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Injuries as a Result of California Earthquakes in the Past Decade

Kimberley I. Shoaf
UCLA

Loc H. Nguyen
UCLA

Harvinder R. Sareen
UCLA

Linda B. Bourque
UCLA

The devastating effects of earthquakes have been demonstrated repeatedly in the past decade, through moderate and major earthquakes such as the October 1987 Whittier Narrows earthquake (5.9 on the Richter scale), the October 1989 Loma Prieta earthquake (7.1) and the January 1994 Northridge earthquake (6.7). While 'official' tallies of injuries and deaths are reported for each event, the numbers vary from report to report. For Northridge, the number of injuries vary between 8,000 and 12,000; the number of deaths from 33 to 73 (Peek-Asa et al., 1997; Durkin, 1996).

While official estimates are commonly reported following disasters, the study of actual numbers, types and causes of casualties has not developed. In this paper, we identify the numbers and risk factors for injuries within community-based samples across three earthquakes in urban California. We first report the numbers and types of injuries in each earthquake and then identify risk factors specifically associated with the Northridge earthquake.

Key words: earthquakes, 1994 Northridge, California, risk factors, injury tally, injury risk.

Introduction

According to official reports, each year approximately 300 natural disasters occur worldwide exacting a human toll of approximately 250,000 lives. Earthquakes alone account for approximately 8,000 deaths and 26,000 injuries globally every year (Alexander, 1996). Past research has suggested that earthquakes in the range of 6.4–7.5 magnitude on the Richter scale will result in injuries and deaths in a ratio of three injuries for every death. This generalisation, however, oversimplifies the impact of earthquakes. Casualties as a direct result of earthquakes vary with the intensity of the shaking, the local soil conditions, the built environment, the time of impact, the population density and the location and behaviour of potential victims (Guha-Sapir, 1991; Alexander, 1985; Mahoney and Reutershan, 1987; Jones et al., 1990; Alexander, 1996).

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The literature also suggests that the number and type of injuries resulting from earthquakes are related to the demographic make-up of the affected community. However, while the various authors consistently suggest that children, women and the elderly are at increased risk for injury and death, the relative number of reported casualties among these groups is inconsistent. For example, in Italy, older children (ages 5–9) were reported to be at increased risk for death, which the authors attributed to parents paying more attention to younger children in the aftermath of the disaster (Guha-Sapir, 1991). In Guatemala, on the other hand, the second-youngest child was most at risk for death with the risk decreasing with increased age (Glass et al., 1977). The authors identified the sleeping patterns of the family as a major contributor to this distribution. The youngest child in Guatemala usually sleeps with the mother and displaces the next-youngest child to another, less protected sleeping position in the household. As children's age increased, they were more likely to be able to move to avoid falling objects.

A range of cultural factors, such as who sleeps where, are most likely a major explanation of the differential morbidity and mortality observed across 'vulnerable' sub-populations. For example, in the Kobe earthquake, more than half of all fatalities were people over 60 years old. One reason for their higher vulnerability was that, in Japan, the elderly often live on the ground floor of dwellings so that they do not have to climb stairs, while younger individuals occupy the upper floor. Collapse of a two-storey structure tends to result in higher mortality on the ground floor rather than the first. The elderly also were more likely to live in old wooden houses or in tenements, which were disproportionately damaged in the earthquake. Thus, the elderly were at greater risk, not necessarily because they were more vulnerable, but because they occupied a more exposed location (Tanida, 1996).

The difficulties associated with studying earthquake-related injuries and deaths is another reason for the variations found in risk factors for injuries across events. One difficulty encountered in the disaster casualty literature is the inconsistency of methodologies and case definitions across studies. In the US, generally mortality data are taken from coroners' reports. While an exact count of most deaths which occur within a certain period after the event can be obtained from these records, attributing those deaths directly to the disaster is not so straightforward.

The variation in the mortality figures for the Northridge earthquake demonstrates this difficulty. The lowest number reported (33, as reported by Peek-Asa et al., 1997) includes only those deaths from physical trauma that could be either directly or indirectly attributed to the earthquake. The highest number (73, as reported by Durkin, 1995) includes medical conditions that occurred after the earthquake. It is difficult to attribute these medical conditions (for example, heart attacks, strokes, etc.) to the earthquake for a variety of reasons. While it would be possible to design a study which assessed whether deaths from medical conditions such as myocardial infarctions increased during and immediately after an earthquake, one would need to study trends over time. However, it is virtually impossible to determine if a given individual's heart attack was in any way 'caused' by an earthquake.

An even more daunting task is identifying the injuries that result from the disaster. Except for the most catastrophic events, severe injuries and deaths directly attributable to the disaster are rare events. Finding those rare events is difficult at best. While identifying those persons who presented at hospitals with injuries on the day of the event is potentially feasible, the task in reality is intimidating. As found in a Los

Angeles County Department of Health Services Injury and Violence Prevention Program study, record keeping at hospitals during a crisis takes a 'back seat' to patient triage and treatment (Mahue, 1996). Emergency-room logs may not be available for a majority of the hospitals involved in the disaster, especially for those institutions that are in the affected area. At hospitals where records were kept, determining the exact cause of the injury may still be difficult because of the incomplete nature of the records. Thus, it is hard to differentiate those injuries caused by the disaster from injuries not attributable to the disaster.

