

**Pedestrian Safety in Peru: The role of visible signalization, transit stops and other features of the
built environment**

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Abstract

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Background: In Peru, pedestrians are 78% of road fatality victims. The objective of the study was to explore the relationship between signalization for pedestrians, bus stop characteristics, and other features of the walking environment and pedestrian-motor vehicle collisions (PMVCs).

Methods: A matched case-control study design was used where the objects of study were crossing locations. A two stage cluster sample was used to select eleven police commissaries in Lima, Peru for study. Case accrual occurred from October, 2010 through January, 2011. Out of 406 PMVCs reported there were 97 incidents at intersections (weighted N=1134) and 40 at mid-blocks (weighted N=469) that met study criteria. Each case was matched to one control based on proximity, street classification and number of lanes. Site characteristics were recorded February, 2011 to September, 2011. Each analysis was controlled for potential confounding variables (vehicle and pedestrian traffic flow, crossing width, and mean vehicle speed) and accounted for the weighted sampling design and matching between case and control sites.

Results: Signalization was not significantly associated with PMVCs. The presence of a phased pedestrian signal (green or red-lit signal) was significantly associated with case status compared to no signalization (OR 8.88, 95% CI 1.32-59.6). Longer pedestrian-specific signal duration was associated with an elevated risk for a pedestrian collision (OR 5.31, 95% CI 1.02-9.60 per 15-second interval). Intersections with bus stops were more likely to have a police-reported pedestrian-vehicle collision (OR 3.28, 95% CI 1.53-7.03). Sites with a curb present (OR 0.51, 95% CI 0.33-0.80) or a pedestrian barricade (OR 0.11, 95% CI 0.01-0.96) were significantly less likely to have had a PMVC. The presence of parked vehicles (OR 3.13, 95% CI 1.08-9.05) or street vendors (OR 2.61, 95% CI 1.55-4.37) increased the likelihood of a PMVC.

Conclusion: Several features appeared to be beneficial to pedestrians (curbs and pedestrian barricades) and others that may have created dangerous situations for pedestrians (signalization, bus stops at intersections, parked vehicles and street vendors). Pedestrian or driver behaviors could possibly explain some of the findings. Better police enforcement or better feature design may help improve the function of the built environment features.

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GLOSSARY

Authorized Bus Stop – A bus stop designated by the MML

Case – A crossing area where the PNP reported a PMVC

Control – A crossing area where no PMVC occurred during the same 24-hr time period as the control it was matched to

Crossing Width – The distance on the Index Crossing a pedestrian must traverse from one edge of the roadway to the opposite side to complete the crossing

Index Crossing – The area where a PMVC occurred for cases or a comparable area for controls

Leg – A road radiating away from the index crossing area

Refuge – An area where pedestrians may pause their crossing

Segment – Gaps between refuge areas where pedestrians could be potentially exposed to vehicles.

Signalization – Refers to phased vehicle signals, phased pedestrian signals, transit police, or stop signs

Unauthorized Bus Stop – A bus stop made informally by bus drivers that is not authorized by the MML

ABBREVIATIONS:

CI	= Confidence Interval
CTLG	= Consejo de Transportes de Lima y Callao
LMIC	= Low- or middle-income country
m	= Meters
MML	= Municipalidad Metropolitana de Lima
MUTCD	=Manual of Uniform Traffic Control Devices
MVC	= Motor vehicle collision
OR	= Odds Ratio
PMVC	= Pedestrian-Motor Vehicle Collision
PNP	= Policía Nacional del Perú
SD	= Standard Deviation

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Chapter 1: Pedestrian Signalization and Pedestrian-Motor Vehicle Collisions

INTRODUCTION

In 2007, Peru had the second highest road fatality rate in Latin America¹ and motor vehicle collisions (MVCs) were among the top 5 causes of death among males ages 5 to 59.² The nearly 2,800 pedestrians killed in 2007 comprised 78% of the country's road traffic fatalities, the highest proportion in the world that year.^{1,3} A recent study has suggested that these official data may have significantly undercounted road traffic deaths, perhaps by two-fold.¹ In 2010, 60% of reported pedestrian-motor vehicle collisions (PMVCs) in Peru occurred in Lima, the capital city of nearly 8 million people.^{4,5}

Research on PMVCs in Peru has been largely descriptive in nature and has primarily reflected conditions in the capital city. A 2008 report on the ten sites in Lima with the highest annual frequency of PMVCs suggested the possible dangers for pedestrians were inadequate signal timing, conflicts between turning vehicles and crossing pedestrians, failure to use designated bus stops, a lack of marked crosswalks, jaywalking, and the pedestrian right of way not being respected.³ A population-based matched case-control study in a low-income district of Lima identified high vehicle volume, high vehicle speed, the presence of street vendors, and the lack of lane demarcation as significant risk factors for child PMVCs.^{6,7} One hospital-based matched case-control study of child pedestrian injury found that retrospective parental report of poor supervision and the need to cross many streets on the way to school were associated with increased risk.⁸ These previous studies were limited by small sample size and possible recall bias. Further, they focused only on child and adolescent pedestrians, and selected controls whose walking habits may have differed from cases (especially in the case of the hospital-based study where controls were children being treated for other reasons at the hospital than for an injury). The hospital-based study may have also been subject to recall bias by the parent interviewed. Finally, each study considered only a limited set of environmental factors.

The response in Lima and the countermeasures (phased pedestrian signals, jaywalking prohibition, pedestrian barricades, etc.) employed varies by municipal districts within the city.^{3 9-16} One of the more prominent and expensive measures to control vehicle and pedestrian traffic in recent years has been the installation of “intelligent” phased countdown signals as part of vehicle traffic lights on several arterial roads (Figure 3b).¹⁶ Other intersections have adopted signals directed at pedestrians, and have installed a pedestrian countdown signal dedicated for pedestrians (typically include a “walking” figure in green or a “stopped” figure in red (Figure 3b). On other arterials there are pedestrian signals that alternate between a motionless green or red figure (Figure 3a). In the central urban core of Lima most intersections are signalized for vehicle traffic with phased signals placed such that they are only visible to vehicles entering an intersection but not to pedestrians.³ In the periphery of Lima where most housing developments have been established informally, there is little signalization for vehicles or pedestrians at intersections, even on arterial roads.³

In high income countries, studies have generally indicated that signalization for pedestrians is a potentially effective means of reducing PMVCs based on pedestrian-vehicle conflicts being reduced by 24-95% depending on the intervention.¹⁷⁻²¹ A variety of signal design factors may impact signal effectiveness: road characteristics (increased number of lanes, vehicle flow, pedestrian flow have a higher risk of a PMVC),¹⁷ an exclusive pedestrian phase may reduce PMVCs by 50%,²²⁻²⁴ the type of pedestrian signal used,²⁵ pedestrian crossing warning signs for drivers may reduce vehicle speeds by 25%,²⁵ and the placement of the signal.^{20 26} The Manual on Uniform Traffic Control Devices (MUTCD) has established recommendations for the use of pedestrian signal installations.^{26 27}

Signal effectiveness can certainly be thwarted by risky pedestrian behaviors such as jaywalking, distracting activity,²⁸⁻³¹ use patterns within subpopulations of pedestrians (adolescents and the elderly),²⁹ risky driver behavior (speeding, ignoring traffic rules),^{32 33} and design factors such as signal placement, street lighting and neighborhood characteristics.^{20 34-37} The effect of signalization installations in low and middle income countries (LMICs) where traffic patterns and behaviors are quite different have not been evaluated widely, and evidence may suggest that these installations are used differently by road users in

these settings.³⁸⁻⁴³ In general, the public health implications of pedestrian signalization have not been widely studied in LMICs except perhaps in a handful of other countries.⁴⁴⁻⁴⁶

The primary objective of this study was to evaluate whether pedestrian signalization efforts in Lima, Peru affected the risk of a police-reported pedestrian-motor vehicle collision in pedestrian crossing areas at intersections. This evaluation of pedestrian signalization treatments included an assessment of the effect of signalization, type and duration of signalization if present, and whether the signalization timing adhered to MUTCD standards.

METHODS

A matched case-control study design was used. The unit of analysis was a pedestrian crossing area. For this analysis, a crossing area was defined as being located at an intersection using similar methods to a US study conducted by Koepsell *et al.*⁴⁷ While data on mid-block sites were collected, none had any signalization for vehicles or pedestrians, thus they were not included in this analysis. PMVCs that occurred within 10 meters of an intersection were considered eligible for this analysis. The index crossing (Figure 1) on one of the streets (intersection legs) that radiated outward from an intersection was identified from the documented police report. For some intersection PMVCs, the police report was not specific enough to determine the exact location within an intersection (14%). For these cases we randomly selected one of the two legs of the intersection of the principal road on which the PMVC occurred to be index leg.

Setting. This study was conducted in the urban area of Lima, Peru within the jurisdiction of 11 police commissaries. The case accrual period occurred October 1, 2010 to January 15, 2011 and observational data from selected sites was collected from February 2011 to September 2011.

Study Population. Pedestrian crossing areas at intersections were the study population. For this study we were interested in the risk of a PMVC occurring at any of these sites. In 2006, there were 15,000 PMVCs reported at 108 police commissaries in Lima. We used a two-stage cluster sampling scheme to select commissaries. The first stage used reported PMVCs incidents in 2006 as the sampling frame where the probability of a commissary being selected was proportional to the number of PMVCs reported in 2006.

The Policía Nacional del Perú (PNP) collect data on MVCs in Peru. Each commissary was fairly autonomous in its collection of PMVC data, though at minimum the police record included victim characteristics, location, time and date, and some description of the circumstances surrounding the collision. Incident data are public records and were available at police commissaries. In order to access large amounts of these data, we arranged an official agreement with the police leadership of the Lima region.

In the second stage a simple random sample of 80% of the reported incidents within each commissary was taken. Before conducting the second stage we excluded cases meeting the following criteria to reduce misclassification errors in order to only study unintentional PMVCs occurring within roadways in the commissaries selected (Figure 2): injured person not a pedestrian (e.g. a cyclist), pedestrian not struck within the roadway (e.g., on the sidewalk), occurring outside the jurisdiction of the commissary, incomplete location address, missing time of incident, high criminal activity sites that could have presented safety issues for study staff, and any intentional injury (e.g. a pedestrian intentionally struck by a vehicle). We excluded incidents that occurred from 8 PM to 6 AM as conducting observations in darkness during these hours would have posed safety risks for study staff.

One matched control was selected for each case. The matched control was randomly drawn from a risk set of potential, matched controls. Risk set sampling allows the population at risk for a disease at a given time to be grouped by characteristics of interest. In this case, the characters of interest are road type, number of lanes and proximity. When a member of the risk set becomes ill, healthy controls can be selected at the time of the incident from the risk set.⁴⁷⁻⁵¹ Once a case subject recovers, he or she could return to be part of future risk sets and can be sampled as a control or become a case again depending on the disease under study. In this case, PMVCs fit this approach since a pedestrian-vehicle collision is nearly instantaneous and thus the duration of the "illness" is very brief. This method was also useful since road conditions can change over time. There were six intersections visited to obtain both a case and a control at different times, nine control intersections visited more than once, and 12 case intersections visited more than once.

Three geographical sources were used to aid control selection to construct the risk set. ArcGIS compatible shapefiles of Lima were provided by the Technical Secretariat of the *Consejo de Transportes de Lima y Callao* (CTLC; Transportation Council of Lima and Callao), a government organization responsible for conducting transportation research in Lima, and included layers for roads, city block shapes, commissary limits, and municipal district limits. The road layer database classified street sections as a highway, arterial, collector, local/residential, non-connecting, and other. In order to obtain a more specific match, satellite images from Google Earth were also obtained to enable visualization of the number of lanes and the direction of vehicle traffic (one-way or two-way) for each site. We used Google Earth to create five categories of road types: 1) one and two lane one-way streets, 2) two lane two-way streets, 3) four lane two-way streets, 4) three lane one-way streets, and 5) more than four lane two-way streets. We examined the two next busiest streets' categories radiating from an intersection to more finely select appropriate controls. Proximity to the case site was defined as a 500 meter radius area from the site. If there was not at least one potential match within this radius, it was expanded by another 100 meters to search for more until 1000 meters was reached or at least one suitable match was found. We were able to identify at least one matched control for every case within at least one of these proximities. When multiple controls were found, one was selected randomly. The third geographical source, *Guia Calles del Perú*, was used to ensure up-to-date street names and numbering as well as to search for streets named by the police reports that were not found in the CTLC shapefiles.

Outcome. There was one outcome and this as the presence of a pedestrian-vehicle collision reported to the police.

Exposures: The primary exposures in this analysis were the presence of any visible traffic control signal (pedestrian signal, phased vehicle signal, stop or yield sign, or transit police directing traffic), the presence of any type of pedestrian signal, the type of pedestrian signal visible (stationary red/green figure phased signal or regressive countdown signal with a moving figure green figure or stationary red figure, Figure 3), the duration of the green and red phases of a traffic signal if present, and the duration of the "Walk" and "Don't Walk" phases of a pedestrian signal if present, and whether the pedestrian signal timing met the MUTCD standard of allowing pedestrians one second for each 3.5 feet crossed from edge

to edge. Visibility was defined as any type of traffic signal (phased pedestrian signal, phased vehicle signal, stop sign, or transit police) visible to pedestrians from at least one side of the crossing area.

Confounding Factors. We collected data on potential confounding factors: pedestrian and vehicle flow, vehicle speed, presence of crosswalk markings, crosswalk marking condition, crossing distance (meters), number of radiating roads, and number of crossing segments (subdivisions of the crossing areas where there is an area where pedestrians can pause crossing outside of vehicle traffic, Figure 3) which were defined as road subdivisions in the crossing area where a pedestrian could potentially wait to complete the crossing, whether intended for that purpose or not (pedestrian refuges, median barriers, and various types of median dividers).

Data Collection. We identified cases at the selected commissaries. To minimize time and resources on the commissary computer, cases were retrospectively collected from Oct 1, 2010 to Jan 15, 2011. The police headquarters provided a liaison officer to accompany study staff at the commissaries in order to ensure cooperation and assist with accessing and recording records. Commissaries were visited during January and February, 2011.

Once sampling case sites and appropriate controls were selected, we visited each site. Incidents occurring on a weekday were visited on any weekday and similarly for weekends. Sites were visited within an hour before or after the time of day at which the case incident occurred. Sites that were cases or controls multiple times were visited multiple times to record factors such as vehicle and pedestrian flow and speed at the appropriate time, but physically stable factors such as road width were only measured once. All field workers were trained by DAQ to collect each type of data. At each site several data collection tasks were undertaken: video recording of the index crossing for 10 minutes for later coding of vehicle and pedestrian volumes, photographing the site, recording vehicle speeds for at least 10 minutes or until 25 vehicles were recorded using a portable velocity speed gun (Bushnell Velocity Speed Gun, Model 101911, Lenexa, KS, USA), measuring various road geometry and physical characteristics, sketching a diagram of the features of the site, and collecting signal timing with a stopwatch and recording the end of each phase beginning with the amber phase. Field workers were blinded to case and control status. Video of the sites were coded by trained research assistants, who recorded the total

number of vehicles passing through the index crossing and the number of pedestrians using the index crossing area during a 10 minute period.

Data Analysis. We descriptively evaluated the closeness of matching using conditional logistic regression to test for statistically significant differences (at $\alpha < 0.05$) with case or control status for road characteristics. Conditional logistic regression accounting for matching was used to calculate odds ratios (OR), 95% confidence intervals (CIs) and P-values to assess the association between risk of a police-reported PMVC and the site characteristics under study. As the primary outcome (pedestrian collision) was a relatively rare event, the OR is a good estimate of relative risk.

We assessed confounding first by selecting *a priori* potentially confounding covariates based on previous literature. Univariate association with case status and the primary exposure were determined. We subsequently examined the effect of each potential confounder on the primary exposure in multivariable models, evaluated the goodness-of-fit of each model and compared likelihood ratios. Continuous variables such as pedestrian and vehicle flow and crossing width were tested in fractional polynomial models for best fit. A single linear term for each of these variables was determined to be the best fit in all models.

All analyses were performed with Stata 11 (STATA Corp, College Station, TX, USA). The svy package in Stata was used to calculate all weighted estimates. Weights (w_{ic}) for each unit sampled were essentially the inverse probability of being selected for the study, $w_{ic} = \frac{N_c}{m\bar{n}\pi'_c}$, where the number of enumeration units in a commissary (N_c) is divided by the number of clusters selected (m) times the number of units sampled within a cluster (\bar{n}) times the probability (π'_c) of an enumeration unit (X_i) being selected from within the total population (X) being sampled ($\pi'_c = \frac{X_i}{X}$).⁵² The study protocol was approved by the University of Washington and Universidad Peruana Cayetano Heredia institutional review boards.

Results

There were 406 pedestrian-vehicle collisions involving 426 pedestrians and 420 drivers at the 12 sampled commissaries. One commissary's PMVCs were dropped from selection for a study visit as there were a

total of three incidents, all within a university campus at unspecified locations. There were 151 cases of 406 eligible for inclusion (Figure 2). There were 7 fatal pedestrian collisions, though all at night and were therefore not visited. Of the 151 visited, 97 occurred at an intersection and had complete data (six were missing video data due to a camera and its data being stolen on one day). Most PMVCs occurred on either an arterial or collector road (Table 1.1). Slightly more than half of the pedestrians struck were male (53%) and most drivers were male (91%), though the sex for 5% of the drivers was unknown due to the incident being a hit-and-run. The majority of vehicles that were involved in PMVCs were passenger vehicles (67%) and motorcycles were the second largest (over 20%). A blood alcohol concentration (BAC) over the legal limit of 0.05% was recorded for 2% of drivers and 4% pedestrians; the status was unknown for the rest of those involved. The majority of PMVCs visited occurred on weekdays.

The 97 weighted cases represented 1134 pedestrian-motor vehicle crashes at intersections throughout metropolitan Lima. No statistically significant differences were observed between cases and controls for most of the road characteristics included in the model (Table 1.2). There was significant difference given the number of road legs (Figure 3) within an intersection ($p = 0.014$). Case sites tended to have a marked crosswalk more than control sites, though not significantly so. Case sites had higher vehicle and pedestrian flows than control sites, but this difference was not significant taking into consideration survey weights. Mean speed (in KPH) was slightly higher at controls sites.

