occurring in the city of Oakland and advocated for installation of speed humps. Over the 5-year period 1995 to 2000, Oakland installed about 1600 speed humps on residential streets. In this study, we examined the effect of residing on a street with speed humps on the odds of child pedestrian injuries in Oakland.

METHODS

We conducted a matched case–control study among Oakland residents younger than 15 years over the 5-year period March 1, 1995, to March 1, 2000. Case patients were children who were seen in the emergency department at Children's Hospital Oakland after having been struck and injured by an automobile on a residential street. Since this hospital receives all pediatric ambulance trauma transports (including deaths on the scene) from the city of Oakland, it was considered an appropriate choice to target child pedestrians injured in Oakland. Case patients were each compared with 2 respective controls matched in regard to age and gender. The purpose of the study was to determine whether these children who had been struck by automobiles were any less likely to live near a speed hump than their peers who lived in the same city boundaries but visited the emergency room that day for a reason other than being hit by a car.

We identified case patients retrospectively from a trauma database using *International Classification of Diseases* (9th Revision)[11] E-code E814.7 (motor vehicle traffic accident involving collision with a pedestrian). Cases were limited to those involving children younger than 15 years who were residents of the city of Oakland and who were injured or died as a result of the collision. We reviewed charts and emergency medical service data sheets to eliminate parking lot injuries, injuries involving bicyclists who had been misclassified as pedestrians, and injuries suffered by children in driveway rollover collisions. In addition, we reviewed traffic report data from the Oakland Police Department, primarily to confirm locations of collisions. When necessary, we reviewed original traffic reports for further clarification.

We also restricted our analysis to children injured or killed within 0.25 mi (0.4 km) of home and used a street atlas[12] to determine whether the injury occurred on the street block of the child's residence (defined by Mueller et al.[2] as the "index street"), within a 0.25-mi radius (about 5 blocks, considered the "surrounding neighborhood"[2]), or at a more distant location within Oakland. The type of street on which a child lived was classified with the street atlas as well.[12] Only children residing on minor roads (residential streets) were eligible for the study, because speed humps are installed only on such roads.

Living on a street with a speed hump, or within 1 block of a speed hump, was our principal predictor variable. We used data from the Department of Traffic Engineering in Oakland to determine the exact locations and dates of installation of speed humps (Department of Traffic Engineering, unpublished data, 1995–2000). Speed humps that were located on the other sides of primary or secondary roads (arteries) or were installed after the date of the injury were not considered.

As mentioned, we matched each case patient, according to age, gender, and date of emergency department visit, with 2 controls seen in the emergency department that same day for a reason other than being struck by a car. We identified all eligible controls of the same sex and with the same year of birth as the case patient from the daily log and randomly selected 2 such individuals. In situations in which there were fewer than 2 control patients born in the same year as the case patient, we made a random decision to search the 1 year above or below the age of the case patient, and then 2 years above or below and so on, until a suitable control was identified. Ninety-three percent of all controls were within 2 years of age of their respective case patients.

Controls were restricted to Oakland residents living on residential streets. We collected information on ethnicity and insurance status (classified as private, public, or self-pay) from medical records. In addition, we categorized the SES of patient and control households, using 1990 census data on median household income within the case patient or control's census tract, as low ($0–$15 736), medium ($15 737–$30 115), or high (more than $30 115).[13] Finally, we examined the records of case patients and controls to ascertain the presence of certain preexisting diagnoses, such as cerebral palsy, mental retardation, paraplegia, and developmental delay, that would have affected their walking ability and, thus, their potential to be exposed as pedestrians to automobile traffic.

Statistical analyses were performed with Stata software (Stata Corp, College Station, Tex). We used McNemar matched pairs analyses in examining the 200 case–control pairs (100 case patients each matched to 2 controls). When a factor is truly protective against disease, there are more case–control pairs in which the case lacks (and the control has) this protective factor than the converse. Separate univariate analyses focused on ethnicity, census tract household income, and insurance status to determine whether they were independent predictors of child pedestrian injuries. Once significant ($P<.05$) variables were determined, we constructed a multivariate conditional logistic regression model that included only these variables.

RESULTS

We identified 236 individuals who had been seen in the emergency department during the study period and had been assigned an E-code of E814.7. We eliminated 52 potential case patients because they (1) were not Oakland residents at the time of admission, (2) were injured outside Oakland, (3) were more than 14 years of age, (4) were bicyclists who had been misclassified as pedestrians, or (5) had been injured by an automobile backing up within a driveway or parking lot. We eliminated an additional 84 potential patients because they either lived on an artery street or had been injured outside of their neighborhood, yielding a final study sample of 100 case patients.

Case patients and controls were similar in terms of age, gender, insurance status, median household income, and proportion with an underlying premorbid neurodevelopmental disease (Table 1). Case patients were more likely to be Asian or of Hispanic ethnicity. The odds of Asian children having been involved as a pedestrian in an accident were 5.8 times as high as those for White children ($P=.018$), and the odds of Latino children having been involved were 4.3 times as high ($P=.038$). Admitting diagnoses of controls are available on request from the authors.