Because of the tedious nature and amount of time involved in actually abstracting medical records from all health-care institutions, reports of injuries, at best, have been based on data received from rapid assessments of major hospitals (Cheu, 1995; Mahue, 1996). The reports given in rapid assessments are often based on quick estimates made by hospital personnel at the time of the crisis and may not be based on any hard data. In addition, these data do not take into account injuries that did not result in care being provided at a hospital. Many individuals may seek care from private physicians, urgent care centres and clinics that are not included in the population of facilities from which assessments are made. Additionally, less-severe injuries may not require care beyond simple first aid and, thus, would not present at any health-care institution. Because of the difficulty in obtaining accurate data, many earthquake casualty studies rely on small studies of selected hospitals, or anecdotal reports of the numbers, types and causes of injuries. Extrapolating from limited studies results in generalisations that if tested may be found to be untrue.

Methodology

Sample

Random-digit-dial (rdd) telephone surveys[1] were conducted with residents of the affected areas after each of three earthquakes in the past decade in California. After the Whittier Narrows earthquake, interviews were conducted with 690 residents of Los Angeles County between 12 and 18 months post-event. Following the Loma Prieta earthquake, interviews were conducted with 656 residents in the five counties in the San Francisco Bay area between six and 10 months following the disaster. After the Northridge earthquake, computer-assisted telephone interviews (CATI) were conducted with a total of 1,830 residents of Los Angeles County in three waves of cross-sectional data collection between six and 24 months post-impact. All three studies used similar instruments in collecting the data and interviews were conducted in both English and Spanish by trained telephone interviewers from the UCLA Institute for Social Science Research, Survey Research Center.

In both the Whittier Narrows and Loma Prieta studies, oversampling was undertaken in the high-impact areas. In the Whittier Narrows study, the areas of oversampling included the communities of Monterey Park, Rosemead, El Monte, South El Monte and Whittier. Respondents from the rest of the county were weighted to represent 2.4 individuals each, for a total weighted sample size of 1,309 cases.

In the Loma Prieta study two different oversampling areas were demarcated. One area of oversampling included those areas of San Francisco and Alameda counties adjacent to the Bay Bridge and included the Marina district. The other area included

parts of Santa Clara and Santa Cruz counties. Weights were calculated based on the sampling proportions with those from the general five-county area receiving a weight of 6.2; those in the oversampled San Francisco/Alameda area being assigned a weight of 6.0; and those in the oversampled Santa Clara/Santa Cruz area being weighted as 1.0. The total weighted sample contains 3,416 cases. The survey following the Northridge earthquake was conducted using a population proportionate to size (PPS) sample with no oversampling, for a total sample size of 1,830 cases in Los Angeles County (see Bourque et al., 1997 for details of the Northridge sample).

Questionnaires

The instrument used to collect the data was similar after all three earthquakes. It collected information about the effect of the earthquake on the household including questions about damage to the house, injuries to household members and power cuts; respondents' reactions to the earthquake including questions about evacuation and information-seeking behaviours; and general socio-demographic characteristics of the household and respondent. The questions about injuries varied slightly between the three studies. Following the Whittier Narrows and Loma Prieta earthquakes, respondents were asked:

> In this earthquake was anyone you know injured? Who was that? Can you tell me about that? Who exactly was this and how were they injured?

Following the Northridge earthquake, respondents were asked:

> First of all, how about you, did you have any physical injuries — even minor cuts and bruises — as a result of this earthquake? When exactly were you injured? Were you injured during the earthquake itself, immediately after the earthquake, within the first 48 hours after the earthquake, during an aftershock, or some other time? Can you describe exactly what happened to cause your injury/injuries? What exactly was your injury? What part(s) of your body was (were) injured? Did you seek medical care for your injury?

Similar questions were asked about other family members. Additionally, in the Northridge study, respondents were asked a similar set of questions about emotional injuries to themselves and other family members.

Analysis

These analyses focus on the numbers and types of injuries incurred by the respondent as a result of the earthquake. Univariate analyses of the number and type of injuries are reported for the three earthquakes. Bivariate analyses are further conducted to identify major trends in injuries for the three quakes.

Additional bivariate and multi-variate analyses were conducted for the Northridge earthquake study to identify demographic and earthquake characteristics which are associated with reporting an injury. Cross-tabs with chi-square analysis examined

associations between variables and one-way analysis of variance (ANOVA) was used where interval level variables were available. A logistic regression was conducted to identify the predictors of being physically injured in the Northridge earthquake. All independent variables of interest were entered into the regression simultaneously. Variables which did not approach significance were eliminated and the model re-run for parsimony.

Demographic variables that were examined as predictors of injury were the respondent's age; gender; marital status (comparing those who are married or living together as married with those who have never been married or who are widowed or divorced); race/ethnicity (white, Hispanic/Latino, black or other in the bivariate analyses; Latino vs all others in logistic regression); family income; and type of dwelling (house, apartment or other). Characteristics of the earthquake's impact on the respondent that are examined include: damage/inspection status of the home (comparing no damage to damaged but not inspected; inspected but not tagged; green tag; yellow tag; or red tag)[2]; Modified Mercalli Intensity (MMI)[3]; Peak Ground Acceleration (PGA)[4]; and perception of oneself as an earthquake victim (comparing those who said they were 'not at all a victim' to those who said 'somewhat a victim' and 'definitely a victim'). The relationship between the respondent's first actions at the time of the earthquake and whether or not s/he was injured was also examined. For those respondents who were not in a car at the time of the earthquake, those who stayed in one place during the earthquake were compared to those who moved or attempted to move.