Case sites were more likely to have any type of crossing signal visible to pedestrians on either or both sides of the crossing than controls sites (OR 3.14, 95% CI 0.54-18.2), though this relationship was not statistically significant (Table 1.3). We did not observe a statistically significant association by the type of traffic regulation with case-control status. While there were a few intersections that had a stop sign on one of the legs, no index crossing area was controlled by a stop sign. Sites with any type of pedestrian signal had an elevated risk for a PMVC compared to sites with none (OR 2.51, 95% CI 0.60-10.5). The only type of pedestrian signal (Figure 3) associated with case status versus no signal was a combined stationary pedestrian figure and phased vehicle signal (OR 11.3, 95% CI 2.86-44.5). Sites with countdown signals for both pedestrians and vehicles had a slightly elevated risk of a PMVC (OR 1.76, 95% CI 0.23-13.6) as did sites with any type of a vehicle signal or transit police, relative to sites with no

signalization. At sites with a pedestrian signal, a longer “green” crossing duration was significantly associated with case status (OR 1.19, 95% CI 1.15-1.23). Most cases and (94%) and controls (73%) met MUTCD standards for the recommended allowed green crossing rate of 3.5 feet per second.

The multivariable analysis did not reveal many changes in the relationship of the signalization characteristics based on case status (Table 1.4). Any visible signal had a slightly higher risk than in univariate analysis, though did not achieve statistical significance. Adjusting for confounding moved the risk of a PMVC in presence of any pedestrian signal towards the null slightly (OR 2.26, 95% CI 0.38-13.3). A combined pedestrian stationary figure and phased vehicle signal still had a significantly high risk of a PMVC when adjusting for confounders with an OR of 8.88 (95% CI 1.32-59.6). The presence of transit police acting as a signal appeared to greatly lower the risk of a PMVC compared to sites with no regulation, though there were few sites that had police present. The “green” crossing duration time remained a statistically significant factor with the risk of a PMVC being 42% higher for each second increase in green duration at case sites compared to control sites (95% CI 1.07-1.90) when adjusting for vehicle flow, pedestrian flow, total crossing width, and mean vehicle speed. Sites that met the MUTCD standard of 3.5 feet per second had a higher risk of a PMVC, but not significantly so.

Discussion

This study suggests that overall the current pedestrian signalization efforts in Lima, Peru did not protect pedestrians from motor vehicles and may have been associated with a higher risk of a pedestrian-motor vehicle crash. This latter possibility is strongly suggested in the case of pedestrian signals that allowed pedestrians more time to cross at the intersection. These analyses included adjustment for pedestrian and vehicle flow, crossing distance and mean vehicle speed.

These results are contrary to our initial hypothesis that signalization would reduce the risk of pedestrian injury and to what has been found in studies in high-income countries,^{17 18 20-23} though these findings may resonate with observations that such interventions may not be as effective in LMICs due to road users circumventing or ignoring these features.^{38 40 53} This elevated risk of a PMVC was most pronounced for prolonged signal crossing times, where longer crossing times were associated with a 5.3-fold (95% CI

1.02-9.60) increase in risk with crossing times of 45 seconds vs. crossing times of 30 seconds. There may be some plausible explanations for this finding from studies on pedestrian crossing behaviors.

A shorter permitted crossing time, perhaps especially in the presence of a visible regressive countdown, may have spurred pedestrians to cross more quickly and may have even affected their decision to cross if they arrive at the end of the green phase. If a green signal for pedestrians was especially long, it may have resulted in a second wave of pedestrians arriving from an adjacent intersection and attempting to cross at the end of the green signal. This could have been compounded by sites with multiple segments and pedestrian refuges. Pedestrians may have become impatient waiting on a refuge and may have crossed against the signal, as was observed in a study in Jordan.⁵⁴ While we were not able to examine this factor in detail due to a limited number of pairs both having any phased signaling on single segment sites, our data suggested that there was higher risk of PMVCs associated with lengthier signal times at sites with multiple crossing segments. This relationship could also be the result of residual confounding by pedestrian and vehicle flow given that sites were only observed for 10 minutes.

Any type of visible signalization for pedestrians appeared to put them at risk for being struck, significantly so for pedestrian signals with a stationary figure only. This elevated risk could also be due to sites with multiple crossing segments due to poor visibility of the signal. Many of these sites only have a signal situated on the far ends of the crossing area rather than at each refuge. Sites with stationary figures can be difficult to see because they are fairly small and not very brilliantly lit. This may be compounded on very wide roads where in some instances the total crossing width was well over 50 meters. It is possible as well that having no signal results in pedestrians and drivers being more cautious, a possibility that resonates with other studies.^{19 29 47 55} Pedestrians may be more careful at checking traffic and crossing when there are wider gaps than when there is signalization present or nearby. Drivers may also be more alert if they notice pedestrians trying to cross at non-signalized intersections.

There are several important behavioral factors that could also affect the relationship between signalization and pedestrian safety. This basic premise of this analysis assumes in a perfect world that pedestrians are respecting and following the signalization as designed, but as any visitor to Peru can observe and as other studies suggest that in reality many pedestrians in LMICs do not obey traffic

signals.^{38 44 53 54 56-64} This could perhaps be in part due to the signal timing being too long, thus causing impatience on the part of pedestrians. Another potential behavioral factor is the use of mobile devices while walking.^{28 30 65} There are 1.2 cell phones per Peruvian (over 33 million total) and nearly two per Peruvian living the Lima and Callao metropolitan area (over 15 million).⁶⁶ While cell phones and texting (nearly 4.4 billion SMS sent or 131 per cell phone per year were sent in 2010) are common in Peru, cell phone use and texting on the street while walking may not be as widespread as in high income countries due to fears of petty robbery of portable electronic devices.

There are a number of limitations to this study. First, police-reported data are not always ideal for research.⁶⁷ The police may not record all incidents and records information relevant for their needs. We attempted to minimize this bias by only using the police data to identify locations of PMVCs regardless of the severity of the incident or injuries to the pedestrian. We excluded 38% of the PMVCs reported by the police from further data collection; mostly for safety reasons due to being at night or high crime areas (26%), but also some were misclassified as PMVCs (4%) or missing data crucial to observation (3%). Nighttime crashes may be influenced by other factors other than road design such as alcohol use by both drivers and pedestrians. Another consideration is that the presence of observers may have impacted pedestrian behavior, though based on many illegal traffic and other behaviors observed our impact was likely minimal. Another potential limitation is the limited observation of pedestrian and vehicle flow (10 minutes). Some traffic researchers believe traffic characteristic observation longer than 30 minutes is needed to appropriately adjust for flow variables. Another limitation of the flow data is that it may not exactly represent the traffic characteristics at the time of the incident, though it should give a fairly good estimate assuming that traffic patterns have remained fairly constant. For three sites (4 cases and 3 controls) there was detailed vehicle and pedestrian flow available from Lima's transport agency from a traffic study they did in the area in 2009 and 2010. Their reported pedestrian and vehicle flows were nearly identical to those that we observed at these same sites during the same time periods.

One final limitation is that there were as many as 10 months difference between the date of an incident and the date when environmental characteristics were collected. Because of this difference, Google Earth archival satellite imagery was retrieved for a random selection of 10% of the cases and controls to

assess whether there were any major visible changes to the sites in the intervening time period. None of the sites exhibited major changes (such as new traffic lights or geometrical changes), though some had fainter paint markings than earlier images and a few had newer paint markings than earlier.

Current signalization efforts in Lima, Peru were associated with an increased risk of pedestrian collision, and may have contributed to an increase in pedestrian risk-taking behaviors. Police enforcement of traffic signalization may be an important tool for making pedestrian signals more effective. We noted that even the presence of police directing traffic appeared to have a protective, though not significant, effect for pedestrians. Lima passed a pedestrian jaywalking law in November of 2010, though it does not appear to be widely enforced based on only about 22,000 tickets being issued in its first year (2.8 per 1,000 residents per year). Future research should examine the role of enforcement on pedestrian safety in settings such as this, as well as examining in more detail ways to improve pedestrian signalization to encourage compliance as well as behavioral factors that could also be important. Pedestrian signalization in LMICs may be less effective than in high-income countries, but ways to improve its effectiveness should be explored as it is an important and necessary component of the walking environment in any major urban area where pedestrians and vehicles interact.

REFERENCES

1. World Health Organization. Global status report on road safety: time for action. Geneva: World Health Organization, 2009.
2. Pan American Health Organization. Peru. *Health in the Americas:2007*. English ed. Washington, DC: Pan American Health Organization, 2007.
3. Secretaría Técnica del Consejo de Transporte de Lima y Callao. La Vulnerabilidad de los Peatones en la Vialidad del Área Metropolitana de Lima y Callao. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2009.
4. Policía Nacional de Peru. Accidentes de Tránsito 2009. Lima, Peru: Ministerio de Defensa de Peru, 2010.
5. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Análisis de los Accidentes de Tránsito en el Área Central de Lima y Callao - Información Base del Año 2006. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2008.
6. Donroe J, Tincopa M, Gilman RH, Brugge D, Moore DAJ. Pedestrian Road Traffic Injuries in Urban Peruvian Children and Adolescents: Case Control Analyses of Personal and Environmental Risk Factors. *PLoS ONE* 2008;3(9):e3166.
7. Donroe J, Gilman RH, Brugge D, Mwamburi M, Moore DAJ. Falls, poisonings, burns, and road traffic injuries in urban Peruvian children and adolescents: a community based study. *Injury Prevention* 2009;15(6):390-96.
8. Pernica JM, Leblanc JC, Soto-Castellares G, Donroe J, Carhuacho-Meza BA, Rainham DG, et al. Risk factors predisposing to pedestrian road traffic injury in children living in Lima, Peru: a case-control study. *Arch Dis Child* 2012.
9. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Localización y Caracterización de los Puentes Peatonales en Lima y Callao. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2008.
10. Ministerio de Educación. Mediante Portal de Internet Enseñarán Seguridad Vial: Ministerio de Educación formó alianza estratégica con el sector Transportes y Comunicaciones y Toyota del Perú, para esta importante herramienta educativa. Lima, Peru: República de Perú, 2010.
11. Ministerio de Vivienda Construcción y Saneamiento. El Manual para la Elaboración de Planes de Desarrollo Urbano. Lima, Peru, 2009.
12. Ministerio de Educación. Transitando. Lima, Perú, 2010.
13. Rivas B. Cómo ordenar el tráfico en Lima, una ciudad hecha para los autos. *El Comercio* 2010 Aug 14.
14. Silva Nole L. Caos vehicular es un infarto a diario en el corazón de Lima. *El Comercio* 2010 Aug 14.
15. Peru21. Buscan frenar accidentes en la Colonial. *Peru21* 2010 Sep 6.
16. Sarria Gomí C. Inteligencia a favor del tránsito. *El Comercio* 2010 Dec 2.
17. Moudon A, Lin L, Hurvitz P, Reeves P. Risk of Pedestrian Collision Occurrence: Case Control Study of Collision Locations on State Routes in King County and Seattle, Washington. *Transportation Research Record: Journal of the Transportation Research Board* 2008;2073(-1):25-38.
18. Leden L, Garder P, Johansson C. Safe pedestrian crossings for children and elderly. *Accident Analysis and Prevention* 2006;38(2):289-94.
19. Zegeer CV, Esse CT, Stewart JR, Huang HF, Lagerwey P. Safety analysis of marked versus unmarked crosswalks in 30 cities. *Journal-Institute of Transportation Engineers* 2004;74(1):34-41.
20. Retting RA, Ferguson SA, McCart AT. A Review of Evidence-Based Traffic Engineering Measures Designed to Reduce Pedestrian-Motor Vehicle Crashes. *Am J Public Health* 2003;93(9):1456-63.
21. Robertson HD, Carter EC, Transportation Research Board rmJWDC. The safety, operational, and cost impacts of pedestrian indications at signalized intersections. *Transportation Research Record, No. 959, 1984, p. 1-7* 1984.
22. Zeeger CV, Cynecki MJ, Opiela KS, Transportation Research Board samJWDC. Effect of pedestrian signals and signal timing on pedestrian accidents. *Transportation Research Record, No. 847, 1982, p. 62-72* 1982.
23. Zaidel DM, Hocherman I. Safety of pedestrian crossings at signalized intersections. *Transportation Research Record* 1987;1141:1-6.
24. Chadda HS, Schonfeld PM. ARE PEDESTRIANS SAFE AT RIGHT-TURN-ON-RED INTERSECTIONS? *Journal of Transportation Engineering-Asce* 1984;111(1):1-16.

25. Zeeger CV, Cynecki MJ, Opiela KS. Evaluation of innovative pedestrian signalization alternatives. *Transportation Research Record* 1984;959:7-18.
26. Zeeger CV. *Design and Safety of Pedestrian Facilities*. Washington, DC: Institute of Transportation Engineers, 1998.
27. National Committee on Uniform Traffic Control Devices. *The Manual on Uniform Traffic Control Devices (MUTCD)*. 2009 ed. Washington, DC: Federal Highway Administration, 2009.
28. Thompson LL, Rivara FP, Ayyagari RC, Ebel BE. Impact of Social and Technological Distraction on Pedestrian Crossing Behavior: An Observational Study. *under review* 2012.
29. Mitman MF, Ragland DR, Zeeger CV. Marked-Crosswalk Dilemma Uncovering Some Missing Links in a 35-Year Debate. *Transportation Research Record* 2008(2073):86-93.
30. Nasar J, Hecht P, Wener R. Mobile telephones, distracted. attention, and pedestrian safety. *Accident Analysis and Prevention* 2008;40(1):69-75.
31. Shi J, Chen Y, Ren F, Rong J. Research on Pedestrian Behavior and Traffic Characteristics at Unsignalized Midblock Crosswalk: Case Study in Beijing. *Transportation Research Record: Journal of the Transportation Research Board* 2007;2038(-1):23-33.
32. Lee C, Abdel-Aty M. Comprehensive analysis of vehicle-pedestrian crashes, at intersections in Florida. *Accident Analysis and Prevention* 2005;37(4):775-86.
33. Smith GA, Baum CR, Dowd MD, Durbin DR, Quinlan KP, Sege RD, et al. Policy Statement- Pedestrian Safety. *Pediatrics* 2009;124(2):802-12.
34. Ewing R, Dumbaugh E. The Built Environment and Traffic Safety: A Review of Empirical Evidence. *Journal of Planning Literature* 2009;23(4):347-67.
35. Moudon AV, Lin L, Jiao JF, Hurvitz P, Reeves P. The risk of pedestrian injury and fatality in collisions with motor vehicles, a social ecological study of state routes and city streets in King County, Washington. *Accident Analysis and Prevention* 2011;43(1):11-24.
36. Mutabazi M. Sight obstruction at at-grade pedestrian crossings: A review of the understanding of the meaning of zigzag lines. *Safety Science* 2010;48(3):283-87.
37. Schneider RJ, Ryznar RM, Khattak AJ. An accident waiting to happen: a spatial approach to proactive pedestrian planning. *Accident Analysis and Prevention* 2004;36(2):193-211.
38. Híjar M, Trostle J, Bronfman M. Pedestrian injuries in Mexico: a multi-method approach. *Social Science & Medicine* 2003;57(11):2149-59.
39. Hidalgo-Solorzano E, Campuzano-Rincon J, Rodriguez-Hernandez JM, Chias-Becerril L, Resendiz-Lopez H, Sanchez-Restrepo H, et al. Use and non-use of pedestrian bridges in Mexico City: the pedestrian perspective. *Salud Publica De Mexico* 2010;52(6):502-10.
40. Nakitto MT, Mutto M, Howard A, Lett R. Pedestrian traffic injuries among school children in Kawempe, Uganda. *African Health Sciences* 2008;8(3):156-59.
41. Sarkar S, Tay R, Hunt JD. Logistic Regression Model of Risk of Fatality in Vehicle-Pedestrian Crashes on National Highways in Bangladesh. *Transportation Research Record* 2011(2264):128-37.
42. Khayesi M, Monheim H, Nebe JM. Negotiating "Streets for All" in Urban Transport Planning: The Case for Pedestrians, Cyclists and Street Vendors in Nairobi, Kenya. . *Antipode* 2010;42:103-26.
43. Gómez LF, Parra DC, Buchner D, Brownson RC, Sarmiento OL, Pinzón JD, et al. Built Environment Attributes and Walking Patterns Among the Elderly Population in Bogotá. *American Journal of Preventive Medicine* 2010;38(6):592-99.
44. Li Y, Fernie G. Pedestrian behavior and safety on a two-stage crossing with a center refuge island and the effect of winter weather on pedestrian compliance rate. *Accident Analysis and Prevention* 2010;42(4):1156-63.
45. Tiwari G, Bangdiwala S, Saraswat A, Gaurav S. Survival analysis: Pedestrian risk exposure at signalized intersections. *Transportation Research Part F-Traffic Psychology and Behaviour* 2007;10(2):77-89.
46. Zeeger CV, Bushell M. Pedestrian crash trends and potential countermeasures from around the world. *Accid Anal Prev* 2012;44(1):3-11.
47. Koepsell T, McCloskey L, Wolf M, Moudon AV, Buchner D, Kraus J, et al. Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians. *JAMA* 2002;288(17):2136-43.
48. Richardson D. An incidence density sampling program for nested case-control analyses. *Occup Environ Med* 2004;61:e59.

49. Rodrigues L, Kirkwood B. Case-control designs in the study of common diseases: updates on the demise of the rare disease assumption and the choice of sampling scheme for controls. *Int J Epidemiol* 1990;19:205-13.
50. Rodrigues L, Kirkwood BR. Case-control designs in the study of common diseases - Updates on the demise of the rare disease assumption and the choice of sampling scheme for controls. *International Journal of Epidemiology* 1990;19(1):205-13.
51. Rothman K, Greenland S, Lash T. Case-Control Studies. In: Rothman K, Greenland S, Lash T, editors. *Modern Epidemiology*. 3rd ed. Philadelphia, PA: Lippincotte Williams & Williams, 2008:111-27.
52. Levy PS, Lemeshow S. *Sampling of populations methods and applications*. Hoboken (N.J.), US: J. Wiley, 2008.
53. Khan FM, Jawaid M, Chotani H, Luby S. Pedestrian environment and behavior in Karachi, Pakistan. *Accident Analysis & Prevention* 1999;31:335-39.
54. Hamed MM. Analysis of pedestrians' behavior at pedestrian crossings. *Safety Science* 2001;38(1):63-82.
55. Zegeer CV, Stewart JR, Huang HH, Lagerwey PA, Feaganes J, Campbell BJ. Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations: Final Report and Recommended Guidelines. McLean, VA: FHWA, 2005:114.
56. Rosenbloom T. Crossing at a red light: Behaviour of individuals and groups. *Transportation Research Part F: Traffic Psychology and Behaviour* 2009;12(5):389-94.
57. Siques JT, Trb. Effects of pedestrian treatments on risky pedestrian behavior. *Transit: Intermodal Facilities, Rail Transit, Commuter Rail, Light Rail Transit, Maintenance, and Ferry Transportation - Public Transit*, 2002:62-70.
58. Cambon de Lavalette B, Tijus C, Poitrenaud S, Leproux C, Bergeron J, Thouez J-P. Pedestrian crossing decision-making: A situational and behavioral approach. *Safety Science* 2009;47(9):1248-53.
59. Chu X, Guttenplan M, Baltes MR. Why People Cross Where They Do: The role of the street environment. *Transportation Research Record* 2004;1878:3-10.
60. Cottrill CD, Thakuria PV. Evaluating pedestrian crashes in areas with high low-income or minority populations. *Accident Analysis and Prevention* 2010;42:1718-28.
61. de Lavalette BC, Tijus C, Poitrenaud S, Leproux C, Bergeron J, Thouez JP. Pedestrian crossing decision-making: A situational and behavioral approach. *Safety Science* 2009;47(9):1248-53.
62. Ren G, Zhou Z, Wang W, Zhang Y, Wang W. Crossing Behaviors of Pedestrians at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board* 2011;2264(-1):65-73.
63. Schattler KL, Wakim JG, Datta TK, McAvoy D. Evaluation of pedestrian and driver Behaviors at countdown pedestrian signals in Peoria, Illinois. *Transportation Research Record* 2007(2002):98-106.
64. Zhou RG, Horrey WJ. Predicting adolescent pedestrians' behavioral intentions to follow the masses in risky crossing situations. *Transportation Research Part F-Traffic Psychology and Behaviour* 2010;13(3):153-63.
65. UNCTAD. Information Economy Report: Trends and Outlook in turbulent times: United Nations Commission on Trade and Development, 2009:153.
66. Organismo Supervisor de Inversión Privada en Telecomunicaciones (OSIPTEL). Indicadores del Servicio Móvil. Lima, Peru, 2012.
67. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Mejoramiento de la calidad de la base de datos de los accidentes de tránsito en el Área Metropolitana de Lima y Callao. Lima, Peru: Consejo de Transporte de Lima y Callao, 2011.