Unadjusted odds ratios (ORs) derived from a matched pairs analysis showed a protective effect of speed humps. In comparison with children living more than a block from a speed hump, those living within a block of a speed hump were significantly less likely to be injured as pedestrians within their neighborhood (14% vs 23%; OR=0.50; 95% confidence interval [CI]=0.27, 0.89) (Table 2). Among the 100 case patients, 49 were actually hit on the block in front of their home (index street). As a subset, these children were even less likely to have a nearby speed hump than their controls (12% vs 24%; OR=0.38; 95% CI=0.15, 0.90) (Table 2).

We performed multivariate logistic regression analyses using both predictor variables and included race and ethnicity in the model. After control for race and ethnicity, speed humps were associated with significantly lower odds of children being injured in their neighborhood (adjusted OR=0.47; 95% CI=0.24, 0.95) and being struck on the block immediately in front of their home (adjusted OR=0.40; 95% CI=0.15, 1.06) (Table 2).

DISCUSSION

In our observational study, we found that children who lived within a block of a speed hump had significantly lower odds of being struck and injured by an automobile in their neighborhood. Living within a block of a speed hump was associated with a roughly 2-fold reduction in the odds of injury within one's neighborhood (adjusted OR=0.47). This protective effect was even more pronounced among the subset of children who were injured on the block immediately in front of their house (index street). Children living within a block of a speed hump exhibited a 2.5-fold reduction in the odds of being injured on their street (adjusted OR=0.4). These results highlight the effectiveness of speed humps in reducing child pedestrian injuries.

TABLE 1—Demographic Characteristics of Case Patients and Controls

	Case Patients (n=100)	Controls (n=200)	Odds Ratio	P[a]
Male, No. (%)	68 (68)	136 (68)	...	...
Age, y, mean (SD)	6.8 (3.5)	6.6 (3.7)	...	.63
Ethnicity, %				
White	3 (3)	16 (8)	Reference	
Black	49 (49)	117 (58.5)	2.4	.187
Native American/other	11 (11)	21 (10.5)	3.2	.115
Hispanic	22 (22)	31 (15.5)	4.3	.038
Asian	15 (15)	15 (7.5)	5.8	.018
Insurance status				
Private insurance	17 (17)	43 (21.5)	Reference	
Public insurance	78 (78)	147 (73.5)	1.3	.366
Self-pay	5 (5)	10 (5)	1.3	.717
Household income, $ (census tract)				
High (>30 115)	12 (12)	39 (19.5)	Reference	
Medium (15 737–30 115)	75 (75)	136 (68)	1.8	.105
Low (0–15 736)	13 (13)	25 (12.5)	1.7	.265
Premorbid diagnosis[b]				
Mild mental retardation	1 (1)	1 (0.5)	...	
Developmental delay	0 (0)	3 (1.5)	...	

Note. A univariate analysis of age, ethnicity, insurance status, household income, and presence of a premorbid diagnosis showed that only ethnicity was independently associated with child pedestrian injury.
[a]All *P* values were obtained from conditional logistic regression analyses, except for age, which was obtained with a 2-tailed test of means.
[b]Case patients and controls were screened for the presence of any of the following premorbid diagnoses: cerebral palsy, mental retardation, quadriplegia, paraplegia, and developmental delay.

Exposure to Traffic

Increased exposure to traffic (especially traffic at high volume and speed) is a known risk factor for child pedestrian injury. Stevenson and colleagues showed that an increase in volume of 100 vehicles per hour is associated with an incremental increase of about 2.0 in the odds of pedestrian injury.[14] Average speeds traveled on streets are also associated with risk of injury, and at least 2 studies have demonstrated that a higher proportion of vehicles exceeding the posted speed limit is associated with higher odds of child pedestrian injuries.[14,15] In addition to the type of street, the number of streets that children cross on their way to school seems to affect their risk.[16]

Need for Passive Environment Modification

Given the relationship between exposure to traffic and risk of child pedestrian injuries, we have essentially 2 prevention strategies at our disposal: we can protect children from fast-moving traffic by modification of either their behavior or their traffic environment. There have been multiple attempts to modify children's behavior, including school training programs,[17] "traffic clubs" designed to educate parents and children about safe behavior on streets,[18] simulation games,[19] and community-level interventions.[20] For the most part, however, these educational efforts have been unable to exert meaningful changes in the long-term behavior of children, largely owing to the developmental limitations of preschool-aged children.[20] As a result, a great deal of attention has shifted to environment modification and the promise it holds for affecting child pedestrian injury rates.