Results

The sample

The samples reflected the demographic characteristics of the respective communities from which they were drawn (see Table 1). All three samples had slightly less than half of the sample as male (46.4 per cent, 43.6 per cent and 45.8 per cent). Differences in age, ethnicity and income between the samples reflect differences between northern and southern California as well as differences across time. For example, northern California has a smaller percentage of Latinos in the population compared with Los Angeles County (17.3 per cent vs 25.4 per cent in the 1990 Census).

Table 1 Selected demographic characteristics of the sample: Whittier Narrows, Loma Prieta, Northridge

Characteristics	*Whittier Narrows*	*Loma Prieta*	*Northridge*
Male	46.4%	43.6%	45.8%
Race/ethnicity			
White	56.4%	68.2%	44.5%
Hispanic	26.3%	12.1%	35.9%
Black	10.2%	9.0%	9.9%
Other	6.2%	10.5%	9.7%
Mean age (years)	43.9	45.8	41.0
Mean family income	$33,281	$47,252	$38,899

Table 2 Demographic characteristics of injured respondents across three earthquakes

Characteristic	*Whittier Narrows*		*Loma Prieta*		*Northridge*	
	Uninjured	*Injured*	*Uninjured*	*Injured*	*Uninjured*	*Injured*
Female	53.2%	90.9%*	56.4%	59.1%	53.4%	63.1%*
Race/ethnicity						
White	56.4%	60.0%	68.0%	100.0%*	43.3%	58.1%*
Black	10.3%	20.0%	12.1%	0.0%	37.2%	11.5%
Latino	26.9%	20.0%	9.0%	0.0%	9.8%	21.6%
Other	n/a	n/a	10.6%	0.0%	9.7%	8.8%
Mean age	43.9	39.8	45.8	57.9*	41.3	37.3*
Mean income	$33,280	$32,000	$40,815	$44,867	$38,847	$39,262

* Chi-square or ANOVA significant $p < 0.05$

Injuries across the three earthquakes

Following both the Whittier Narrows and Loma Prieta earthquakes, less than 1 per cent of respondents reported being physically injured as a result of the earthquake (0.8 and 0.7 per cent, respectively). Following the Northridge earthquake, 8.2 per cent of respondents reported being injured as a result of the earthquake.

Characteristics of those injured

Table 2 compares the basic demographic information for those reporting injuries in or after each of the three earthquakes against those not reporting injuries. After the two Los Angeles County earthquakes, females were more likely to report being injured. After the Loma Prieta and Northridge earthquakes, whites were more likely to report being injured. There was no difference in income between injured and non-injured for any of the three earthquakes. There was a relationship between age and injury for Northridge and Loma Prieta. After the Loma Prieta earthquake, injured respondents were significantly older than non-injured (57.9 vs 45.8 years old). After the Northridge earthquake, injured respondents were significantly younger than non-injured (37.3 vs 41.3 years old). Following the Whittier Narrows earthquake, there was no significant difference in age between injured and non-injured.

Types and causes of injury

The majority of injuries reported in all three earthquakes are minor. For the Loma Prieta and Northridge earthquakes most reported injuries are cuts, bruises and sprains (83 per cent for Northridge and 45 per cent for Loma Prieta). Following the Whittier Narrows earthquake, however, 40.5 per cent of injured respondents reported minor head injuries (Figure 1). Emotional injuries were self-reported by 23 per cent of respondents following the Whittier Narrows earthquake. No reports of emotional injuries followed the Loma Prieta earthquake. After Northridge, the separate question about emotional injuries resulted in 32 per cent of respondents reporting them; these are not included in the analyses.