FIGURES AND TABLES**Figure 1.** Road geometry of an intersection. Image attribution: © 2012 Google and © 2012 GeoEye.

Figure 2. Flow chart showing the selection of cases for study.

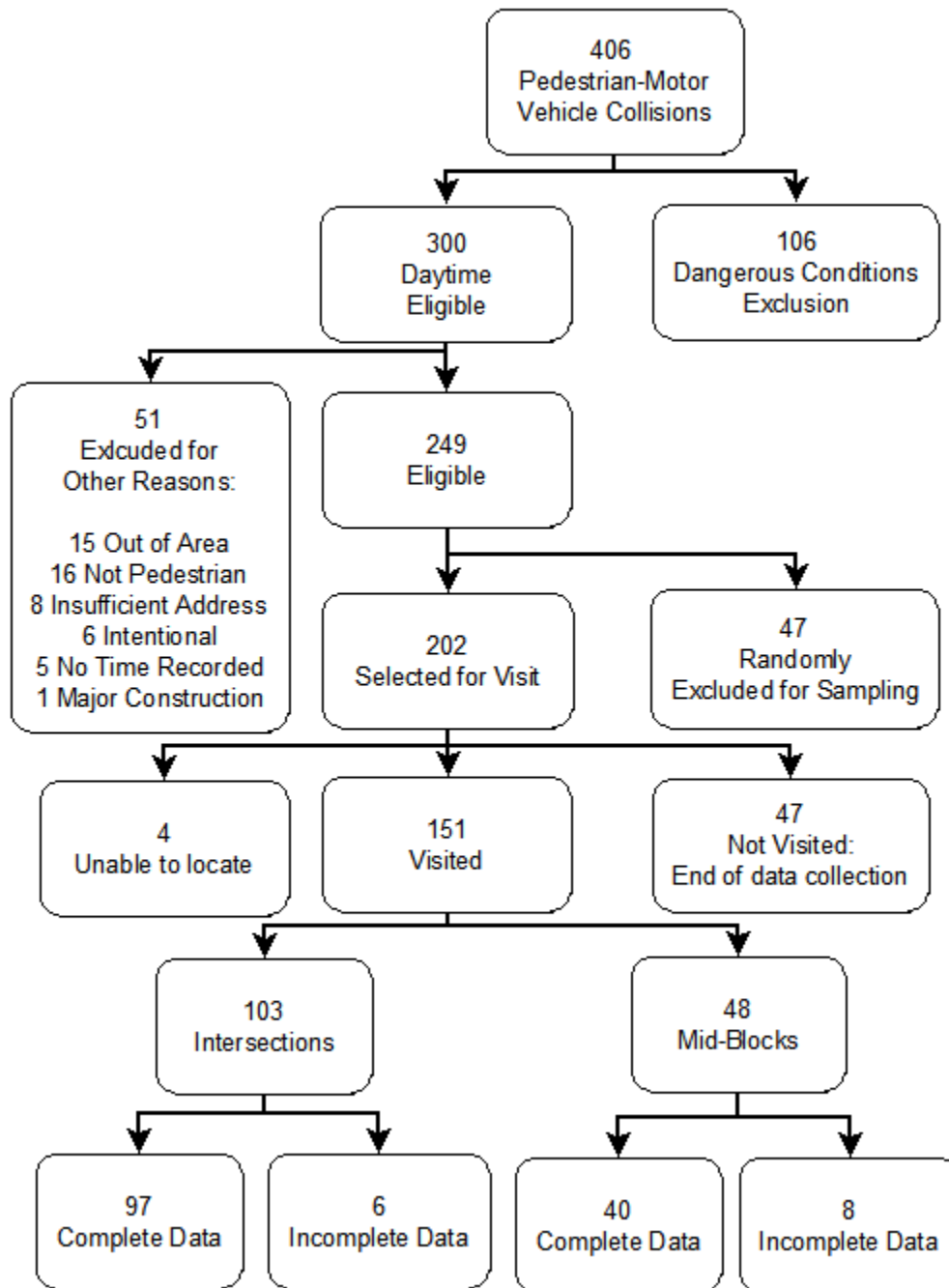


Figure 3. Two types of pedestrian signals found in Lima: a) signal with alternating green- and red-lit with a non-moving figure; b) signal with a regressive countdown and a moving figure.

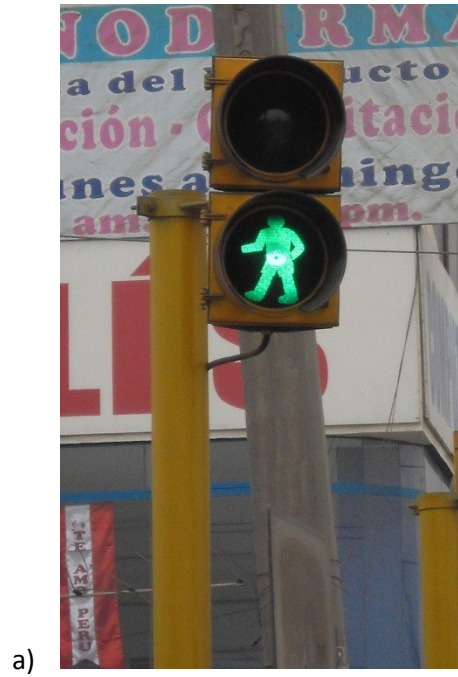


Table 1.1 Characteristics of police reported pedestrian-motor vehicle crashes included for study.^a

	N=97
	%
Road Type	
Arterial	41
Collector	41
Local	11
Non-Connecting	1
Highway	5
Pedestrian Sex Male	53
Index Driver Sex	
Male	91
Female	4
Missing	5
Index Pedestrian Age	
<10 Years	6%
10-18 years	7%
19-65 years	56%
66-95 years	17%
Missing	11%
Index Driver Age	
<26 years	13%
26-60 years	73%
61-78 years	5%
Missing	9%

Table 1.1 (cont.)

	N=97
	N (%)
Type of Vehicle	
<i>Passenger Vehicles</i>	65%
2- or 4-door sedan	33%
Light Truck/Sport Utility Vehicle	13%
Station Wagon	17%
Compact ^c	2%
<i>2- or 3- Wheeled Motorcycles</i>	20%
Motorcycle	11%
Motorcycle taxi ^d	9%
<i>Public Transit Vehicles</i>	15%
Full-size bus (Omnibus)	9%
Minibus (Coaster)	2%
Van-Converted Minibus (Combi)	4%
<i>Missing</i>	1%
Weekday Occurrence	85%

^aVisited cases were selected according the criteria described in the Methods.

^bThese cases were missing road type because the names given in the police record could not be found in any of the geographical sources used.

^cMost of these compacts were Daewoo model "Tico." They are almost exclusively used by taxi companies throughout Peru.

^dA motorcycle taxi is a three-wheeled, motorized cabin cycle, also known as an auto rickshaw, mototaxi or motocar, used in low-income areas of Lima and in many cities throughout Peru as a lower cost alternative to regular taxi passenger vehicles.

^eA motorized tricycle in Peru is a vehicle with a small trailer bed on two wheels on the front of the vehicle attached to a motor bike engine and seat on the end. It is typically used for small cargo transport.

Table 1.2. Characteristics of the intersection and index crossing for cases and controls, unweighted and weighted.

	Unweighted		P	Weighted		P
	Cases	Controls		Cases	Controls	
	N=97 N (%)	N=97 N (%)		N=1134 %	N=1134 %	
No. of Legs			0.170			0.014
3	32 (33)	27 (28)		39	29	
4	65 (67)	68 (70)		61	70	
5	0 (0)	2 (2)		0	1	
No. of Segments			0.385			0.366
1	30 (31)	27 (28)		32	29	
2	52 (54)	55 (57)		58	62	
3	8 (8)	7 (7)		8	7	
4	7 (7)	8 (8)		2	3	
No. of lanes, Mean (SD)	4.4 (2.1)	4.5 (2.0)	0.550	4.2 (2.0)	4.4 (1.9)	0.322
Crossing Distance (m), Mean (SD)	21.2 (13.4)	20.9 (13.3)	0.756	17.9 (10.0)	18.8 (10.7)	0.520
Any refuge			0.327			0.577
No	32 (33)	29 (30)		40	44	
Yes	65 (67)	68 (70)		59	56	
Refuge Width (m), Mean (SD)	8.3 (7.7)	8.5 (7.3)	0.380	5.2 (4.5)	5.7 (5.2)	0.680

Table 1.2 (cont.)

	Unweighted		P	Weighted		P
	Cases N=97 N (%)	Controls N=97 N (%)		Cases N=1134 %	Controls N=1134 %	
Surface Material			0.484			0.448
Asphalt	92 (95)	90 (93)		88	87	
Concrete or Brick	5 (5)	7 (7)		12	1	
Surface Condition			0.913			0.645
Excellent	4 (4)	8 (8)		10	14	
Good	52 (54)	48 (49)		47	44	
Fair	31 (32)	28 (29)		33	33	
Poor	10 (10)	13 (13)		10	9	
Marked Crosswalk			0.339			0.073
No	38 (39)	43 (44)		34	41	
Yes	59 (61)	54 (56)		65	59	

Table 1.2 (cont.)

	Unweighted		P	Weighted		P
	Cases	Controls		Cases	Controls	
	N=97 N (%)	N=97 N (%)		N=1134 %	N=1134 %	
Crosswalk Marking Visibility			0.567			0.303
Unmarked	38 (39)	43 (44)		35	41	
Good Visibility	23 (24)	20 (21)		20	21	
Fading	22 (23)	20 (21)		25	19	
Almost Gone	14 (14)	14 (14)		20	18	
Vehicles per hour, Mean (SD)	1715 (967)	1553 (1001)	0.053	1677 (951)	1429 (868)	0.114
Pedestrians per hour, Mean (SD)	436 (505)	305 (404)	0.007	360 (396)	285 (378)	0.331
Mean Speed (KPH), Mean (SD)	33.7 (6.1)	34 (6)	0.442	31.9 (5.8)	33.8 (5.7)	0.230
Max Speed (KPH), Mean (SD)	55.9 (28.2)	54.4 (10.2)	0.625	50.0 (9.8)	53.3 (9.4)	0.936

Table 1.3. Univariate analysis of pedestrian-motor vehicle risk by signalization characteristics on the index crossing for cases and controls, unweighted and weighted.

	Unweighted		Weighted					
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=97	N=97			N=1134	N=1134		
	N (%)	N (%)			%	%		
Any visible signal								
No	51 (53)	60 (62)	Ref.		53	63	Ref.	0.178
Yes	46 (45)	37 (38)	2.50 (0.97-6.44)		47	37	3.14 (0.54-18.2)	
Traffic Regulation^a								
None	50 (52)	54 (56)	Ref.		48	54	Ref.	
Phased Signal	30 (31)	25 (26)	2.11 (0.71-6.25)	0.180	30	27	1.75 (0.49-6.20)	0.347
Countdown Signal	12 (13)	15 (16)	0.84 (0.28-2.48)	0.748	19	17	1.76 (0.27-11.4)	0.516
Police	2 (2)	3 (3)	0.44 (0.36-5.48)	0.530	2	2	0.72 (0.22-2.33)	0.548
Phased Signal Duration^b								
Green (seconds), <i>Mean (SD)</i>	51.4 (20.0)	45.9 (15.5)	1.02 (0.99-1.06)	0.259	48.9 (16.7)	44.4 (12.9)	1.02 (0.98-1.08)	0.287
Red (Seconds), <i>Mean (SD)</i>	47.8 (28.6)	45.6 (16.8)	1.01 (0.98-1.04)	0.527	47.7 (26.3)	44.1 (15.2)	1.02 (0.96-1.08)	0.544
Any Pedestrian Signal				0.416				0.205
No	61 (63)	65 (67)	Ref.		62	72	Ref.	
Yes	36 (37)	32 (33)	1.40 (0.62-3.15)		38	28	2.51 (0.60-10.5)	

Table 1.3. (cont.)

	Unweighted		OR (95% CI)	P	Weighted		OR (95% CI)	P
	Cases N=97 N (%)	Controls N=97 N (%)			Cases N=1134 %	Controls N=1134 %		
Type of Pedestrian Signal								
None	51 (53)	60 (62)	Ref.		53	63	Ref.	
Stationary Figure	25 (26)	17 (18)	5.80 (1.32-25.6)	0.020	20	11	11.3 (2.86-44.5)	0.003
Countdown & Figure	12 (12)	15 (16)	1.16 (0.39-3.49)	0.789	19	17	1.76 (0.23-13.6)	0.549
Vehicle Signal	7 (7)	3 (3)	4.58 (0.90-23.4)	0.067	6	7	1.86 (0.20-17.3)	0.549
Transit Police	2 (2)	2 (2)	1.08 (0.06-18.2)	0.959	2	2	1.33 (0.48-3.68)	0.549
Pedestrian Signal Duration^c								
Green (Seconds), <i>Mean (SD)</i>	44.1 (21.8)	39.0 (13.1)	1.21 (1.02-1.44)	0.031	38.4 (20.6)	35.5 (14.5)	1.19 (1.15-1.23)	<0.001
Red (Seconds), <i>Mean (SD)</i>	63.6 (31.3)	57.2 (16.5)	1.02 (0.98-1.06)	0.247	63.2 (27.9)	53.4 (15.3)	1.04 (0.98-1.10)	0.236
Allowed Crossing Rate <3.5 Ft/Sec^f	37 (80)	28 (70)	4.00 (0.45-35.8)	0.215	94	73	9.14 (0.46-182)	0.127

^aStop signs or markings were excluded due to only being present at 2 cases and no controls.

^bN=29 unweighted matched pairs & 205 weighted matched pairs where both case and control have phased vehicle signals

^aN=21 unweighted matched pairs, N=115 weighted matched pairs where both case and control have pedestrian signals

^dThe allowed crossing rate is how fast a pedestrian must cross the total crossing distance in the allowed green signal time for pedestrians in feet per second

^eN=31 unweighted matched pairs & N=208 weighted matched pairs where both case and control have any phased signal

^fThe rate recommended by the 2009 MUTCD

Table 1.4. Multivariable analysis evaluating the association of signalization characteristics with case-control status.

	Unweighted		Weighted	
	OR (95% CI)	P	OR (95% CI)	P
Any Visible Signal^a	2.89 (0.76-10.96)	0.119	3.67 (0.34-39.7)	0.252
Traffic Regulation^b				
None	Ref		Ref	
Phased Signal	1.50 (0.43-5.23)	0.522	1.71 (0.43-6.74)	0.407
Countdown Signal	0.73 (0.20-2.64)	0.636	1.51 (0.14-16.8)	0.711
Police	0.05 (0.002-1.26)	0.069	0.05 (0.004-0.60)	0.023
Phased Signal Duration				
Green (Seconds) ^c	1.04 (0.99-1.09)	0.107	1.07 (0.98-1.17)	0.100
Red (Seconds) ^c	1.00 (0.97-1.04)	0.871	1.00 (0.93-1.08)	0.990
Any Pedestrian Signal^d	1.11 (0.44-2.78)	0.825	2.26 (0.38-13.3)	0.330
Type of Pedestrian Signal^d				
No Signalization	Ref.		Ref.	
Stationary Figure	5.55 (0.95-32.3)	0.056	8.88 (1.32-59.6)	0.029
Countdown & Figure	0.73 (0.21-2.50)	0.613	1.53 (0.09-27.0)	0.748
Vehicle Signal	5.51 (0.83-36.6)	0.077	2.52 (0.22-29.2)	0.419
Transit Police	0.12 (0.004-3.62)	0.221	0.09 (0.01-1.02)	0.052
Pedestrian Signal Duration				
Green (Seconds) ^c	1.30 (1.02-1.67)	0.035	1.42 (1.07-1.90)	0.024
Red (Seconds) ^c	1.26 (0.96-1.66)	0.099	1.74 (0.56-5.40)	0.267
Crossing Rate<3.5 Ft/Sec^e	5.09 (0.36-71.9)	0.229	8.28 (0.02-3786)	0.449

^aAdjusted for Total Width, Vehicles per Hour, Pedestrians per Hour, Marked Crosswalk, Mean Vehicle Speed and Number of Segments

^bAdjusted for Total Width, Vehicles per Hour, Pedestrians per Hour, Mean Vehicle Speed and Number of Segments

^cAdjusted for Total Width, Vehicles per Hour, Pedestrians per Hour, and Mean Vehicle Speed

^dAdjusted for Total Width, Vehicles per Hour, Pedestrians per Hour, and Number of Segments

^e Adjusted for Vehicles per Hour, Pedestrians per Hour, and Mean Vehicle Speed

Chapter 2: Public Transit Stops and Pedestrian-Motor Vehicle Collisions

INTRODUCTION

Pedestrian-motor vehicle collisions (PMVCs) were the largest contributor to traffic fatalities in Peru in 2008 at 78% of traffic fatalities and were a major contributor to injuries at 38% of traffic injuries.¹ The majority of PMVCs in Peru occur in the capital city of Lima. The public transportation system could be an important contributing factor to this public health issue in Lima and possibly in other low- and middle-income countries.^{1,2} Bus and foot traffic are the primary modes of transport in Lima where more than half the 12 million daily trips taken in Lima occur on public transit vehicles (excluding paratransit services such as taxis) and an additional 25% occur on foot.¹ Because public transit has mostly been operated by the private sector in Lima, there is a highly competitive atmosphere between bus operators and companies to get passengers. This competitiveness may endanger pedestrians because of the driving behaviors of the operators, and may be further aggravated by how these drivers use some of the design features of bus stops in Lima.