TABLE 2—Odds of Pedestrian Injury Within a Child's Neighborhood and Odds of Injury on a Child's Index Street of Residence When Child's Home Is Within 1 Block of a Speed Hump: Multivariate Model

	Case Patients (n=100), No. (%)	Control Subjects (n=200), No. (%)	OR (95% CI)[a]	Adjusted OR (95% CI)[b]
Neighborhood injury	14 (14)	46 (23)	0.50 (0.27, 0.89)	0.47 (0.24, 0.95)
Index street injury	6 (12)	24 (24)	0.38 (0.15, 0.90)	0.40 (0.15, 1.06)

Note. OR = odds ratio; CI = confidence interval.
[a]Calculated from McNemar matched pairs analysis.
[b]Calculated from multivariate model including ethnicity.

Focus on Neighborhood Injury

The deliberate focus of our study was on pedestrian injuries occurring in a child's own neighborhood (defined here as within a 0.25-mi radius of the child's home) as opposed to all injuries, including those occurring at more distant sites. We focused on such injuries because although children leave their neighborhoods with adults (and often in automobiles), most of their unsupervised time is likely to be near home. In addition, the traffic calming methods we examined can be applied only to residential streets. One 8-year study that examined fatal head injuries revealed that injuries to pedestrians were the most common cause of fatal head injuries and that 53% of those injured were playing in the street at the time of the injury. Of the 135 accidents that fell into this category, only 1 involved a child who had been under adult supervision at the time of the accident (the remaining children had been supervised by siblings or other children).

The same study showed that 80% of fatal pedestrian injuries had taken place within 1 mi (1.6 km) of the child's home.[21] Among the 184 children we initially identified for this study, 125 (68%) were eligible for the study because their injury occurred within 0.25 mi of home (the other children were eliminated because they lived on arterial streets). Therefore, our data suggests that roughly two thirds of injuries occur within the 0.25 mi surrounding a child's home. Passive interventions that reduce child pedestrian injuries are likely to be of greater benefit in areas where children are prone to spend time without adults.

In our study, SES was not a significant independent predictor of child pedestrian injury. Mueller and colleagues found that living in a census tract with a median household income level below $20 000 was associated with 7.0-fold higher odds of injury than living in a census tract with a median income level above $30 000.[2] Other research points toward an association between increasing rates of pedestrian injury and lower SES, as approximated by census tract of residence,[4] spatial modeling of census tract and other data with a geographic information system,[22] and more indirect indicators of lower SES such as living near a convenience store, gas station, or fast food store.[15]

It is possible that, in our population, "overmatching" was the reason SES was not found to be an independent risk factor. Case patients were not matched with controls on SES, but if lower SES is associated with both increased odds of injury[2] and increased odds of an emergency department visit,[23] choosing controls from the emergency department may have resulted in overmatching in terms of SES.

Limitations

Our study involves potential methodological limitations. For example, limiting measurement to speed humps on a child's street ignores the potential protective effect of speed humps around the corner from a child's house. Thus, by measuring speed humps lateral to an index street (rather than in a 1-block radius), we may have underestimated the relevant rate of exposure to this intervention, which would have affected our estimation of the intervention's protective impact.

There are also limitations involved with our study sample. While relying on emergency department visits ensured that we incorporated higher severity injuries (including deaths), injuries that were not reported to the emergency medical services (and for which children may have been taken by their family to their regular doctor) would have been missed. This would mean that our sample underrepresented lower acuity injuries. It is also possible that our sample underrepresented younger children, in that children younger than 5 years are more likely to be hit in their driveway (often by a backing automobile)[24,25]; we excluded children in this age group from our study because such injuries are not related to the flow of street traffic.

Finally, it is possible that significant confounding factors were not addressed in this study. Some research suggests that the presence of sidewalks is not a significant contributor to odds of injury,[2,15] and other research suggests that the presence of sidewalks is a strong risk factor, with an odds ratio of 11.0.[14] We would have liked to control for the presence of sidewalks, but there were no reliable retrospective data on sidewalk or curb presence available to do so. Also, since much of the earlier literature points to lower SES as a risk factor for child pedestrian injury, the reason for our inability to reproduce this relationship may have been that the factors we used to approximate SES—census tract household income and medical insurance status—are inappropriate proxies for SES.

CONCLUSIONS

We found that speed humps were associated with a 53% to 60% reduction in the odds of injury or death among children struck by an automobile in their neighborhood. These findings invite additional research on the protective effects of traffic calming interventions and offer a framework for studying pedestrian injuries in relation to physical interventions implemented within a localized geographic region. Further confirmation of the protective effects of speed humps would be useful and could be augmented by additional information on stop signs or other factors that would affect slowing distances on either side of a speed hump. Our study provides direct observational evidence that speed humps are associated with a reduction in the odds of childhood pedestrian injuries and supports the installation of speed humps by traffic engineering departments. ■

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Contributors

J.M. Tester conceived the study, performed all analyses, and led the writing of the article. G.W. Rutherford assisted in data analyses, interpretation of findings, and revisions of the article. Z. Wald contributed to conceptualization of ideas as well as reviews of the article. M.W. Rutherford contributed to the study design and interpretation of the findings.

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Human Participant Protection

This study was reviewed and approved by the institutional review board of Children's Hospital and Research Center at Oakland. Informed consent was not required by the review board because patients did not need to be contacted for this retrospective data analysis.

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