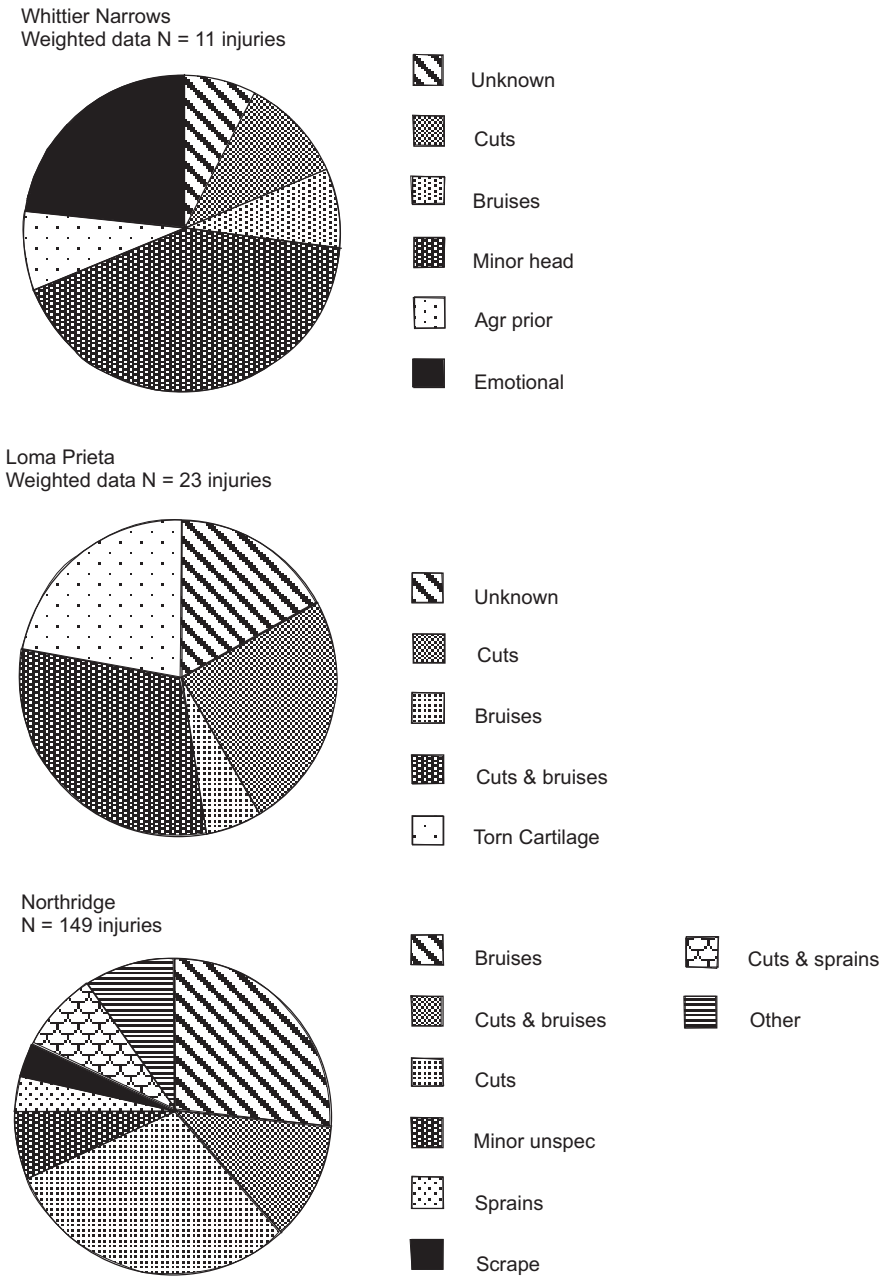

Figure 1 Types of injuries in Whittier Narrows, Loma Prieta and Northridge

The mechanisms of injury varied across the three earthquakes (Figure 2). In the Whittier Narrows earthquake, non-structural elements (objects, pictures and lights) were reported as the cause of approximately half of the reported injuries. Falls accounted for an additional 19 per cent of the injuries in that quake. Following the

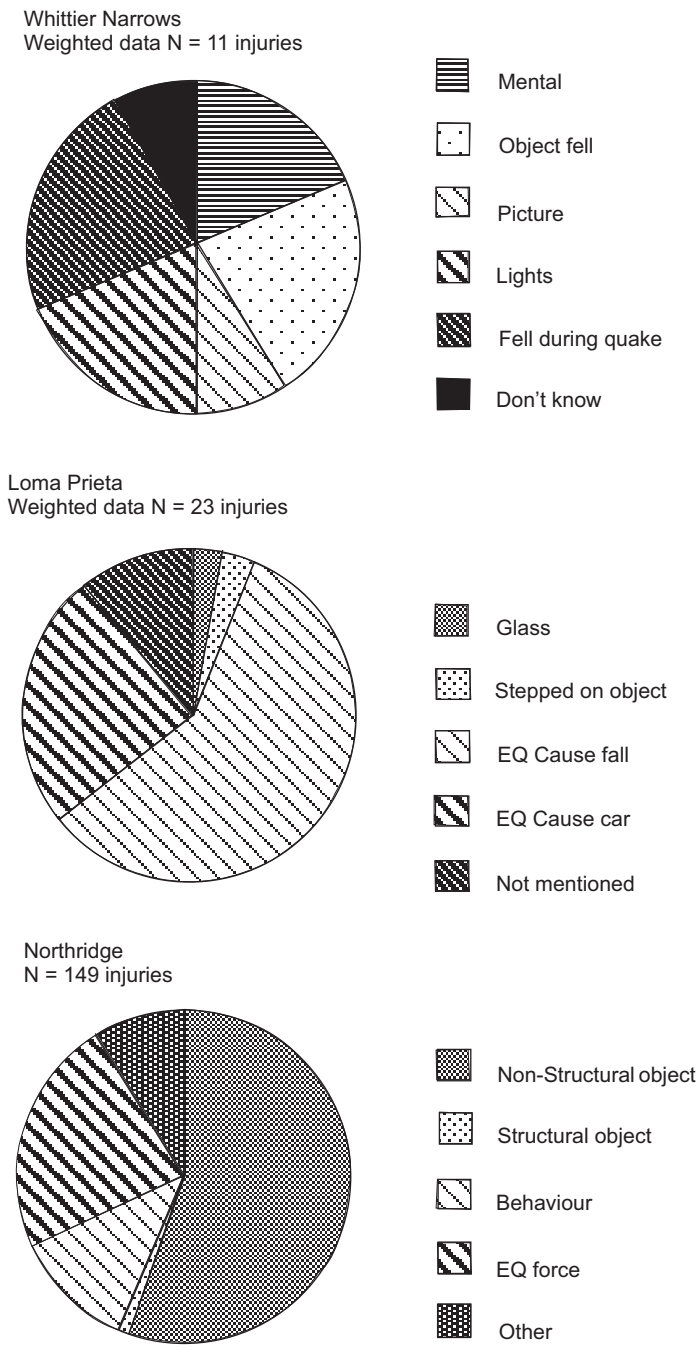

Figure 2 Cause of injuries in Whittier Narrows, Loma Prieta and Northridge

Loma Prieta earthquake, non-structural elements accounted for less than 10 per cent of injuries. The force of the earthquake caused 55 per cent of injured respondents to fall, while 27 per cent had the force of the earthquake move their car, thereby causing an injury. During the Northridge earthquake the majority of injuries were caused by non-