Bus transit is usually economical, can reduce traffic congestion, and promotes walking, but it also subjects pedestrians to potential conflict with motor vehicle traffic. Public transit stops are major pedestrian volume generators and thus the frequency of PMVCs will likely be higher in their vicinity.³ Even accounting for pedestrian volumes, however, there may be excess risk for a PMVC at transit stops.⁴ This may be due to bus stop design, reduced pedestrian visibility due to transit vehicles, risky bus driver behaviors, and risky pedestrian behaviors to board or alight a bus at transit stops.³⁻¹¹

The objective of this study was to evaluate the relationship between pedestrian-motor vehicle collisions and the built environmental features of the bus transit system in Lima, Peru. This was accomplished by assessing the risk of a pedestrian-motor vehicle collision in relation to the presence of transit stops and various features of these stops.

METHODS

Design: We used a matched case-control design. Similar to a US study conducted by Koepsell *et al* the unit of analysis was a pedestrian crossing area at an intersection or a mid-block.¹² Study methods are described in greater detail in a previous publication [CH1]. Each case was a pedestrian crossing area where there had been a police reported a pedestrian-motor vehicle collision. Each control was a pedestrian crossing area in the same neighborhood as the case area where no police-reported pedestrian-motor vehicle collision had occurred during the same 24-hour period.

Setting. We limited the study to the jurisdiction of 11 police commissaries. Cases occurred October 1, 2010 through January, 2011. Site and observational data were collected from February 2011 to September 2011.

Context: Public transit in Lima is operated by the private sector with the exception of the Metropolitano bus rapid transit line run by the Metropolitan Municipality of Lima (MML). Public transit in Lima has a long history of operating independent of government regulation. In 1991, the national government ceded oversight of public transit to the private sector. Bielich has described in detail how this law has led to the current public transit situation in Lima.¹³ Essentially, this law legalized any operator of a vehicle with more than two wheels to offer public transportation whether as a bus or taxi service. In 1999 the municipal government of Lima began requiring all bus companies to propose and apply for desired routes. It also imposed requirements meant to improve safety include requiring drivers to use only official transit stops, driving a reasonable speed, using only the right lane except to pass vehicles, and limiting the number of passengers allowed by vehicle size. In 2008 there were 322 independent transportation companies operating nearly 30,000 buses on 424 privately owned bus routes.¹⁴ Many of these routes are very similar but have slightly different starting and end points to distinguish themselves. Further complicating the system, while transport companies owned the rights to use the routes they usually leased their use to independent bus owners who then hired drivers and fare collectors to run the bus.¹⁵ The pay for drivers and fare collectors is typically linked to meeting route checkpoints and the number of passenger fares collected, though variations of this model are common. This mostly privatized public

transit system created a highly competitive atmosphere, even within the same company, as drivers compete for the same passengers at each transit stop on major arterial roads.¹³

Study Population. We selected study cases using two-stage cluster sampling. In the first stage we randomly sampled police commissaries. The probability of selection was proportional to the number of PMVCs they reported in 2006.^{1 16} In the second stage we took a simple random sample of 80% of PMVCs reported within a commissary during the study time period. Before sampling PMVCs at the second stage we excluded cases where the injured person was not a pedestrian (e.g. a cyclist), the pedestrian was not struck within the roadway (e.g., on the sidewalk), the PMVC occurred outside the jurisdiction of the commissary, information on the location was incomplete, the time of the incident was not recorded, or the collision was deemed intentional. Sites in areas with high criminal activity and incidents that occurred from 8 PM to 6 AM were excluded due to the safety risks for study staff.

For each case, one matched control was randomly selected from a risk set of potential matched controls.^{12 17-19} Controls were matched to cases based on road type, number of lanes, and the type of second road intersecting the primary road if the case occurred at an intersection or the types of the roads intersecting the primary road at both ends if the case occurred at a mid-block. Risk sets were created by first identifying the geographic location and area of the case. Proximity to the case site was defined as an area within a 500 meter radius from the site. If there was not at least one potential match within this area, the radius was expanded by another 100 meters until at least one suitable match was found. Using this strategy we were able to identify at least one suitable control for every case within a maximum of a 1000 meter radius.

Data Collection. Cases were first identified at the selected commissaries. We had an agreement with the police leadership of the Lima region of the Policía Nacional del Perú to access records. We visited sites that occurred on weekdays on any weekday and similarly for weekends. The timing of a visit was within an hour of the time of the incident recorded by the police for each case and its matched control. The index crossing and leg (a leg is a radiating road from an intersection or a mid-block crossing, Figure 1) corresponded to the area where the police indicated the incident had occurred for cases and a similar location within the matched control site was selected. We video recorded 10 minutes of vehicle and

pedestrian flow, photographed the site, and recorded vehicle speeds for 10 minutes or until at least 25 vehicles were recorded using a portable speed gun. Physical characteristics of the road were recorded, measured and sketched. Field workers were blinded to whether a site was a case or control. Videos of the pedestrian and vehicle flows were coded for the total number of vehicles passing through the index crossing and the number of pedestrians using the index crossing area during the 10 minute recorded period.

Data Elements. The primary outcome was the presence of a pedestrian-motor vehicle collision reported to the police. The primary exposures examined in this analysis were the presence of any type of a bus stop, the type of bus stop (authorized or unauthorized, Figure 4), whether there were any bus-dedicated traffic lanes (Figures 5 and 6), the presence of a painted stop area for buses (Figure 7), the presence of a bus bay area for boarding and alighting passengers (Figure 8), and whether there was a route checker (*datero*) present. Authorized bus stops are stops marked with a sign that has been placed there by the city (Figure 4). Unauthorized stops are where we observed buses picking up or dropping off passengers where there was no municipal sign present. The route checker informs bus drivers about antecedent bus activity on his route and how long ago the last competitor passed. The route checker may also report on the presence of transit police nearby.

We also collected data on important variables (pedestrian and vehicle flow) and potential confounders including mean vehicle speed, presence of crosswalk markings, crosswalk marking condition, number of crossing segments (road subdivisions created by pedestrian refuges, median barriers, median dividers, or other physical structures separating lanes of vehicular traffic, Figure 1), number of radiating roads, vehicle signalization and crossing distance. It is important to note that pedestrian flow may be both a confounder and a mediator in terms of the relationship between bus stops and the risk of a PMVC. Bus stops will attract pedestrians whether they are safe or unsafe for pedestrians. Since eliminating bus stops is not a viable or desirable option, we are more interested in design features that make a bus stop safe or unsafe. For this reason we attempted to control for pedestrian flow as a confounder in order to understand the effect of bus stops on pedestrian safety beyond their ability to affect pedestrian flow.

Data Analysis. Conditional logistic regression to account for case-control matching was used to calculate odds ratios (OR), 95% confidence intervals (CIs) and P-values. We examined the association between risk of a police-reported PMVC and the site characteristics related to bus transport. The OR is a reasonable estimate of the relative risk because PMVCs are rare events in terms of how many pedestrians and vehicles use a road. Confounding was assessed both with *a priori* selected covariates and on the basis of univariate association with case status and the primary exposure. Multivariable models were built to evaluate confounders using the goodness-of-fit of each model and through comparison of likelihood ratios. Fractional polynomial models were evaluated for the continuous covariates including vehicle and pedestrian flow, total crossing width, and mean vehicle speed for best fit and accuracy. A single linear term for each of these variables was determined to provide the best fit and representation in the models. We evaluated whether to present combined estimates from both intersection and mid-block sites by testing the significance of an interaction term between an exposure of interest and whether a site was a mid-block or intersection. We found intersection risk estimates significantly differed from mid-block sites, thus we present their results separately.

All analyses were performed with Stata 11 (STATA Corp, College Station, TX, USA). We accounted for survey weights and cluster sampling using the SURVEY package in Stata. Weights (w_{ic}) for each unit sampled and collected were calculated with the equation $w_{ic} = \frac{N_c}{m\bar{n}\pi'_c}$, where the weight for each observation was the inverse of its overall probability of selection for study.²⁰ The inverse probability of selection for each unit was reached by dividing the number of enumeration units in a commissary (N_c) by the number of clusters selected (m) times the number of units sampled within a cluster (\bar{n}) times the probability (π'_c) of an enumeration unit (X_i) being selected from within the total population (X) being sampled ($\pi'_c = \frac{X_i}{X}$).

The study protocol was approved by the University of Washington and Universidad Peruana Cayetano Heredia institutional review boards.

RESULTS

There were 97 intersection and 40 mid-block cases with complete data representing 1134 pedestrian-motor vehicle crashes at intersections and 469 at mid-blocks throughout metropolitan Lima. Eight additional sites lacked video data due to a camera being stolen and a flash card being lost and were excluded from analysis since we lacked pedestrian and vehicle flow measures. There was no evidence of difference between cases and controls for most road characteristics (Table 2.1). For mid-block sites, controls were slightly more likely to have a pedestrian refuge present and if there was a refuge it was wider than at case sites. The mean speed at mid-block control sites was significantly higher than case sites when accounting for survey weights (34.6 KPH vs. 32.7 KPH, P-value=0.020).

At intersection sites, cases and controls differed by most of the bus stop characteristics collected (Table 2.2). Cases were more likely to have any type of bus stop present (80% vs. 66%, weighted) and to have unauthorized stops (43% vs. 30%, weighted). Cases and controls had similar proportions of bus stops on bus-dedicated lanes (13% and 14%, weighted). Case sites were also more likely to have a painted bus stop area (18%) and to have a bus bay (8%). Controls had double the proportion of (17%) route checkers than cases (8%). At mid-block sites cases and controls were homogenous on most transit characteristics, though cases had more unauthorized stops than controls.

We found that having any type of bus stop present (authorized or unauthorized) at intersections was significantly associated with a PMVC (OR 3.28, 95% CI 1.53-7.03) when adjusting for pedestrian and vehicle flow, mean vehicle speed and total crossing width (Table 2.3). When examining the type of stop, this significant relationship persisted with pedestrians three times as likely to be hit at sites with an unauthorized bus stop (95% CI 1.37-6.49) and over six times more likely at authorized stops (95% CI 1.76-22.0) compared to sites with no stops, though there was no statistically significant difference between these two subgroups (P-value=0.276). While a bus stop with bus lanes had a slightly lower occurrence of a PMVC, bus stops not on bus lanes were four times (95% CI 1.94-8.26) as likely to have a PMVC compared to a site with no bus stop. Bus stops with bus lanes were statistically different from those without lanes (P-value=0.004). Bus stops with a painted bus stop area or a bus bay were both significantly associated with case status, though the confidence intervals were quite wide for both. While a bus stop with a route checker had a slightly elevated occurrence of a PMVC, bus stops with no route

checker were nearly three times as likely to have a PMVC than sites with no bus stop present (OR 2.73, 95% CI 1.22-6.13).

In general we observed that bus stops at mid-blocks were less likely to have a PMVC than sites with no bus stop present when adjusting for confounding, although the confidence limits were quite wide and include 1.0 (Table 2.3). This lower occurrence of PMVCs for bus stop sites at mid-blocks persisted when examining them by authorized and unauthorized sites, but there was not a statistical difference between them and sites with no bus stops. Sites with bus lanes present where there was a bus stop were 2.36 (95% CI 1.02-5.42) times more likely to have a PMVC than sites with no bus stop. When we examined bus stops with painted or no painted stop area for buses we found that PMVCs were 73% less likely (95% CI 0.08-0.97) compared to sites with no bus stops. Bus stops with a bus bay were also significantly less likely to have a PMVC compared to sites with no bus stop (OR 0.16, 95% CI 0.03-0.96).

DISCUSSION

Painted bus stop areas and bus pullout areas appeared to be associated with the occurrence of PMVCs, though this seemed to only be the case at intersection sites. Buses provide the main form of transportation in Lima and are heavily utilized. Bus transit is generally economical, improves traffic congestion, and promotes walking; however the public transit system also places walkers in close contact with vehicle traffic. While the importance of a well-functioning public transportation system is critical to urban and economic health, the interaction between fixed bus structures, commuting congestion and financial incentives may add unnecessary risk for walkers.

A few studies that have examined bus stops in both high-income and low- and middle-income settings lend some support our findings that the presence of a bus stop at intersections can be associated with conditions that may lead to pedestrian-motor vehicle collisions,^{9-11 21-24} though other studies have indicated that there are ways to improve the safety of bus stops to reduce the risk of PMVCs.^{25 26} Our results suggest that the behavior of bus drivers jockeying for passengers near bus stops may put pedestrians at risk.^{1 13} Bus drivers in Peru appear to be under immense pressure to complete their routes quickly, pick up as many passengers as possible, and to work long hours with few and short rest periods.

In order to quickly move to the next group of potential stop/passengers, they often do not stop near or completely at the curb and may sometimes force passengers to disembark or alight in traffic if a competing bus is nearby. They may also not completely stop when taking on or letting off passengers. To prevent competitors from overtaking them and reaching potential customers first, bus drivers commonly employ tactics such as blocking traffic by angling the vehicle across lanes. They may also wait at a phased signal until the amber phase and then rush through the intersection so that competitors are trapped at a red light. This tactic has been aided by the addition of phased countdown signals on several arterial roads implemented in 2009 and 2010.

Both painted stop areas and bus bays play an important role in how bus drivers act at bus stops where these features are present. Both painted areas and bays usually precede the intersection by two to three meters. While the Municipality requires to bus drivers to use these areas when present, they may be less inclined to use these areas as designed because there is enough space between the feature and intersection to allow competitors to engage in the tactics described above. These behaviors may explain, at least in part, why they are so strongly associated with the occurrence of PMVCs.

There were different findings between the mid-block bus stops and those at the intersections. At mid-blocks, tactics used by bus drivers at intersections may not be as beneficial or other tactics may be used to get passengers and beat the completion that do not have the same effect on pedestrian safety. While our sample size was small for mid-block sites, we did find that bus stops without painted stop areas at mid-blocks appear to be inversely associated with PMVCs and bus stops with bus bays at mid-blocks exhibited a similar association, even when adjusting for pedestrian and vehicle volumes. It is important to consider that in the US the Federal Highway Administration recommends bus bays for roads with speed limits over 40 MPH, vehicle volume over 250 vehicles per peak hour, high bus volumes, high transit rider volumes, and other road features.⁶ We did not explore whether the roads with bus bays in our study met these criteria, though they were exclusively on arterial roads whose speed limits were 45 KPH or less typically. It may be that bus bays on mid-blocks better met these suggested characteristics, while those at intersections did not and thus they are not serving their purpose of improving traffic flow on arterial roads. It is also possible also that they are not sufficiently long enough to handle the volume of bus traffic

at the stop. It was not uncommon at busy bus stops at intersections for as many as 10-15 buses to be present at the same time.

The discordant findings between intersections and mid-blocks could relate to the positioning of the bus stop relative to the intersection. At intersections, bus stops in Lima are nearly always located proximally (on the near-side of the intersection) in the direction of traffic rather than on the far-side. Mid-blocks stops may receive the benefit of increased pedestrian visibility because bus stops are on the far-side of an intersection in the direction of traffic.^{6, 27-29} This configuration may reduce conflicts between turning traffic and transit vehicles and increase the visibility of pedestrians when crossing behind the bus. Almost all authorized formal bus stops except two were placed on the near-side of intersections, thus we could not evaluate the benefit of such placement in our study. Those with only signs would be fairly easy to change from a near-side to a far-side if merited.

Bus-dedicated lanes are meant to enhance traffic flow and lessen non-transit vehicle conflicts with public transit.³ The effect of transit-dedicated lanes on pedestrian safety is unknown though they improve motor vehicle flow.^{28, 30-32} In this study, this feature could not be examined fully due to a small number of sites with any transit-dedicated lanes. Bus lanes may have offered some benefit to pedestrians at intersections, but were associated with PMVCs at mid-block sites. The latter finding could be due to unsafe crossing conditions at mid-block sites where bus lanes were present. The crossing distance is much larger when bus lanes are present, and pedestrians may be more exposed to vehicle traffic, especially if there is no traffic control in place. It should also be noted that there appeared to be an association between bus stops at intersections without any bus lanes and the occurrence of PMVCs. These findings provide a mixed picture for the role of bus lanes and pedestrian safety that suggest more detailed research of these structures is needed to understand how to improve their safety.

While we did not study pedestrian behaviors in this study, it is possible that risk-taking behaviors could be part of the reason that bus stops were associated with PMVCs. Pedestrians who use public transit in Peru are at times complicit with the dangerous behaviors of bus drivers by demanding to be dropped off or picked up at non-sanctioned stop areas. These stops are often brief and not completely at the curb because bus drivers are less likely to find passengers to pick up when making an unauthorized stop.

Pedestrians may also have put themselves at risk by crossing the road against a phased signal to catch a bus, crossing unsafely between stopped vehicles or trying to get on or off a bus as it is beginning to pull away from a stop. This last behavior can be aggravated by buses that are carrying too many passengers which can make it difficult to get to the door to disembark in time or to fully enter the bus before it starts moving, even though bus drivers can be heavily fined for not fully stopping.

Traffic enforcement of existing public transport regulations may be one method of reducing PMVCs at bus stops. Recently the municipal government has placed municipal inspectors on some sections of a few busy arterial roads to enforce the use of authorized bus stops and to enforce municipal laws regarding public transport. While the primary goal of these inspectors is to improve vehicle flow, they may also contribute to pedestrian safety. A previous analysis of our data on pedestrian signalization indicated that the presence of transit police controlling vehicle traffic was inversely related to the occurrence of PMVCs, though there were only a few sites where police were present. Further research on the role of police presence and enforcement may confirm these potential benefits for pedestrian safety.

An important limitation to this study may be the role of pedestrian volume in relationship to bus stops. As mentioned earlier, bus stops are pedestrian generators. We decided to adjust for pedestrian volume in order to better understand the relationship between bus stops and PMVCs on their own. Our strategy may not have fully controlled for the role of pedestrian volume in relationship to PMVCs, thus some of the results we observed could be due to residual confounding. If there still were uncontrolled confounding from pedestrian volume, then the effect sizes obtained may be biased upward because of the likely positive association between it and the outcome. Similarly for vehicle volume, bus stops also generate vehicle traffic in the form of buses but for the same reasons we were constrained to only recording total vehicle volume rather than a more detailed coding of the number of different types of vehicle traffic.