structural elements falling (55.2 per cent), followed by the physical force of the earthquake (22.1 per cent). Approximately 15 per cent of injuries immediately after the Northridge earthquake were caused by the behaviour of the individual (for example, jumping out of a window, catching a falling television, etc.). Less than 1.0 per cent of injuries in the Northridge earthquake and no injuries following either Whittier Narrows or Loma Prieta were caused by structural elements falling or building collapse.

Body part injured

The body part that sustained injury was specifically reported following both the Loma Prieta and Northridge earthquakes. In the Loma Prieta earthquake, injuries to the trunk were most common (54.8 per cent) whereas in Northridge, the extremities were the most commonly reported injury site (68.4 per cent). The only mention of body site after the Whittier Narrows earthquake was by those suffering from minor head injuries (40.5 per cent). There were no mentions of head injuries following Loma Prieta. In the Northridge earthquake, 11.9 per cent of injured respondents reported injuries to the head (Figure 3).

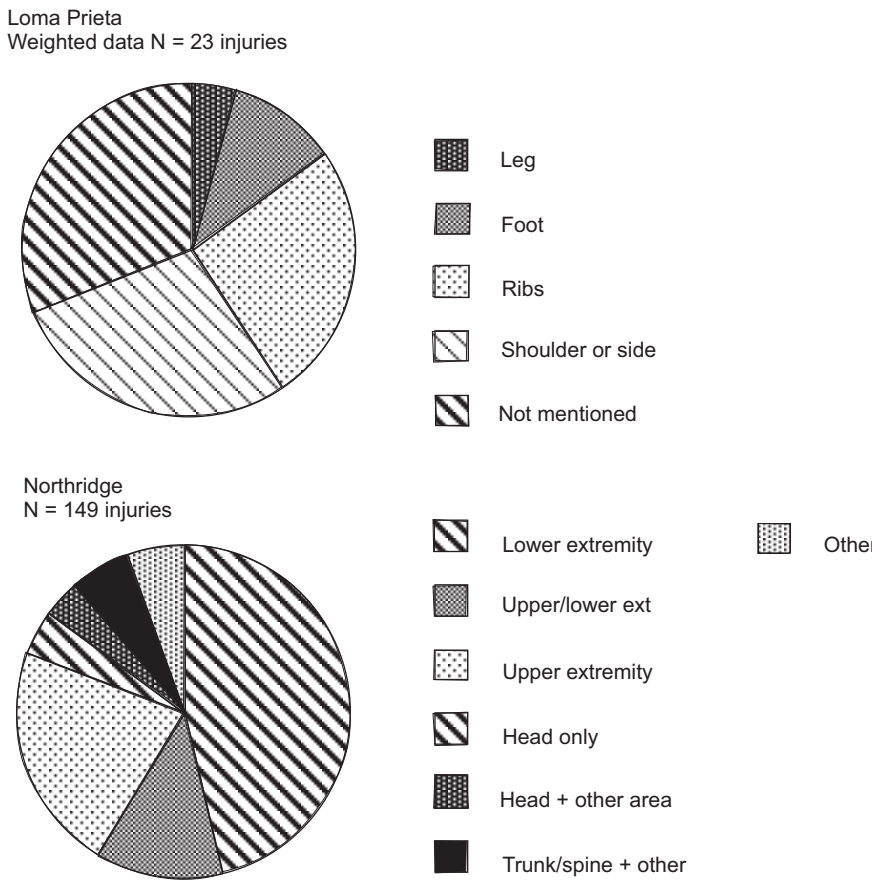

Figure 3 Body site of injury in Whittier Narrows, Loma Prieta and Northridge

Care seeking

Respondents were not specifically asked about whether or not they sought care for their injuries after either the Whittier Narrows or Loma Prieta earthquakes. After the Northridge earthquake, however, the question was asked explicitly. Approximately 10 per cent of injured respondents ($n = 15$) sought care for their injuries. Of those seeking care, one-third ($n = 5$) sought care at hospitals, one-third ($n = 5$) sought care from clinics or private physicians. The final third either did not mention the source of care or received care from friends, neighbours, the Red Cross or the EMS system.

Predictors of injury

Bivariate analyses of the Northridge earthquake data indicate that both demographic characteristics of the respondent and experiences during the earthquake were related to reporting being physically injured. Those who were married or living together; males; those living in single-family dwellings (houses); and Latinos were less likely to report being injured in the Northridge earthquake (Table 3). Older individuals were also less likely to report being injured in the earthquake. The mean age for injured respondents was 37.3 years whereas that for the non-injured was 41.3 years. Education was also related to reporting a physical injury. Those reporting an injury had a mean of 13.9 years of schooling compared with 12.9 years for those not reporting an injury. The type of dwelling that one lived in was also related to being injured. Those who lived in houses or single-family dwellings (6.2 per cent) were almost half as likely to report being injured as those living in apartments (10.7 per cent) or other types of dwellings (10.7 per cent). Having children present in the home was unrelated to being injured (8.1 vs 8.3 per cent).