There are also some limitations to the bus stop characteristics we examined. For unauthorized bus stops, if signs authorizing bus stops were absent and we observed buses boarding or alighting passengers then we coded the site as having an unauthorized site. It is possible that such authorized activity was not occurring at the time of the incident or was a regular occurrence at the site, thus the findings could be spurious if the site does not regularly have unauthorized stops. Because such stops are

common in most parts of Lima,^{13 15} however, it is possibly a safe assumption that these sites regularly have unauthorized bus stops. Related to this issue is that since we only briefly observed sites, we may have coded sites as “No Bus Stop” that may have regular unauthorized stops that happened to occur outside our observation time. This could affect the associations we observed, and could either attenuate or strengthen the association between unauthorized stops and PMVCs. The route checker coding may also be similarly affected since they are an informal part of public transit system, thus may not be present where we observed them or may have been present at other sites outside of our time of observation.¹³

Another limitation is that the source of data on PMVC is police-reported, thus we could only identify a PMVC and not the severity of the collision or outcomes. We also excluded 38% of the police-reported PMVCs, mostly due to safety reasons. We were also limited by the amount of time we were able to collect vehicle and pedestrian flow. A longer observation time than 10 minutes may have been needed in order to have appropriately adjusted for these important covariates, thus some of the elevated risk observed could be due to residual confounding. These same data are also limited because they may not necessarily represent the exact conditions under which the PMVC took place. Finally, there were as many as 10 months between the date of an incident and the date of a site visit. Google Earth archival satellite imagery was used to assess observable changes in 10% of the sites. No sites appeared to exhibit major changes (such as new bus bays or painted bus stop areas), though many of them had fainter paint markings than earlier images and a few had newer (not different) paint markings than the satellite image.

In conclusion, certain features of bus stops may play a role in putting pedestrians at risk for a PMVC. Future studies should examine how pedestrians and buses interact at bus stops in the presence and absence of these features. If these features are truly harmful then designs that reduce or prevent these behaviors may need to be developed. Increased risk may result from the interaction between design features and behavioral incentives which favor competitive jockeying for passengers and rapid disembarkation over rider and pedestrian safety. While the nature of public transit in Lima is unique, other studies have reported similar behaviors by both bus drivers and pedestrians, thus these findings may be useful for providing direction for future research in these settings.^{9 10 33-36}

A well-functioning public transportation network is crucial to economic health, active living, and environmental sustainability.³⁷⁻⁴³ Many wealthier nations aspire to improve the saturation of public transportation already operating in cities like Lima, where 52% utilize the bus system.¹ Nonetheless, the results of this study and others may point to opportunities to improve pedestrian safety and efficiency while interacting with the public transportation system. . Having access to public transport is very important to road users in low- and middle-income countries, as well as feeling safe while using roadways and accessing transportation.⁴⁴ In order to have both efficient and safe public transport in settings such as Peru innovative approaches are needed to increase regulation and enforcement of practices that will maintain the safety of public transit users while balancing and maintaining equitable transportation solutions for all.³⁷

REFERENCES

1. Secretaría Técnica del Consejo de Transporte de Lima y Callao. La Vulnerabilidad de los Peatones en la Vialidad del Área Metropolitana de Lima y Callao. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2009.
2. Forjuoh SN, Li GH. A review of successful transport and home injury interventions to guide developing countries. *Social Science & Medicine* 1996;43(11):1551-60.
3. Zeeger CV. *Design and Safety of Pedestrian Facilities*. Washington, DC: Institute of Transportation Engineers, 1998.
4. Hess PM, Moudon AV, Matlick JM. Pedestrian Safety and Transit Corridors. *Journal of Public Transportation* 2004;7(2):73-93.
5. Berger W. Urban Pedestrian Accident Countermeasures Experimental Evaluation: Volume 1— Behavioral Studies. Washington, DC: US Dept of Transportation, 1975.
6. Fitzpatrick K, Hall K, Perkinson D, Nowlin R, Koppa R. Guidelines for the Location and Design of Bus Stops. Washington, DC: Transportation Research Board, 1996.
7. Campbell BJ, Zeeger CV, Huang HH, Cynecki MJ. A Review of Pedestrian Safety Research in the United States and Abroad. Mclean, VA, USA: Federal Highway Administration 2004.
8. Carney JF, editor. Effective pedestrian safety programs. Effectiveness of highway safety improvements.; 1986; New York, N.Y. ASCE.
9. Nantulya VM, Reich MR. Equity dimensions of road traffic injuries in low- and middle-income countries. *Injury Control & Safety Promotion* 2003;10(1/2):13.
10. Mirza S, Mirza M, Chotani H, Luby S. Risky behavior of bus commuters and bus drivers in Karachi, Pakistan. *Accident Analysis & Prevention* 1999;31(4):329-33.
11. Brenac T, Clabaux N. The indirect involvement of buses in traffic accident processes. *Safety Science* 2005;43(10):835-43.
12. Koepsell T, McCloskey L, Wolf M, Moudon AV, Buchner D, Kraus J, et al. Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians. *JAMA* 2002;288(17):2136-43.
13. Bielich Salazar C. La Guerra del Centavo: Una mirada actual al transporte público en Lima Metropolitana. *Economía*, 49. Lima, Peru: Consorcio de Investigación Económica y Social, Instituto de Estudios Peruanos, 2009.
14. Agencia de Cooperación Internacional de Japón. Estudio de Factibilidad de Transporte Urbano para el Área Metropolitana de Lima y Callao en la República del Perú. Lima, Peru: Consejo de Transportes de Lima y Callao, Ministerio de Transportes y Comunicaciones, Yachiyo Engineering Co., LTD, Chodai Co., LTD,, 2007.
15. Mendoza R, Bielich Salazar C. El transporte en Lima no es un problema técnico sino político. *La Republica* 2011 24 JUL.
16. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Análisis de los Accidentes de Tránsito en el Área Central de Lima y Callao - Información Base del Año 2006. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2008.
17. Richardson D. An incidence density sampling program for nested case-control analyses. *Occup Environ Med* 2004;61:e59.
18. Rodrigues L, Kirkwood BR. Case-control designs in the study of common diseases - Updates on the demise of the rare disease assumption and the choice of sampling scheme for controls. *International Journal of Epidemiology* 1990;19(1):205-13.
19. Rothman K, Greenland S, Lash T. Case-Control Studies. In: Rothman K, Greenland S, Lash T, editors. *Modern Epidemiology*. 3rd ed. Philadelphia, PA: Lippincotte Williams & Williams, 2008:111-27.
20. Levy PS, Lemeshow S. *Sampling of populations methods and applications*. Hoboken (N.J.), US: J. Wiley, 2008.

21. af Wåhlberg AE. Characteristics of low speed accidents with buses in public transport: part II. *Accident Analysis & Prevention* 2004;36(1):63-71.
22. Habyarimana J, Jack W. Heckle and Chide: Results of a randomized road safety intervention in Kenya. Washington, DC: Georgetown University, 2009.
23. Hedelin A, Bunketorp O, Björnstig U. Public transport in metropolitan areas — a danger for unprotected road users. *Safety Science* 2002;40(5):467-77.
24. Weddle M, Bissell R, Shesser R. Perceptions of preventability among acutely injured Hispanic patients. *Journal of Safety Research* 1996;27(3):175-81.
25. Zeeger CV, Seiderman C, Lagerwey P, Cynecki MJ, Ronkin M, Schneider B. Pedestrian Facilities Users Guide - Providing Safety and Mobility. Chapel Hill, NC: Highway Safety Research Center, University of North Carolina, 2002.
26. Harkey DL, Zeeger CV. PEDSAFE: Pedestrian Safety Guide and Countermeasure Selection System. Chapel Hill, NC: Highway Safety Research Center, University of North Carolina, 2004.
27. Shahla F, Shalaby AS, Persaud BN, Hadayeghi A. Analysis of Transit Safety at Signalized Intersections in Toronto, Ontario, Canada. *Transportation Research Record* 2009(2102):108-14.
28. KFH Group Inc. Guidelines for the Design and Placement of Transit Stops for the Washington Metropolitan Area Transit Authority. Washington, DC: Washington Metropolitan Area Transit Authority, 2009.
29. Nabors D, Schneider R, Leven D, Lieberman K, Mitchell C. Pedestrian Safety Guide for Transit Agencies. Washington, DC: Federal Highway Administration Office of Safety, 2008.
30. Kiesling M, Ridgway M. Effective bus-only lanes. *ITE Journal-Institute of Transportation Engineers* 2006;76(7):24-29.
31. Miller MA. Bus Lanes/Bus Rapid Transit Systems on Highways: Review of the Literature: California PATH Program, University of California - Berkeley, 2009.
32. Office of Transportation. Transit Preferential Streets Program: Final Report. Portland, OR: City of Portland, Oregon, 1997.
33. Issever H, Onen L, Sabuncu HH, Altunkaynak O. Personality characteristics, psychological symptoms and anxiety levels of drivers in charge of urban transportation in Istanbul. *Occupational Medicine-Oxford* 2002;52(6):297-303.
34. Jayatilleke AU, Poudel KC, Nakahara S, Dharmaratne SD, Jayatilleke AC, Jimba M. Traffic Rule Violations of Private Bus Drivers and Bus Crashes in Sri Lanka: A Case-Control Study. *Traffic Injury Prevention* 2010;11(3):263-69.
35. Lund J, Aaro LE. Accident prevention. Presentation of a model placing emphasis on human, structural and cultural factors. *Safety Science* 2004;42(4):271-324.
36. Ma M, Yan XP, Huang HL, Abdel-Aty M. Safety of Public Transportation Occupational Drivers Risk Perception, Attitudes, and Driving Behavior. *Transportation Research Record* 2010(2145):72-79.
37. Cervero R, Golub A. Informal transport: A global perspective. *Transport Policy* 2007;14(6):445-57.
38. Zeeger CV, Bushell M. Pedestrian crash trends and potential countermeasures from around the world. *Accid Anal Prev* 2012;44(1):3-11.
39. American Public Health Association. At the Intersection of Public Health and Transportation: Promoting Healthy Transportation Policy. Washington, DC: American Public Health Association, 2009.
40. Jackson RJ. The Impact of the Built Environment on Health: An Emerging Field. *American Journal of Public Health* 2003;93(9):1382-84.
41. Rao M, Prasad S, Adshead F, Tissera H. The built environment and health. *The Lancet*;370(9593):1111-13.
42. Kohl 3rd HW, Craig CL, Lambert EV, Inoue S, Alkandari JR, Leetongin G, et al. The pandemic of physical inactivity: global action for public health. *The Lancet*;380(9838):294-305.

43. Jackson RJ, Kochtitzky C. Creating A Healthy Environment: The Impact of the Built Environment on Public Health. *Sprawl Watch Clearinghouse Monograph Series*. Atlanta, GA: Centers for Disease Control and Prevention, 2001.
44. Villaveces A, Nieto LA, Ortega D, Ríos JF, Medina JJ, Gutiérrez MI, et al. Pedestrians' perceptions of walkability and safety in relation to the built environment in Cali, Colombia, 2009–10. *Injury Prevention* 2012.

FIGURES AND TABLES

Figure 4. Sign indicating an authorized bus stop.



Figure 5. Curb-side or exterior type bus lanes (far right lanes) with private/mixed vehicle traffic in the median lanes.



Figure 6. Median or interior bus-dedicated lanes (left lanes) with private/mixed traffic lanes on the exterior/curb-side (right two lanes).



Figure 7. A bus stop with a painted area designating where buses are authorized to alight and board passengers.



Figure 8. A bus stop with a bus bay or pullout area allowing buses to exit moving traffic to board and alight passengers.



Table 2.1. Descriptive characteristics of intersection and mid-block sites by case or control status, unweighted and weighted proportions.

	Intersection Sites					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=97	N=97		N=1134	N=1134	
%	%		%	%		
No. of Segments			0.385			0.366
1	31	28		32	29	
2	54	57		58	62	
3	8	7		8	7	
4	7	8		2	3	
No. of lanes, Mean (SE)	4.4 (2.1)	4.5 (2.0)	0.550	4.2 (2.0)	4.4 (1.9)	0.322
Crossing Width (Meters), Mean (SD)	21.2 (13.4)	20.9 (13.3)	0.756	17.9 (10.1)	18.8 (10.7)	0.520
Any refuge			0.327			0.577
No	33	30		40	44	
Yes	67	70		59	56	

Table 2.1. (cont.)

	Intersection Sites					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=97	N=97		N=1134	N=1134	
%	%		%	%		
Refuge Width (Meters), Mean (SD)	8.3 (7.7)	8.5 (7.3)	0.380	5.2 (4.5)	5.7 (5.2)	0.680
Surface Material			0.484			0.448
Asphalt	95	93		88	87	
Concrete or Brick	5	7		12	13	
Surface Condition			0.714			0.994
Good	58	58		57	58	
Fair	32	29		33	33	
Poor	10	13		10	9	
Marked Crosswalk			0.339			0.073
No	39	44		35	41	
Yes	61	56		65	59	

Table 2.1. (cont.)

	Intersection Sites					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=97	N=97		N=1134	N=1134	
%	%		%	%		
Crosswalk Marking Visibility			0.567			0.347
Unmarked	39	44		35	41	
Visible	24	21		19	22	
Faded	37	35		46	37	
Vehicles per hour, Mean (SD)	1715 (967)	1553 (1001)	0.053	1677 (951)	1429 (868)	0.114
Pedestrians per hour, Mean (SD)	436 (505)	305 (404)	0.007	360 (396)	285 (378)	0.331
Mean Speed (KPH), Mean (SD)	33.7 (6.1)	34.0 (6.0)	0.442	31.9 (5.8)	33.8 (5.7)	0.230
Max Speed (KPH), Mean (SD)	55.9 (28.2)	54.4 (10.2)	0.082	50.0 (9.8)	53.3 (9.4)	0.936

Table 2.1. (cont.) Mid-block Descriptive Statistics

	Mid-Block Sites					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=40	N=40		N=469	N=469	
%	%		%	%		
No. of Segments			1.000			1.000
1	48	43		32	28	
2	48	50		58	62	
3	3	3		8	7	
4	3	5		2	3	
No. of lanes, Mean (SD)	3.7 (2.0)	3.4 (1.9)	0.446	3.2 (1.8)	3.7 (2.2)	0.488
Crossing Width (Meters), Mean (SD)	16.3 (11.1)	17.0 (12.6)	0.620	14.2 (9.0)	16.9 (12.5)	0.108
Any refuge			N/A			0.085
No	48	43		52	44	
Yes	52	57		48	56	

Table 2.1. (cont.)

	Mid-Block Sites					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=40	N=40		N=469	N=469	
%	%		%	%		
Refuge Width (Meters), Mean (SD)	5.1 (3.6)	6.5 (5.2)	0.526	4.6 (3.2)	6.0 (5.3)	0.085
Surface Material			N/A			N/A
Asphalt	90	85		93	88	
Concrete or Brick	15	10		7	12	
Surface Condition			0.169			0.154
Good	48	65		50	61	
Fair	27	22		35	24	
Poor	15	12		15	15	
Marked Crosswalk			0.341			0.674
No	83	88		83	86	
Yes	17	12		17	14	

Table 2.1. (cont.)

	Mid-Block Sites					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=40	N=40		N=469	N=469	
%	%		%	%		
Crosswalk Marking Visibility			0.461			0.891
Unmarked	83	88		83	86	
Visible	5	2		6	2	
Faded	12	10		12	12	
Vehicles per hour, Mean (SD)	1359 (1050)	1341 (1077)	0.889	1227 (999)	1335 (1034)	0.380
Pedestrians per hour, Mean (SD)	190 (255)	123 (173)	0.140	169 (222)	103 (132)	0.266
Mean Speed (KPH), Mean (SD)	33 (6.6)	35 (8.5)	0.126	32.7 (6.5)	34.6 (8.0)	0.020
Max Speed (KPH), Mean (SD)	51 (12.2)	53 (13)	0.401	50 (12.3)	52 (11.6)	0.179

Table 2.2. Univariate analysis of the relationship between bus stop characteristics and a pedestrian-vehicle motor vehicle collision at intersections and mid-blocks, both unweighted and weighted. All numbers are proportions except where noted.

	Intersection					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=97	N=97		N=1134	N=1134	
	%	%	%	%	%	
Any Type of Bus Stop Present	77	65	0.020	80	66	0.023
Type of Bus Stops Present			0.034			0.088
None	23	35		20	34	
Authorized	39	30		37	36	
Unauthorized	38	35		43	30	
Any Bus Lanes Present	19	20	0.571	14	15	0.213
Type of Bus Lanes Present			1.000			<0.001
None	81	81		86	85	
Interior	16	16		9	9	
Exterior	3	3		5	6	
Any Painted Bus Stop at Intersection	23	14	0.038	18	8	0.033
Painted Bus Area Length (m), Mean, SD	41 (21)	47 (21)	0.934	30 (16)	37 (21)	0.657

Table 2.2. (cont.)

	Intersection					
	Unweighted			Weighted		
	Cases	Controls	P	Cases	Controls	P
	N=97	N=97		N=1134	N=1134	
	%	%	%	%		
Any Bus Bay Area at Intersection	14	8	0.069	8	3	0.385
Bus Bay Area Length (m), Mean, SD	61 (36)	61.(16)	0.264	53 (38)	46 (23)	N/A
Route Checker Present	13	7	0.232	8	17	0.384
	Mid-Block					
	Cases	Controls	P	Cases	Controls	P
	N=469	N=469		N=469	N=469	
	%	%	%	%		
	Any Type of Bus Stop Present	38	35	0.706	44	40
Type of Bus Stops Present			0.472			0.576
None	62	65		56	60	
Authorized	15	20		23	26	
Unauthorized	23	15		21	13	
Any Bus Lanes Present	8	5	0.571	9	8	0.512

Table 2.2. (cont.)

	Mid-Block					
	Cases	Controls	P	Cases	Controls	P
	N=469	N=469		N=469	N=469	
	%	%	%	%		
Type of Bus Lanes Present			1.000			<0.001
None	92	95		91	92	
Interior	5	5		1	8	
Exterior	3	0		8	0	
Any Painted Bus Stop Area Present	8	10	N/A	16	17	N/A
Painted Bus Area Length (m), Mean, SD	37 (38)	33 (19)	0.655	14 (15)	31 (22)	0.55
Any Bus Bay Area at Intersection	5	8	0.451	4	7	0.451
Bus Bay Area Length (m), Mean, SD	55 (13)	37 (9)	N/A	48 (8)	37 (8)	N/A
Route Checker Present	3	0	N/A	4	0	<0.001

Table 2.3. Multivariable analysis of the relationship between bus stop characteristics and a pedestrian-vehicle motor vehicle collision. All bus stops at intersection sites were proximal to the intersection in the direction of vehicle traffic. The P-value is the hypothesis test of no difference between the previous subgroup.