Earthquake-related variables associated with reporting an injury included damage/inspection status of the home; Modified Mercalli Intensity; peak ground acceleration and one's self-perception as an earthquake victim (Table 4). As the level of damage suffered by the respondent increased as measured by either PGA, MMI or inspection status of the home, the percentage of individuals reporting injuries increased. The relationship, however, is not a simple linear one, as those whose homes were yellow tagged and those in MMI VIII areas have higher rates of injury than those with red tags and those in MMI IX, respectively. A one-way analysis ofvariance of the PGA and injury showed that the PGA for those who were injured was 0.41 compared with 0.24 for those not reporting an injury ($F = 172.9$, $p < 0.001$). The relationship between injury and PGA within postal code areas is linear. A bivariate correlation between percentage of respondents injured and the mean PGA by post code shows a moderate positive linear relationship ($r = 0.59$).

Being injured is also related to perception of oneself as a victim of the earthquake. Those who perceived themselves as 'very much a victim' have twice the rate of injury as those who perceived themselves as 'somewhat a victim' and seven times the rate as those who did not perceive themselves as victims (20.8 vs 11.6 vs 3.0 per cent).

Whether or not the respondent moved or attempted to move at the time of the earthquake was also related to reporting injuries. For those who reported moving or attempting to move from where they were, 10.4 per cent reported being injured, whereas only 6.1 per cent of those who stayed in place reported being injured.

Table 3 Demographic characteristics of injured respondents in Northridge earthquake (n = 1,827)

Characteristic	*Injured*
Gender*	
Female	9.5%
Male	6.6%
Marital status*	
Married or living together	6.7%
Single, widowed, divorced	9.6%
Race/ethnicity*	
White	10.6%
Hispanic	4.9%
Black	9.4%
Other	7.4%
Children in the home	
Yes	8.1%
No	8.3%
Type of dwelling*	
House	6.2%
Apartment	10.7%
Other	10.7%

* Chi-square statistic $p < 0.05$

Table 4 Earthquake characteristics of injured respondents in the Northridge earthquake (n = 1,827)

Characteristic	*Injured*
Damage/inspection status of home*	
Not damaged	2.3%
Not inspected	10.9%
Not tagged	15.7%
Green tag	27.6%
Yellow tag	45.0%
Red tag	28.6%
MMI*	
< VI	2.2%
VI	1.8%
VII	11.1%
VIII	24.6%
IX	22.2%
Mean PGA*	
Injured	0.41g
Not injured	0.24 g
Perceive self as victim*	
Not at all	3.0%
Somewhat	11.6%
Very much	20.8%
First action at time of quake (n = 1,715)*	
Stayed in place	6.1%
Moved or attempted to move	10.4%

* Chi-square statistic $p < 0.05$

Who moved

Those who moved or attempted to move after the earthquake differed by their age, whether they did or did not have children in the home and by their race/ethnicity (Table 5). Neither gender nor marital status were predictive of moving at the time of the earthquake. Latinos were most likely to move from where they were at the time of the earthquake, followed by blacks (67.2 and 59.5 per cent, respectively). Those who moved were also significantly younger than those who stayed in place (38.8 vs 44.1 years of age). Those who had children in the home were also more likely to move (66.2 vs 52.7 per cent).

Logistic regression model

A logistic regression model indicates that both demographic characteristics and earthquake-related variables are important in predicting physical injuries. Table 6 demonstrates that when all other variables in the model are controlled for, those who

Table 5 Characteristics of individuals who moved or attempted to move during the Northridge earthquake

Moved or attempted to move	
Race/ethnicity*	
White	53.7%
Latino/Hispanic	67.2%
Black	59.5%
Other	51.6%
Gender	
Male	57.1%
Female	60.5%
Marital status	
Married/living together	58.2%
Not currently married	59.6%
Children in the home	
Yes	66.2%
No	52.7%
Mean age (years)	
Moved	44.1
Didn't move	38.8

* Chi-square or ANOVA significant, $p<0.05$

are younger, not married and Latino are less likely to report being injured. Latinos are almost half as likely to report being injured as those from other racial/ethnic groups (OR = 0.54). Those who are married (or living together) are two-thirds as likely to report being injured as those who are divorced, widowed or never been married (OR = 0.64). Females are 1.6 times as likely to report being injured as males.

Earthquake characteristics are also predictive of injury. In the logistic regression model, damage and inspection status of the home continues to demonstrate an almost linear relationship with reporting an injury. Comparing each category with those reporting no damage to their home or personal property, those who had damage to their home but no inspection were 3.2 times as likely to report injuries; those whose home was inspected but not tagged were four times as likely; those whose home received a green tag were seven times as likely; those whose home received a yellow tag were almost 10 times as likely; and those with a red tag were seven times as likely to report being injured as those with no damage to their homes.

Two other measures of the effect of the earthquake are also predictive of reporting being injured in the earthquake. The estimated PGA in the postcode area where the respondent's home is located is a strong predictor of injury. For every increase of 0.1g in acceleration, the odds of being injured increase 1.3 times. Those who felt that they were 'somewhat a victim of the earthquake' were 2.5 times as likely to report being injured as those who said that they were 'not at all a victim of the earthquake'. Those reporting being 'definitely a victim' were 3.2 times as likely to report being injured as those who were 'not at all a victim'.

A final predictor for being injured is the respondent's actions at the time of the earthquake. When controlling for demographic and earthquake characteristics, those

Table 6 Logistic regression predicting physical injury, Northridge earthquake

Characteristic	*B*	*Significance*	*Odds ratio*
Age (for 10 years increase)	−0.35	0.00	0.70
Married/living together	−0.44	0.05	0.64
Female	0.50	0.03	1.64
Latino	−0.61	0.03	0.54
Damage/inspection status of home (no damage is comparison category)		0.00	
Not inspected	1.17	0.00	3.21
Not tagged	1.40	0.00	4.04
Green tag	1.95	0.00	7.02
Yellow tag	3.20	0.00	9.98
Red tag	1.95	0.02	7.01
PGA (for 0.1 increase)	0.27	0.00	1.30
Perceive self as victim (Not at all is comparison category)		0.00	
Somewhat a victim	0.91	0.00	2.49
Definitely a victim	1.17	0.00	3.22
Respondent moved or attempted to move	0.72	0.00	2.05
CONSTANT	−3.82	0.00	

Initial −2 log likelihood = 824.69; −2 log likelihood = 597.29;
Model improvement chi-square = 227.4; $p < 0.05$

respondents who reported moving or attempting to move at the time of the earthquake were twice as likely to have been injured in the earthquake as those who reported staying where they were (OR = 2.05).

Discussion

All three of these earthquakes were moderate-intensity earthquakes which occurred in urban areas, yet their impact on the population differed greatly. The differences in wording of the questions about injuries may have accounted for some of the disparity in injury rates between the Northridge earthquake (8.2 per cent) and the smaller Whittier Narrows event (0.7 per cent injured) and the larger Loma Prieta event (0.8 per cent injured). After the Northridge earthquake, respondents were asked separately about injuries to themselves and to others. The question also specifically asked about 'even minor injuries such as cuts and bruises'. This may have led to the increase in the number of respondents who reported minor injuries in the Northridge event.

The differences, however, may be real differences in injury rates. The Loma Prieta event was the largest event, measuring 7.1 on the Richter scale. Yet the epicentre of the earthquake was in the mountains far from the densely populated sections of the Bay area. The distance from the epicentre to the most populated parts of the area may account for the lower injury rate as compared to the Northridge earthquake. Modified Mercalli Intensities for the areas outside of Santa Cruz/Santa Clara did not exceed VIII and most respondents lived in areas represented by MMI VI or VII. Likewise, the

MMIs in the Whittier Narrows event were VII/VIII in the high-intensity area and VI in the rest of the county. In the Northridge earthquake, around 2.0 per cent of respondents in the areas with MMIs of VI or less were injured, similar to that found in both the Whittier Narrows or Loma Prieta earthquakes. In the higher intensity areas in the Northridge earthquake, 20–25 per cent of respondents reported being injured. While the higher intensity areas in the Northridge event did not represent the largest portion of Los Angeles County, it is a larger and more densely populated area than the high-intensity areas of the Loma Prieta earthquake. This suggests that more people were at risk of injury in the Northridge event because of the proximity of high levels of shaking to densely populated areas. These results indicate that injuries generally occur in earthquakes that result in MMIs of VII or greater, with an increasing proportion of the population being injured as the Mercalli Index increases.

Intensity of the earthquake's impact on an area, as measured by MMI, PGA and damage/inspection status of the respondent's home were significantly associated with injury status in the Northridge earthquake. Those individuals who were in the areas of higher intensity were more likely to be injured than those in the lower intensity areas. However, the relationship is not invariable. Around 2.0 of individuals who were not significantly affected by the earthquake in other ways (as measured by MMI and damage/inspection status of the home) were injured as a result of the earthquake. Generally, one would expect very little damage in areas with an MMI of less than VI as that is part of the definition of the MMI scale. An MMI of VI is generally associated with minor amounts of damage — especially to poorly constructed buildings — and no structural collapse. This suggests that injury is not just a factor of the amount of damage suffered in an earthquake and certainly not just a factor of structural collapse as often reported. There are obviously other factors which must be taken into consideration.

While the percentage of individuals injured differed between the three events, the types of injuries were similar across the events. The vast majority of injuries reported for all three earthquakes were minor injuries, mostly cuts and bruises. There are however, some differences in locations of injuries. In the Loma Prieta earthquake, the majority of injuries were to the trunk and upper extremities. In the Northridge earthquake, most injuries were to the lower extremities. This may have to do with the time of day that the earthquake occurred. In the dark, respondents could not see objects that they struck or fell over, whereas in the light, victims were more likely upright and struck by falling objects.

Factors associated with being injured

These analyses, like the studies reported in the literature, also provide contradictory evidence of those who are most 'at risk' for being injured in an earthquake. Women had higher rates of injury in the two southern California earthquakes but not in the Loma Prieta earthquake. Likewise, the question remains as to whether or not injury in an earthquake is associated with age. In Loma Prieta older individuals were more at risk; in Northridge younger individuals were; in Whittier Narrows age did not matter. This suggests that neither age nor gender can be considered simple risk factors for injury in an earthquake. Both of these characteristics, however, may be indicative of other risk factors, which are associated with age and gender. The time of day that an earthquake strikes is an important factor in injuries. What needs further exploration is

how gender and age relate to where an individual is at the time of an earthquake. The Loma Prieta earthquake occurred in the afternoon, whereas the Northridge event occurred at 4:31 a.m. Those who were indoors were more likely to be injured. Older individuals were more likely to be at home (and indoors) in the afternoon, therefore the elderly were more likely to suffer minor injuries. Since the Northridge earthquake occurred when more than 90 per cent of respondents were at home (and to a lesser extent Whittier Narrows), older age was not predictive of injury in either of those earthquakes.