	Intersection		Mid-Block	
	OR (95% CI)	P	OR (95% CI)	P
Any Bus Stop Present	3.28 (1.53-7.03) ^a	0.003	0.15 (0.005-4.21) ^b	0.220
Type of Bus Stop				
None	Ref ^a		Ref ^b	
Unauthorized	2.98 (1.37-6.49)		0.80 (0.06-11.2)	
Authorized	6.23 (1.76-22.0)	0.276	0.22 (0.02-2.03)	0.059
Any Bus Lanes				
No Bus Stop	Ref ^a		Ref ^a	
Any Bus Stop without Bus Lanes	4.00 (1.94-8.26)		0.23 (0.01-6.82)	
Any Bus Stop with Bus Lanes	0.58 (0.23-1.48)	0.004	2.36 (1.02-5.42)	0.143
Bus Stop Painted Area				
No Bus Stop (including unauthorized)	Ref ^c		Ref ^d	
Bus Stop without Painted Area	0.51 (0.06-4.34)		0.27 (0.08-0.97)	
Bus stop with Painted Area	14.6 (1.30-165)	0.065	^e	<0.001

Table 2.3. (cont.)

	Intersection		Mid-Block	
	OR (95% CI)	P	OR (95% CI)	P
Bus Stop Bay/Pullout Area				
No Bus Stop		Ref ^a		Ref ^b
Bus Stop with No Bay	3.30 (0.52-20.8)		0.64 (0.04-11.1)	
Bus Stop with Bay	40.7 (4.70-352)	0.069	0.16 (0.03-0.96)	0.3661
Route Checker				
No Bus Stop		Ref ^a		Ref ^d
Bus Stop with no Route Checker	2.73 (1.22-6.13)		0.95 (0.26-3.45)	
Bus stop with Route Checker	1.61 (0.62-4.19)	0.361	†	<0.001

^aAdjusted for vehicles per hour, pedestrians per hour, mean vehicle speed, and total crossing width of Leg A

^bAdjusted for vehicles per hour, pedestrians per hour, and total crossing width of Leg A

^cAdjusted for vehicles per hour, pedestrians per hour, and mean vehicle speed

^dAdjusted for vehicles per hour and pedestrians per hour

^eTerm was perfectly correlated with control status

^fTerm was perfectly correlated with case status

Chapter 3. The Walking Environment of Pedestrians and Pedestrian-Motor Vehicle Collisions

INTRODUCTION

Pedestrians comprised 78% of Peruvian road fatality deaths in 2007, the highest proportion recorded anywhere in the world.¹ Over 60% of the pedestrian-motor vehicle collisions (PMVCs) reported to the *Policía Nacional del Perú* (National Police of Peru, PNP) in 2010 occurred in the sprawling capital city of Lima. Pedestrians in Lima face a number of potential dangers in the walking environment that expose them to vehicles: high density vehicle traffic, limited walking paths and spaces, ambulatory street vendors blocking access, poor walking surfaces, visibility reduced by vehicle parking reduces, and poorly maintained road markings.^{2 3} A previous study on child pedestrians in Lima found that at least two of these factors, street vendors and poor lane demarcation, were significantly associated with a parent-reported child PMVC.^{4 5}

One approach to pedestrian safety is the modification of the physical environment in which they walk.⁶⁻¹¹ Many potential design modifications (traffic calming, crosswalk signalization, marked crosswalks, stop lines, sidewalks, etc.) have been evaluated in various study designs and have demonstrated some effectiveness at preventing injury and fatalities or at least reducing pedestrian-vehicle conflicts.^{8 9 12-16} With a few notable exceptions,¹⁶⁻²³ nearly all of these studies occurred in high income countries where traffic patterns, law enforcement practices and commuting behaviors can be hugely different from those in low- and middle-income countries (LMICs). One study in Mexico indicated that the effectiveness of engineering interventions deployed there may be somewhat reduced relative to the effectiveness in high income settings due to circumvention and misuse by road users.²²

Traffic engineers in Lima have deployed a number of modifications to the built environment which could potentially decrease the danger to pedestrians, though these modifications vary by district and have not been evaluated. For example, some high-speed, vehicle-dense arterial roads have barricades to prevent pedestrians from crossing except at specific areas. Over 200 pedestrian footbridges are scattered along

the Pan-American Highway that runs through the North-South corridor of Lima. At other sites, speed bumps have been placed near crossing areas to slow down vehicle traffic. Pedestrian crossing signals have been added at some intersections. We previously evaluated the relationship between pedestrian crossing signals and PMVCs and found that, paradoxically, pedestrian signals may be associated with PMVCs.[Ch1] Anecdotally, pedestrians in Lima often ignore such measures, possibly reducing their effectiveness.²

The objective of this exploratory study was to evaluate the relationship between features of the walking environment in Lima with the occurrence of a pedestrian-motor vehicle collision. We were interested in exploring environmental features intended to improve pedestrian, including those that may have reduced the speed of vehicles and those that sought to separate, improve pedestrian visibility, and organize and separate pedestrian flow from vehicle flow to prevent or reduce shared space between them. Some examples of these features include sidewalks and curbs, pedestrian barricades, speed bumps, and pedestrian footbridges. We examined these factors together through a process of multivariable modeling to determine which were most strongly associated with the outcome.

METHODS

Design: We used a matched case-control design similar to a US study conducted by Koepsell *et al.*²⁴ A pedestrian crossing area at an intersection or in a mid-block area was the unit of analysis.²⁴ We defined a case as a pedestrian crossing area where the police reported a pedestrian-motor vehicle collision. A control was a pedestrian crossing area in the same neighborhood as the case where no pedestrian-motor vehicle collision had been reported by the police during the same 24-hour period. Detailed methods of this study can be found in Chapter 1.

Setting: We limited the study to the jurisdiction of 11 police commissaries. Cases occurred October 1, 2010 to Feb, 2011 and observational data were collected from February 2011 to September 2011.

Study Population. We selected cases for study through two-stage cluster sampling. The first stage used probability proportional-to-size to select police commissaries where the probability of random selection was proportional to the number of PMVCs reported in 2006. In the second stage a simple random

sample of 80% of the reported incidents within each of the 11 commissaries was taken. Before selecting PMVCs during the second stage, we excluded cases where the injured person was not a pedestrian (e.g. a cyclist), the pedestrian was not struck within the roadway (e.g., on the sidewalk), the PMVC occurred outside the jurisdiction of the commissary, information on the location was incomplete, the time of the incident was not recorded, sites in areas with high criminal activity, and any intentional collisions. Incidents that occurred from 8 PM to 6 AM were excluded due to various safety risks posed to study staff. Weights (w_{ic}) for each unit sampled and collected were calculated using the formula $w_{ic} = \frac{N_c}{m\bar{n}\pi'_c}$, where essentially the weight of each unit is the inverse of its probability of selection for study. This inverse probability is obtained by dividing the number of enumeration units in a commissary (N_c) by the number of clusters selected (m) times the number of units sampled within a cluster (\bar{n}) times the probability (π'_c) of an enumeration unit (X_i) being selected from within the total population (X) being sampled ($\pi'_c = \frac{X_i}{X}$).²⁵

We randomly drew one matched control from a risk set of potential matched controls. Initial matches were made by locating the geographic location the case and creating an initial 500 meter radius from the case to search for potential controls. Potential controls within this radius were matched to the case by the index road type (highway, arterial, arterial-collector, collector, or residential) and by the number of lanes of vehicle traffic. For cases occurring at intersections, the matched controls had to take place at an intersection and two of the radiating roads of the intersection had to be of the same road type as two at the case intersection. For mid-block cases, the road on which a mid-block control site was situated had to be of the same road type as at the mid-block case site. If no controls matching these criteria were found within this initial radius, the area was expanded by 100 meters until at least one suitable match was found. We were able to identify at least one control meeting the needed criteria for every case within a maximum 1000 meter radius.

Data Collection. Cases were first identified at the selected commissaries. An official agreement with the Lima regional police department allowed access to police records. After identifying and sampling case sites and selecting appropriate controls, we visited each site. Visits occurred on a weekday if the reported PMVC occurred on any weekday; and similarly for weekend sites. Sites were visited within an hour of the time that the original incident occurred. At each site we recorded 10 minutes of video of vehicle and

pedestrian flow and took pictures of the physical characteristics of the site. We measured vehicle speeds for 10 minutes or for 25 vehicles using a portable speed radar gun. We measured and sketched physical characteristics of the sites. Field workers were blinded to case and control status. Videos of the pedestrian and vehicle flows were viewed and we recorded the total number of vehicles passing through the index crossing and the number of pedestrians using the index crossing area.

Data Elements. The primary outcome was the presence of a PMVC reported to the police. For this exploratory analysis, we examined environmental factors that could potentially affect the occurrence of PMVCs. We classified these factors as roadside, crossing area, and zone-specific context characteristics (Table 3.1). Roadside factors include features such as sidewalks and curbs that are meant to dedicate roadway space to pedestrians to separate them from vehicle traffic and factors that could affect their use of these areas such as the presence of street vendors. Crossing area characteristics were roadway features that facilitate or impede pedestrians' ability to cross vehicle traffic such as a marked crosswalk or pedestrian bridge, obstructions that can affect their ability to see and be seen by drivers such as parked vehicles and traffic direction, or that are meant to change vehicle flow near where pedestrians are expected to cross roadways such as speed bumps and stop lines. The third group of characteristics, zone-specific context, groups together factors that may affect driver behavior and included mostly roadway signs warning them about pedestrians crossing or that disallowed certain behaviors such as parking or stopping vehicles. We also created a fourth group of characteristics that we considered confounding factors based on published literature that could be strongly related to both the environmental exposures described above and the outcome (pedestrian and vehicle flow, mean vehicle speed, crossing width and traffic control).

Data Analysis. We first evaluated the univariate relationship between each exposure in Table 3.1 and the outcome by examining both unweighted and weighted proportions and means (if applicable) by case status. We also calculated odds ratios (OR), 95% confidence intervals (CIs) and P values using conditional logistic regression to assess the associations between likelihood of a police-reported PMVC and characteristics of the walking environment. P values in unweighted analysis were based on the likelihood ratio and on the Wald test in weighted analysis. The *svy* package in Stata 11 (STATA Corp,

College Station, TX, USA) was used to account for weighting as described earlier. We evaluated the exposures and confounders together in a weighted multivariable model and eliminated factors from the model in a manual stepwise procedure. The starting model included variables that were statistically associated with the outcome at $P < 0.40$ and with known confounders. One factor at a time was eliminated from the model based on its statistical significance ($P > 0.40$), its effect size, the change in F statistic (likelihood ratios are not available from the *svy* package in Stata), and whether the effect size of any remaining characteristics was dramatically affected (greater than 10% change in estimate) by the removal of the factor. Because of the potential impact of vehicle and pedestrian flow as *a priori* confounders, we kept them in every model regardless of their statistical significance. After reaching a parsimonious model of the most statistically significant factors, factors with a strong univariate relationship with case-control status were reentered into the model one-by-one to evaluate their fit in the model and effect on other factors. Because of the small sample size we attempted to keep the final model to less than 10 terms and to limit those terms to factors whose statistical significance in the multivariable was less than 0.05. Fractional polynomial models were evaluated for the continuous covariates vehicle flow, pedestrian flow, mean vehicle speed, total crossing width, and number of street vendors. A single linear term for each of these variables was determined to be the simplest and best fit.

The study protocol was approved by the University of Washington and Universidad Peruana Cayetano Heredia institutional review boards.

RESULTS

A total of 137 case sites had complete data (97 intersection sites and 40 mid-block sites) representing 1,603 pedestrian-motor vehicle crashes in Lima during the study time period (1,134 at intersections and 469 at mid-blocks). In unweighted univariate analysis, sidewalks, curbs, street vendors, parked vehicles, pedestrian barricades, lane markings, pedestrian flow, and the maximum vehicle speed recorded were all significantly associated with case-control status when accounting for matching (Table 3.2). When adjusting for survey weighting, only curbs, street vendors and pedestrian barricades of these factors remained statistically significant. Additionally, the presence of a school and a sign warning drivers to “Slow Down” were two additional factors in weighted univariate analysis that were associated with case-

control status. Sites with curbs appeared to be less likely to have a PMVC whether there was one on only one side (weighted OR 0.16, 95% CI 0.03-0.91) of the index road or both sides (weighted OR 0.13, 95% CI 0.06-0.28). Sites with any street vendors were much more likely to have a PMVC (weighted OR 1.92, 95% CI 1.30-2.84). While there were few sites that had a school nearby, they did appear to be associated with less PMVCs (weighted OR 0.22, 95% CI 0.07-0.67). Having a “Slow Down” sign also appeared beneficial (weighted OR 0.05, 95% CI 0.003-0.79), though this was not a frequent characteristic.

Many of the factors that were significantly associated with case-control status in univariate analysis maintained this relationship in the multivariable model (Table 3.3). Because we found that curbs and sidewalks were strongly associated, we used curbs in the multivariable modeling because it had a stronger, more consistent relationship with the primary outcome. We also reduced the curb variable to two categories (no curb or a curb on either or both sides of the roadway) in order to improve the model fit since there was no significant difference between the effect sizes of the categories. Sites with curbs were half as likely to have had a PMVC as those with no curbs (OR 0.51, 95% CI 0.33-0.80). The presence of pedestrian barricades was also associated with control status (OR 0.11), though the confidence interval was quite wide (95% CI 0.01-0.96). The presence of a school on the index road was another potentially beneficial factor that had 40% lower odds of a PMVC (95% CI 0.42-0.86).

Two of the factors were associated with an increased chance of a PMVC occurring: the presence of street vendors and parked vehicles. Each street vendor present was associated with over a 2.6-fold increase in the likelihood of a PMVC (95% CI 1.55-4.37). Parked vehicles had a slightly stronger association at slightly over a 3-fold increase, though the confidence interval was fairly wide and approached the null on the lower bound (95% CI 1.08-9.05). We allowed two exposures (presence of a pedestrian footbridge and a sign warning vehicles to slow down) to remain in the final model though they did not quite meet statistical significance because they appeared to improve the fit of the overall model and improved the fit of other terms that were statistically significant. As expected, vehicle flow was significantly associated with PMVCs with every 100 vehicles passing through the crossing area increasing the odds of the

outcome by 10%. Surprisingly pedestrian flow did not appear to be significantly associated with the occurrence of PMVCs in the final model.

DISCUSSION

As high-income countries struggle with epidemic rates of obesity and sedentary life styles,²⁶⁻²⁸ many low and middle income countries, by necessity, have enviable rates of pedestrian commuting and utilization of public transportation. The challenge for large urban planners is to help shape a safe walkable environment which will accommodate healthful demographic and economic growth and continue to encourage foot traffic.^{29 30} Relative to wealthier nations, low and middle income countries struggle with high levels of pedestrian risk, and significant resource limitations. For burgeoning urban megacities such as Lima, there is an urgent need to explore the association between potentially costly environmental modifications and pedestrian risk.^{11 14 15 17 31-34} This work can identify promising interventions, redirect attention to traffic enforcement where needed, and equally importantly, may suggest some investments which are wasteful and should not be replicated.

In this exploratory analysis of the walking environment for pedestrians in Lima, we found several features of the built environment may have a beneficial effect on pedestrian safety. The presence of hard-edged curbs was associated with a lower likelihood of a PMVC, as were pedestrian barricades. Hard-edged curbs are not consistently present in Lima. On some roads, especially more residential-type roads, there is not a curb separating the pedestrian walking area from the roadway; rather, the transition may be gently sloped or angled or it is a dirt or concrete area. These transitions allow vehicles to park in these areas and which may then block the paths of pedestrians and force them walk in the roadway to get around the parked vehicle. A high, hard-edged curb may help reduce this type of behavior by drivers and can keep them in the roadway were they belong.³¹

Pedestrian barricades were also a potential beneficial feature for pedestrians. The structures that we considered barricades to direct and block pedestrian traffic serve several purposes on the roadways. Some of the barricades we observed functioned to discourage pedestrian crossing in unsafe areas, or directed pedestrian traffic to a specific crossing area. There were many types of barricades but most

were concrete median barrier or metal fences. At mid-blocks, barricade structures likely prevented most pedestrians from crossing, because they were difficult to circumvent. At intersections, barricades herded pedestrians towards the designated crosswalk area, and may reduce the incidence of dashing into the street in order to beat a changing traffic light. Wider use of pedestrian barricades may be a feasible solution for some high-risk arterial roads in Lima to reduce dangerous crossings.

A factor that encouraged better pedestrian crossings was the presence of a school. While this of course is not an intervention that could be placed at every roadway, it does potentially reveal that drivers are more cautious near schools.³² This could also indicate that drivers understand the need for caution while driving where there are likely to be a large number of child pedestrians nearby.

We found the presence of street vendors to be strongly associated with the likelihood of a PMVC. Our risk estimate (OR 2.61, 95% CI 1.55-4.37) for each vendor present was twice as large as that observed by *Donroe et al* (OR 1.25, 95% CI 1.01-1.55).⁴ These differences may be due to examining different pedestrian populations (all pedestrians vs. child pedestrians), covering different geographic areas (all of Lima vs. one district) and sample size (our study had more than three times as many matched pairs). Clearly both indicated that street vendors are problematic for pedestrian safety in Peru.

There are several potential dangers that street vendors may present to pedestrian safety. We observed that vendors tended to place themselves at or near street corners at intersections. This placement seemed to cause problems such as blocking or reducing entry into the walking path area from the roadway, reducing the waiting area to cross the roadway resulting in pedestrians spilling onto the roadway, and limiting the ability of drivers to spot pedestrians who may dash out into the roadway to cross. These situations may be further complicated if the vendors have several customers being served or waiting to be served. One would also expect street vendors to potentially draw foot traffic to an intersection, which might increase pedestrian exposure. Our study approach allowed us to separately control for pedestrian volume and thus to incorporate information about exposure as well as risk.³³ While banning all street vendors is one possible solution in principle, this would likely impose serious economic hardship on those that rely on this as their livelihood and would probably not be met with enthusiasm. Another option could be prohibiting selling within the pedestrian corridor (street corners, near a crosswalk

entrance, near the roadway, etc.), though this would require consistent and constant enforcement. Alternatively there might be an opportunity to designate areas for street vendors, well separated from the roadway, with accommodation for pedestrians. Many of the street vendors observed appeared to be authorized to work by the local municipality, though most did not appear to have any authorization visible. These results are exploratory, thus it would be important to conduct further studies that examine how street vendors may be related to pedestrian safety and to look for more specific solutions based on that evidence.

The presence of parked vehicles at a crossing area was another factor with a higher likelihood of a PMVC. Vehicles parked on the street can limit both pedestrian and motorist views, especially when there are many parked vehicles.¹⁰ Street parking in many parts of Lima is costly and limited. Vehicle owners frequently park cars in a lane of vehicle traffic (typically on residential roads) or park on the sidewalk area where there are low or non-existent curbs. Traffic congestion and renegade parking will likely be exacerbated by Lima's burgeoning middle class,³⁴ Peru has one of the highest rates per capita of new vehicle sales in South America.^{35 36} A comprehensive planning approach will require focused attention on building walkable cities with accessible, affordable, and efficient public transportation. Limitation of renegade parking, with detrimental impact on both pedestrian safety and traffic congestion, requires aggressive parking enforcement. At present, parking enforcement is only done with any regularity in a few districts of Lima, representing an opportunity to improve safety, reduce commute times and provide a progressive source of revenue, which can then be used to support additional traffic safety measures. Once again, due to the exploratory nature of this analysis, further research on the relationship between parking and pedestrian safety is merited.

While our final model included the presence of a pedestrian footbridge and signs that warn drivers to "Slow Down," they were not statistically significant at the 0.05 level in the final model. They did however appear to improve the fit of the model because of their apparent relationship with the other factors in the model. Dropping them from the model pushed effect sizes for pedestrian barricades and parked vehicles towards the null by nearly 15% and led to wider 95% confidence intervals for curb and school presence.

They did not appear to affect the effect sizes of the number of vendors present. Both leaned toward a beneficial effect for pedestrians, though relatively few sites had either of these features.

Some of the features we examined did not appear to have the benefits found in other studies. Sidewalks in other studies have been shown to be effective at reducing pedestrian-vehicle conflicts and PMVCs,^{37,38} but the relationship we observed in this study was not as clear. This could be due to the small sample size, most sites had some sort of a sidewalk and therefore there were relatively few discordant pairs between case and control sites. We observed (but did not record for this analysis) the condition or completeness of sidewalks. In some cases sidewalks were in poor condition, incomplete, irregular or non-uniform. Frequently, illegally parked vehicles encroached upon sidewalks, a practice which may also speed the degradation of the sidewalk. The findings observed for curbs may be in part due to sidewalks as well since the two were strongly correlated, thus adjusting for only curbs in this analysis may be a better proxy for the completeness and effectiveness of a sidewalk than only the presence of a sidewalk.

Speed bumps (or humps) were another feature that seemed to provide no benefit to pedestrians in our study, though they have been found to have a strong protective effect on pedestrian safety in other studies,¹⁵ including several in developing countries.^{39,40} The most likely explanation is that in our study of congested urban streets, average vehicle speed was relatively low (32 KPH at case sites and 34 KPH at control sites with both having a SD of around 6 KPH). The few speed bumps we observed were in poor condition (missing pieces, faded paint markings, worn down, etc.) and did not always seem to have been placed by the municipality. The speed bumps were not uniformly implemented with a variety of bumps, rumble strips, and tables used. Their apparent lack of effectiveness may also have resulted from placement too far from pedestrian crossing areas to be effective or non-functional speed bumps whose shape did not encourage drivers to slow down. Some speed bumps were placed in areas of heavy vehicle and pedestrian traffic in order to slow vehicle traffic at an uncontrolled crossing. While the speed bump may have slowed vehicles at such sites, the flow of vehicle traffic was often constant throughout the observation period, requiring crossing pedestrians to venture into the intersection and weave between moving or stopped vehicles.

While we did observe some potentially useful and important exploratory results, our analysis is limited by a modest sample size and also by multiple comparisons. A larger sample size may have allowed us to explore the covariates in more detail, may have provided a wider distribution of categories within factors and perhaps fit a larger, more inclusive multivariable model. There are limitations as well to the factors we explored, particularly those that vary over time and that may not be the same as when the incidents occurred. There was a lag of up to 10 months between the occurrence of a PMVC and a site visit to collect data. It is possible that environmental changes could have been made to the sites over that period, potentially in response to documented pedestrian risk, which might have modified the dynamic traffic characteristics surrounding the index incident. To address this potential problem, we randomly selected 10% of the case sites and compared our recorded data to archival satellite imagery from Google Earth. We observed no major physical changes to this sample of sites (addition of traffic lights, sidewalks, change to road layout, etc.). There were noted differences in paint markings, which may have been clearer or more faded than when we had visited the sites. For five sites we were able to collect both vehicle and traffic flow data from two studies conducted within one year prior to our study.⁴¹ For each of these 5 sites, observed vehicle and pedestrian flow fell within the 24-hour range of the previously measured values.

It should also be noted that our PMVC data were police-reported, and were not collected for the purposes of research.⁴² These data may not include all PMVCs and there was limited reporting of specific types of pedestrian injury (the most common injury reported was "*multiple contusion*"). Because of this limitation, we used the police data to identify locations of PMVCs, but did not consider the severity of the incident or injuries to the pedestrian. As noted in the methods section, we excluded 38% of the police-reported PMVCs for concerns about the personal safety during data collection (26% occurred at nighttime or in an unsafe neighborhood). A small number of PMVC reports were excluded as they were not truly PMVCs (4%) or the report lacked data crucial to observation (3%). The results we report here may not be applicable to nighttime crashes which may be influenced by additional factors such as poor visibility and prevalence of alcohol use by drivers and pedestrians. It is possible that the presence of observers may have impacted behavior, though based on many illegal traffic and other behaviors observed, we felt impact was likely minimal.

Lima has one of the highest rates of pedestrian injury in the world, and effective strategies to improve safety in the walkable environment are urgently needed. The municipal government has invested in a number of approaches, and an evaluation of these approaches is important in order to guide scarce resources towards the greatest public benefit. This exploratory study has identified some candidate risk and protective factors associated with pedestrian collisions, including curb presence, pedestrian barricades, street vendors, and parked vehicles. We hope these results may prove useful to scientists and leaders in pedestrian safety in Peru, and perhaps also other urban cities with similar risk. This study builds on previous road traffic injury research in Peru.^{4 43-45} It provides some insight into the impact of the built environment on pedestrian safety. In several instances, some road features designed to improve pedestrian safety may not function as expected. Our study also identified potentially modifiable factors. Further real-world research is needed to develop, test, and disseminate promising interventions to curb the epidemic of pedestrian death and injury.^{6 46}

REFERENCES

1. World Health Organization. Global status report on road safety: time for action. Geneva: World Health Organization, 2009.
2. Secretaría Técnica del Consejo de Transporte de Lima y Callao. La Vulnerabilidad de los Peatones en la Vialidad del Área Metropolitana de Lima y Callao. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2009.
3. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Evaluación de Tránsito y Seguridad Vial en 5 Puntos Negros de Lima y Callao. Lima, Peru, 2009.
4. Donroe J, Tincopa M, Gilman RH, Brugge D, Moore DAJ. Pedestrian Road Traffic Injuries in Urban Peruvian Children and Adolescents: Case Control Analyses of Personal and Environmental Risk Factors. *PLoS ONE* 2008;3(9):e3166.
5. Donroe J, Gilman RH, Brugge D, Mwamburi M, Moore DAJ. Falls, poisonings, burns, and road traffic injuries in urban Peruvian children and adolescents: a community based study. *Injury Prevention* 2009;15(6):390-96.
6. Mock C, Quansah R, Krishnan R, Arreola-Risa C, Rivara F. Strengthening the prevention and care of injuries worldwide. *Lancet* 2004;363(9427):2172-79.
7. Sebert Kuhlmann AK, Brett J, Thomas D, R. Sain S. Environmental Characteristics Associated With Pedestrian-Motor Vehicle Collisions in Denver, Colorado. *Am J Public Health* 2009;99(9):1632-37.
8. Ewing R, Dumbaugh E. The Built Environment and Traffic Safety: A Review of Empirical Evidence. *Journal of Planning Literature* 2009;23(4):347-67.
9. Retting RA, Ferguson SA, McCartt AT. A Review of Evidence-Based Traffic Engineering Measures Designed to Reduce Pedestrian-Motor Vehicle Crashes. *Am J Public Health* 2003;93(9):1456-63.
10. Agran PF, Winn DG, Anderson CL, Tran C, Del Valle CP. The Role of the Physical and Traffic Environment in Child Pedestrian Injuries. *Pediatrics* 1996;98(6):1096-103.
11. Zegeer CV, Bushell M. Pedestrian crash trends and potential countermeasures from around the world. *Accid Anal Prev* 2012;44(1):3-11.
12. Duperrex O, Bunn F, Roberts I. Safety education of pedestrians for injury prevention: a systematic review of randomised controlled trials. *British Medical Journal* 2002;324(7346):1129-31.
13. Gandhi T, Trivedi MM. Pedestrian protection systems: Issues, survey, and challenges. *Ieee Transactions on Intelligent Transportation Systems* 2007;8(3):413-30.
14. Forjuoh SN, Li GH. A review of successful transport and home injury interventions to guide developing countries. *Social Science & Medicine* 1996;43(11):1551-60.
15. Bunn F, Collier T, Frost C, Ker K, Steinbach R, Roberts I, et al. Area-wide traffic calming for preventing traffic related injuries. *Cochrane Database of Systematic Reviews* 2003(1).
16. Mohan D. Traffic safety and city structure: lessons for the future. *Salud Publica De Mexico* 2008;50:S93-S100.
17. Mohan D, Bawa PS. An analysis of road traffic fatalities in Delhi, India. *Accident Analysis & Prevention* 1985;17(1):33-45.
18. Hidalgo-Solorzano E, Campuzano-Rincon J, Rodriguez-Hernandez JM, Chias-Becerril L, Resendiz-Lopez H, Sanchez-Restrepo H, et al. Use and non-use of pedestrian bridges in Mexico City: the pedestrian perspective. *Salud Publica De Mexico* 2010;52(6):502-10.
19. Afukaar FK. Speed control in developing countries: issues, challenges and opportunities in reducing road traffic injuries. *Injury Control and Safety Promotion* 2003;10(1-2):77-81.
20. Damsere-Derry J, Afukaar FK, Donkor P, Mock C. Study of Vehicle Speeds on a Major Highway in Ghana: Implication for monitoring and control *Traffic Injury Prevention* 2007;8(2):142-46.
21. Damsere-Derry J AF, Donkor P, Mock C. Assessment of vehicle speeds on different categories of roadways in Ghana. *Int J Inj Contr Saf Promot* 2008;15(2):82-91.

22. Híjar M, Trostle J, Bronfman M. Pedestrian injuries in Mexico: a multi-method approach. *Social Science & Medicine* 2003;57(11):2149-59.
23. Tiwari G, Bangdiwala S, Saraswat A, Gaurav S. Survival analysis: Pedestrian risk exposure at signalized intersections. *Transportation Research Part F-Traffic Psychology and Behaviour* 2007;10(2):77-89.
24. Koepsell T, McCloskey L, Wolf M, Moudon AV, Buchner D, Kraus J, et al. Crosswalk Markings and the Risk of Pedestrian-Motor Vehicle Collisions in Older Pedestrians. *JAMA* 2002;288(17):2136-43.
25. Levy PS, Lemeshow S. *Sampling of populations methods and applications*. Hoboken (N.J.), US: J. Wiley, 2008.
26. Knoblauch R, Tustin B, Smith S, Pietrucha M. Investigation of Exposure-Based Pedestrian Accident Areas: Crosswalks, Sidewalks, Local Streets, and Major Arterials. Washington DC: US Dept of Transportation, 1987.
27. McDonald NC, Brown AL, Marchetti LM, Pedroso MS. U.S. school travel, 2009 an assessment of trends. *Am J Prev Med* 2011;41(2):146-51.
28. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of obesity in the United States, 2009-2010. *NCHS data brief* 2012(82):1-8.
29. Jacobsen PL. Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Inj Prev* 2003;9(3):205-9.
30. Pucher J, Dijkstra L. Promoting safe walking and cycling to improve public health: lessons from The Netherlands and Germany. *Am J Public Health* 2003;93(9):1509-16.
31. Sawalha Z, Sayed T. Evaluating safety of urban arterial roadways. *Journal of Transportation Engineering-Asce* 2001;127(2):151-58.
32. Dumbaugh E, Frank L. Traffic Safety and Safe Routes to Schools: Synthesizing the Empirical Evidence. *Transportation Research Record: Journal of the Transportation Research Board* 2007;2009(-1):89-97.
33. Christie N, Cairns S, Towner E, Ward H. How exposure information can enhance our understanding of child traffic "death leagues". *Inj Prev* 2007;13(2):125-9.
34. Silva Nole L. Caos vehicular es un infarto a diario en el corazón de Lima. *El Comercio* 2010 Aug 14.
35. Vial J, Perea H, Gripa F, Barco D, Foinquinos I. Situación Automotriz Peru 2011: Análisis Económico. Lima, Peru: BBVA, 2011.
36. Asociación de Representantes Automotrices del Perú. Ventas Mayo 2012. Lima, Peru, 2012.
37. Boarnet MG, Day K, Anderson C, McMillan T, Alfonzo M. California's Safe Routes to School Program: Impacts on Walking, Bicycling, and Pedestrian Safety. *Journal of the American Planning Association* 2005;71(3):301-17.
38. Poudel-Tandukar K, Nakahara S, Ichikawa M, Poudel KC, Jimba M. Risk perception, road behavior, and pedestrian injury among adolescent students in Kathmandu, Nepal. *Injury prevention : journal of the International Society for Child and Adolescent Injury Prevention* 2007;13(4):258-63.
39. Afukaar FK, Damsere-Derry J. Evaluation of speed humps on pedestrian injuries in Ghana. *Inj Prev* 2010;16:A205-A06.
40. Afukaar FK. Speed control in developing countries: issues, challenges and opportunities in reducing road traffic injuries. *Inj Control Saf Promot* 2003;10(1-2):77-81.
41. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Actualización de la Base de Datos del Plan Maestro de Transporte Urbano: Aforos Vehiculares 2009. Lima, Peru: Ministerio de Transportes y Comunicaciones, 2010:157.
42. Secretaría Técnica del Consejo de Transporte de Lima y Callao. Mejoramiento de la calidad de la base de datos de los accidentes de tránsito en el Área Metropolitana de Lima y Callao. Lima, Peru: Consejo de Transporte de Lima y Callao, 2011.

43. Huicho L, Adam T, Rosales E, Paca-Palao A, Lopez L, Luna D, et al. Evaluation of interventions on road traffic injuries in Peru: a qualitative approach. *BMC Public Health* 2012;12:71.
44. Huicho L, Trelles M, Gonzales F, Mendoza W, Miranda J. Mortality profiles in a country facing epidemiological transition: An analysis of registered data. *BMC Public Health* 2009;9:47.
45. Pernica JM, Leblanc JC, Soto-Castellares G, Donroe J, Carhuancho-Meza BA, Rainham DG, et al. Risk factors predisposing to pedestrian road traffic injury in children living in Lima, Peru: a case-control study. *Arch Dis Child* 2012.
46. Rydin Y, Bleahu A, Davies M, Davila JD, Friel S, De Grandis G, et al. Shaping cities for health: complexity and the planning of urban environments in the 21st century. *Lancet* 2012;379(9831):2079-108.

FIGURES AND TABLES**Figure 9.** Example of a pedestrian barricade.

Figure 10. Mid-block crossing with pedestrian barricades and a (modified) pedestrian crossing sign.



Figure 11. Typical hard-edged curb.

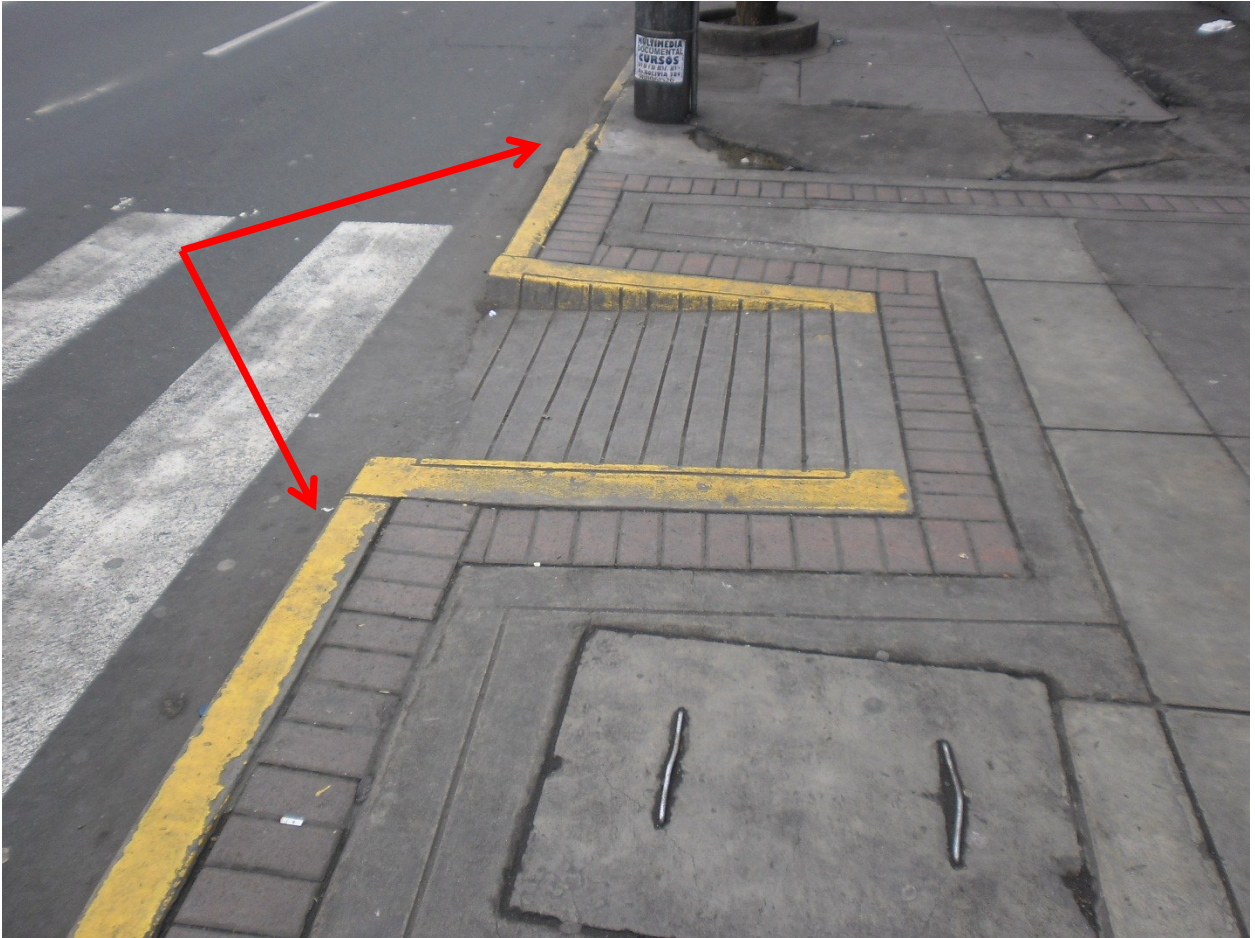


Figure 12. Typical speed limit sign.



Figure 13. Example of a pedestrian bridge over the Panamerican Highway and a “Slow Down” (Disminuir Velocidad) sign.



Figure 14. Example of street vendors near an intersection.

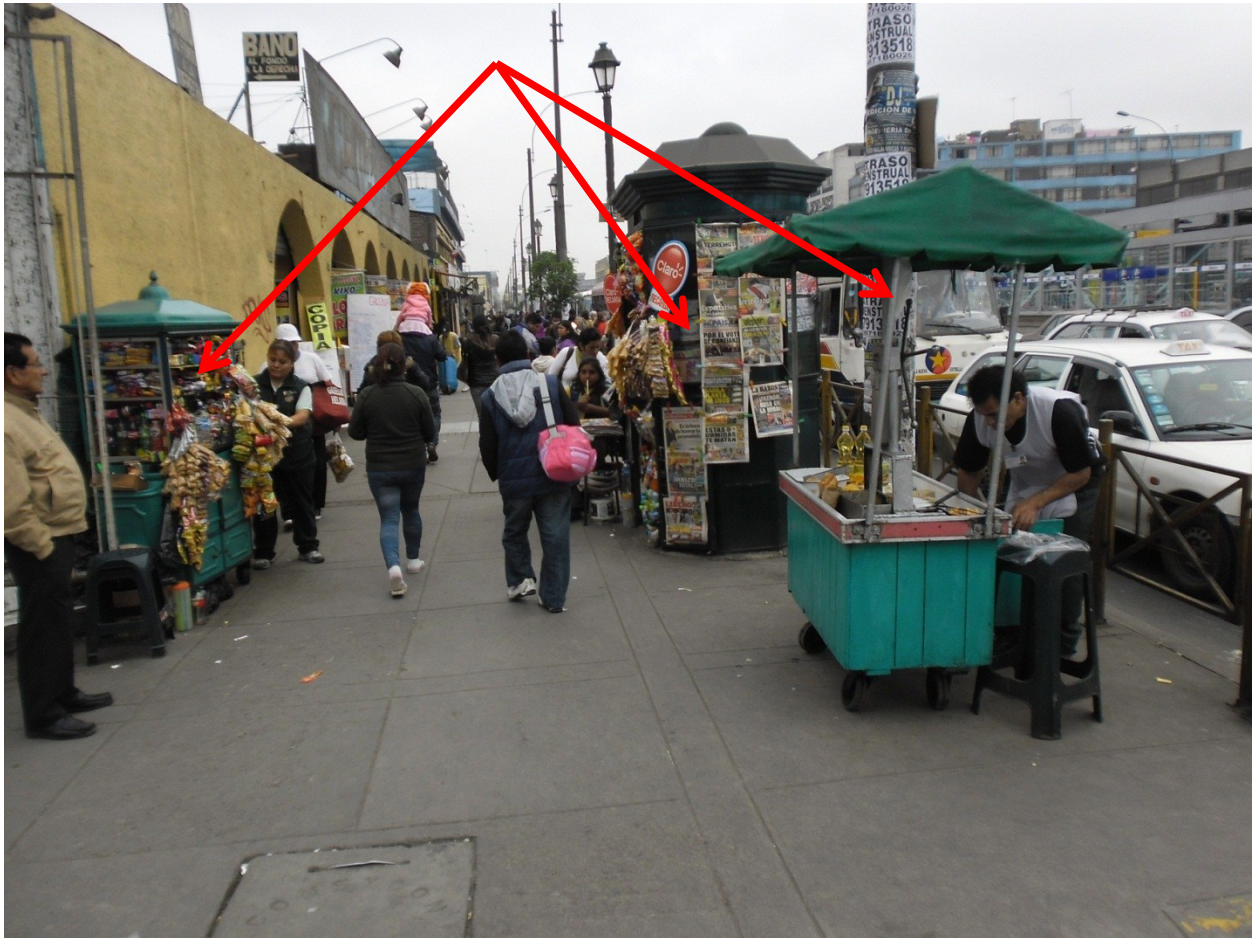


Figure 15. Street vendors blocking access to the sidewalk on one side of the road.



Table 3.1. Description of walking environment characteristics of index street being crossed.

Factor	Description	Categories
Roadside		
Sidewalk	Recorded the presence of any type of sidewalk regardless of uniformity	None, One Side, Both Sides
Shoulder	An area on the side of the road where vehicles could potentially stop in outside of moving vehicles	None, One Side, Both Sides
Curbs	Hard-edged at the edge of the roadway (Figure 11)	None, One Side, Both Sides
Edge lines	Edge lines mark where the roadway for moving vehicles end and where stopped vehicles or sidewalks may be present	None or Both Sides
Bike Lanes	Any roadway or sidewalk area designated for bicycle traffic	Present/Not Present
Street Vendors	Any ambulatory or fixed vendor occupying space on or near walking areas of pedestrians (Figures 14 and 15).	Continuous; Categorical: 0, 1 or 2, 3 or more
Crossing Area		
Parked Vehicles	Any parked vehicles observed, parked legally or illegally	Present or Not Present

Table 3.1. (cont.)

Factor	Description	Categories
Crossing Area (cont.)		
Traffic Direction	Direction of vehicle traffic	One-way or Two-way
Pedestrian Barricades	Any barricade preventing pedestrians from crossing the roadway except at designated areas. Materials, dimensions, and functionality were not accounted for in this analysis, only presence (Figures 9 and 10).	Present/Not Present
Stop Line	Presence of a painted line where vehicles should stop at traffic control points	Present/Not Present
Stop Line Visibility	A qualitative measure of how faded the stop line was	Unmarked, Poor Visibility, Good Visibility
Pedestrian Bridge	Presence of a pedestrian footbridge near the site (Figure 13).	Present/Not Present
Speed Bumps	Any type of speed bump, hump, table, rumble strips or other modification of the roadway surface to slow down vehicles. Condition and dimensions of this feature were not considered in this analysis.	Present/Not Present
No. of Segments	Number of sections that the vehicle flow area is divided into by barriers, medians, and other physical features.	Continuous

Table 3.1. (cont.)

Factor	Description	Categories
Crossing Area (cont.)		
Any refuge	The presence of any type of area for pedestrians to stop at within the crossing area.	Present/Not Present
Refuge Width	The average width of any refuge in a crossing area	Continuous
Surface Condition	The condition of the crossing area - are there potholes, utility covers, etc. that may interfere with foot traffic	Good, Fair, Poor
Marked Crosswalk	Any marked area designating where pedestrians should cross	Present or Not Present
Crosswalk Visibility	Qualitative rating of how faded any crosswalk markings were	None, Visible, Faded
Lane Marking Visibility	Qualitative rating of how visible painted lane markings were	None, Poor, Fair, Good, Excellent
Zone Specific Context		
Speed Limit Sign	A sign indicating the maximum vehicle speed allowed (Figure 4).	Present/Not Present
School on Road	A sign or observer confirmed presence of a school	Present/Not Present
Pedestrian Crossing	A sign indicating where pedestrians should cross	Present/Not Present
Slow Down Sign	A sign warning vehicles to slow down (Figure 12).	Present/Not Present

Table 3.1. (cont.)

Factor	Description	Categories
Zone Specific (cont.)		
No Turns Allowed	A sign indicating no turns (right or left) are allowed	Present/Not Present
No Parking Allowed	A sign indicating that no parking or stopping is allowed	Present/Not Present
Potential confounders		
Vehicle Flow	Number of vehicles observed passing through the crossing area	Vehicles per hour
Pedestrian Flow	Number of pedestrians observed using the crossing area	Pedestrians per hour
Average Vehicle Speed	Average speed of vehicles at site	Kilometers per hour
Maximum Vehicle Speed	Highest vehicle speed recorded at site	Kilometers per hour
Crossing Distance	Distance between the two edges of the roadways	Meters
Traffic Control	Type of vehicle traffic regulation	None, Phased Signal, Phased Countdown Signal, Transit Police
Pedestrian Signal	Any signals present indicating when pedestrians should cross	Present/Not Present

Table 3.2. Descriptive and univariate statistics of cases and controls, unweighted and weighted.

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%			%	%			
A. SIDEWALK AREA								
Sidewalk				0.002				0.051
Neither side	3	2	Reference		3	1	Reference	
One-side	4	13	0.26 (0.04-1.78)		3	12	0.10 (0.02-0.55)	
Both Sides	93	85	2.63 (0.37-18.6)		94	87	2.47 (0.51-12.1)	
Shoulder				0.424				0.922
Neither side	80	77	Reference		84	85	Reference	
One-side	8	9	0.74 (0.27-2.02)		7	7	1.14 (0.56-2.32)	
Both Sides	12	15	0.45 (0.13-1.58)		9	8	1.41 (0.08-24.8)	
Curb				0.004				0.001
Neither side	11	2	Reference		12	3	Reference	
One-side	7	14	0.11 (0.02-0.54)		7	10	0.16 (0.03-0.91)	
Both Sides	82	84	0.18 (0.04-0.82)		81	87	0.13 (0.06-0.28)	
Edge lines Both Sides				0.315				0.527
No	87	84	Reference		89	88	Reference	
Yes	13	16	0.60 (0.22-1.65)		11	12	0.69 (0.19-2.47)	

Table 3.2. (cont.)

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%	%	%	%	%			
Bike Lanes				1.000				0.841
No	92	92	Reference		94	94	Reference	
Yes	8	8	1.00 (0.20-4.95)		6	6	1.10 (0.38-3.17)	
Street Vendors				<0.001				0.004
0	54	71	Reference		58	77	Reference	
1 to 2	32	24	2.65 (1.33-5.30)		28	20	2.95 (1.66-5.23)	
3 or more	13	4	11.2 (2.80-45.1)		14	3	24.4 (3.85-155)	
Mean, SD	1.3 (2.9)	0.5 (0.9)	1.85 (1.28-2.68)	<0.001	1.5 (4.0)	0.4 (0.8)	1.92 (1.30-2.84)	0.004
B. CROSSING AREA								
Any Parking Either Side				0.005				0.386
No	50	64	Reference		43	52	Reference	
Yes	50	36	2.25 (1.25-4.05)		57	48	1.56 (0.52-4.68)	
Traffic Direction				0.526				0.369
Two-way	78	80	Reference		72	75	Reference	
One-way	22	20	1.50 (0.42-5.32)		28	25	2.34 (0.31-17.6)	
Pedestrian Barricades				0.015				0.144
No	82	75	Reference		81	74	Reference	
Yes	18	25	0.29 (0.09-0.87)		19	26	0.28 (0.05-1.68)	

Table 3.2. (cont.)

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%	%	%	%	%			
Stop Line				0.591				0.539
No	61	63	Reference		57	59	Reference	
Yes	39	37	1.21 (0.60-2.46)		43	41	1.31 (0.50-3.42)	
Stop Line Visibility				0.590				0.293
Unmarked	61	63	Reference		57	59	Reference	
Good visibility	19	26	0.69 (0.29-1.68)		19	27	0.73 (0.23-2.34)	
Poor visibility	20	11	1.75 (0.79-3.89)		24	13	1.90 (0.54-6.60)	
Pedestrian Bridge				0.705				0.976
No	96	96	Reference		97	97	Reference	
Yes	4	4	1.33 (0.30-5.96)		3	3	0.97 (0.11-8.69)	
Speed Bumps				0.796				0.760
No	92	93	Reference		92	93	Reference	
Yes	8	7	1.14 (0.41-3.15)		8	7	1.37 (0.15-12.7)	
No. of Segments				0.385				0.454
1	36	32	Reference		38	33	Reference	
2	52	55	0.40 (0.10-1.53)		54	57	0.31 (0.05-2.08)	
3	7	6	0.47 (0.02-11.5)		6	5	0.23 (0.001-42.7)	
4	6	7	0.18 (0.01-3.42)		2	4	0.05 (0.001-2.04)	

Table 3.2. (cont.)

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%	%	%	%	%			
Any pedestrian refuge				0.125				0.983
No	37	34	Reference		44	44	Reference	
Yes	63	66	0.38 (0.10-1.41)		56	56	0.98 (0.09-10.7)	
Width of Refuges (M), Mean (SD)	6.0 (4.3)	6.5 (4.9)	1.00 (0.92-1.09)	0.999	5.0 (4.2)	5.8 (5.2)	0.99 (0.90-1.08)	0.807
Surface Condition				0.477				0.836
Good	55	60	Reference		55	58	Reference	
Fair	34	27	1.40 (0.79-2.48)		33	31	1.20 (0.61-2.32)	
Poor	12	13	1.01 (0.43-2.40)		11	11	1.13 (0.35-3.64)	
Marked Crosswalk				0.207				0.166
No	52	57	Reference		49	54	Reference	
Yes	48	43	1.58 (0.77-3.26)		51	46	1.77 (0.75-4.17)	
Crosswalk Marking Visibility				0.436				0.447
Unmarked	52	57	Reference		49	54	Reference	
Visible	18	15	1.69 (0.71-4.03)		16	16	1.49 (0.69-3.23)	
Faded	30	28	1.52 (0.70-3.3)		36	30	2.04 (0.63-6.63)	

Table 3.2. (cont.)

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%	%	%	%	%			
Lane Markings				0.003				0.407
Unmarked	13	13	Reference		8	10	Reference	
Excellent 90-100%	3	15	0.10 (0.01-0.81)	0.031	4	17	0.15 (0.01-4.86)	0.255
Good 50-90%	46	46	0.64 (0.13-3.27)	0.605	49	44	1.74 (0.19-16.0)	0.589
Fair 10-49%	24	15	1.27 (0.25-6.56)	0.773	22	15	3.49 (0.28-44.4)	0.298
Poor <10%	14	12	1.13 (0.26-4.84)	0.873	17	14	2.77 (0.29-26.7)	0.340
C. ZONAL AREA								
Speed Limit Posted				0.592				0.131
No	95	93	Reference		98	94	Reference	
Yes	5	7	0.75 (0.26-2.16)		2	6	0.37 (0.09-1.43)	
School on Road				0.165				0.012
No	99	96	Reference		98	95	Reference	
Yes	1	4	0.25 (0.03-2.24)		2	5	0.22 (0.07-0.67)	
Pedestrian Crossing Sign				0.637				0.165
No	89	91	Reference		87	94	Reference	
Yes	11	9	1.25 (0.49-3.17)		13	6	3.60 (0.54-24.2)	

Table 3.2. (cont.)

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%	%	%	%	%			
Slow Down Sign				0.088				0.036
No	99	96	Reference		99	96	Reference	
Yes	1	4	0.20 (0.02-1.71)		1	4	0.05 (0.003-0.79)	
No Turns Allowed				0.739				0.217
No	96	96	Reference		96	98	Reference	
Yes	4	4	0.80 (0.21-2.98)		4	2	2.78 (0.49-15.7)	
No Parking Allowed				0.654				0.427
No	97	96	Reference		98	97	Reference	
Yes	3	4	0.67 (0.11-3.99)		2	3	0.65 (0.21-2.05)	
D. CONFOUNDERS								
Vehicles per hour, Mean (SD)	1596 (1001)	1464 (1012)	1.04 (1.00-1.08)	0.072	1545 (985)	1401 (919)	1.04 (0.98-1.10)	0.141
Pedestrians per hour, Mean (SD)	355 (455)	250 (366)	1.02 (1.01-1.03)	<0.001	304 (364)	232 (336)	1.01 (0.99-1.04)	0.247
Mean Speed (KPH), Mean (SD)	33.4 (6.2)	34.4 (6.8)	0.96 (0.92-1.01)	0.108	32.1 (6.0)	34.0 (6.5)	0.92 (0.83-1.02)	0.114
Max Speed (KPH), Mean (SD)	51.9 (11.3)	54.0 (11.1)	0.97 (0.95-1.00)	0.048	50.1 (10.6)	52.8 (10.1)	0.96 (0.93-1.00)	0.067
Crossing Width (M), Mean (SD)	19.8 (13.1)	19.8 (13.3)	1.01 (0.96-1.04)	0.972	16.8 (9.9)	18.2 (11.3)	0.96 (0.89-1.04)	0.262

Table 3.2. (cont.)

	Unweighted				Weighted			
	Cases	Controls	OR (95% CI)	P	Cases	Controls	OR (95% CI)	P
	N=137	N=137			N=1603	N=1603		
%	%	%	%	%	%			
Traffic Control				0.519				0.850
None	65	68	Reference		62	67	Reference	
Phased	23	19	1.69 (0.61-4.71)	0.312	22	20	1.45 (0.35-6.01)	0.569
Countdown	9	11	0.70 (0.25-2.02)	0.513	13	12	1.40 (0.21-9.16)	0.696
Police	1	2	0.39 (0.03-4.87)	0.468	1	2	0.62 (0.18-2.09)	0.404
Any Pedestrian Signalization				0.413				0.234
No	74	77	Reference		73	80	Reference	
Yes	26	23	1.40 (0.62-3.15)		27	20	2.61 (0.50-12.7)	

Table 3.3. Final weighted multivariable model of walking environment factors associated with PMVCs.

	OR (95% CI)	P
Any Curb	0.51 (0.33-0.80)	0.008
No. Vendors	2.61 (1.55-4.37)	0.002
Any Parked Vehicles	3.13 (1.08-9.05)	0.038
Pedestrian Barricades	0.11 (0.01-0.96)	0.046
Pedestrian Bridge	0.17 (0.01-2.36)	0.163
School Nearby	0.60 (0.42-0.86)	0.011
Slow Down Sign	0.09 (0.01-1.27)	0.070
Vehicle Flow (100 VPH)	1.10 (1.03-1.17)	0.011
Pedestrian Flow (10 PPH)	1.01 (0.99-1.04)	0.323

Vita

Duane Alexander Quistberg was born in Bountiful, Utah and grew up mostly in Sandy, Utah. He moved to Philadelphia to study at the University of Pennsylvania (Penn) where he majored Health and Societies and minored in Biology. After his freshman year at Penn he took a two-year leave of absence to serve as a voluntary missionary for The Church of Jesus Christ of Latter-Day Saints. He spent those two years in and around Santiago, Chile and became fluent in Spanish. After graduating from Penn with distinction he worked in the Division of General Internal Medicine of the School of Medicine of the University of Pennsylvania and later at the Center for Injury Research and Prevention at The Children's Hospital of Philadelphia. He entered graduate school at the University of Washington in the Department of Epidemiology in the School of Public Health where he first obtained a MPH later a PhD. After completing graduate school he became a Post-Doctoral Fellow at the Harborview Injury Prevention and Research Center.