Older individuals may also be less likely to attempt risky behaviour associated with injury in an earthquake, such as running or trying to catch falling objects. Indeed, those who attempted to move or moved during the Northridge earthquake were significantly younger than those who stayed in place. Yet staying in place during the earthquake does not present a full picture of who was most likely to report being injured either.

Some variables associated with movement during the earthquake — children in the home, age and race/ethnicity — act in different directions. Age is associated with movement in the expected direction. Those who move are more likely to be younger, and younger individuals are more likely to be injured. Latinos, however, are most likely to move in the earthquake yet are least likely to be injured. Latinos were more likely to live in areas with MMIs of VII or less which could contribute to their lower injury rates, regardless of their movement in the earthquake. Individuals who have children in the home are more likely to move, although having children in the home is not associated with injury. This needs to be explored further.

Another factor which needs to be examined more carefully is the mechanism by which the majority of injuries occur across the three earthquakes. Non-structural items falling were the cause of more injuries across the three events than any other single element. Structural reinforcement of the home is emphasised in earthquake-preparedness activities, with only secondary attention paid to securing non-structural items such as bookcases and heavy furniture. While the structural integrity of a building was the major cause of mortality in the Northridge earthquake (22 of 33 earthquake-related injury deaths), injury morbidity was mostly associated with non-structural elements that either hit or cut individuals or caused them to fall (Peek-Asa et al., 1997).

Implications

These surveys demonstrate that many more individuals may be injured in moderate-intensity earthquakes in the United States than previously thought. Extrapolated to the 1990 Census data for the San Francisco/Oakland/San Jose Metropolitan Statistical Area (MSA) and Los Angeles County, these injury rates suggest that approximately 24,000 households in the Whittier Narrows earthquake, 16,100 households in the Loma Prieta earthquake and 240,000 households in the Northridge earthquake had at least one adult occupant injured. If the 10 per cent of injured respondents seeking care in the Northridge event is applicable to the other two events, this would suggest that, at a minimum, care was sought by individuals from 2,400 households in Whittier Narrows, 1,600 households in Loma Prieta and 24,000 households in Northridge.

These numbers do not match well with the ‘official’ reports of the number of individuals injured in any of the three earthquakes. For Whittier Narrows, the number

derived from this survey is almost double the 1,349 reported injuries (Tierney, 1988). For Loma Prieta, the number is less than half the official number of 3,757 (Benuska, 1990). For Northridge, the number is two to three times the reported numbers of 8,000–11,000 injuries (OES, 1994; Durkin, 1995). The difference may be explained partly by where individuals seek care for their injuries and how likely they are to be picked up in 'official' reports. Following the Northridge earthquake, one-third of injured respondents who sought care did so at hospitals. The remaining 66 per cent sought care either at clinics, private physicians' offices or other sources of care such as the Red Cross or friends, where the likelihood of being included in an official count is small. When we use survey data to estimate the number of individuals who sought care at hospitals after the Northridge earthquake, approximately 8,000 injuries are calculated. This number is similar to that reported in official documents for the earthquake. The official number, however, ignores a significant number of injuries that were treated elsewhere in the health-care system. Even if we exclude those who received care through an informal network of friends and family members, a minimum of 8,000 additional individuals were treated by the health-care system in the aftermath of the Northridge earthquake.

These studies should also cause us to reflect on the earthquake-preparedness messages that are being sent out to the community. Securing non-structural items should be emphasised in messages, not as a secondary strategy, but as a primary mechanism for reducing morbidity from injuries. These messages should include suggestions not only for securing heavy furniture but for the placement and security of small items that can be thrown about in an earthquake such as glass, mirrors, books and knick-knacks. Many items are currently available for securing both heavy furniture and smaller items and should be promoted as an injury-prevention technique.

The suggestions to 'duck' under a heavy piece of furniture, 'cover' your head and 'hold' on to the furniture may be valid in a daytime earthquake when people may be in vulnerable areas and can see what is around them. An earthquake that occurs when individuals are in bed and in the dark is a different situation. The Northridge data indicate that those individuals who stayed in bed were less likely to be injured in this earthquake. The fact that this earthquake occurred not only when most people were still in bed, but when it was extremely dark, compounded the danger of getting out of bed and walking (or running) to a 'more secure' place. Items flew about and broke on the floor, heavy furniture overturned or moved, and the darkness prevented individuals from seeing the dangerous route that they needed to take to 'duck' under a heavy piece of furniture. Under the circumstances, it is not surprising that staying in bed was safer.

Conclusion

These three moderate earthquakes had a significant impact on the populations affected. These studies, like others in the literature, continue to provide mixed results as to who are most susceptible to injuries in an earthquake. It is not a simple matter of there being a 3:1 ratio of injuries to deaths. Nor are there clearly identifiable 'vulnerable' populations that are always at increased risk for injuries in an earthquake.

These studies also suggest that the focus of preparedness messages for earthquakes might require updating. It is not always best to 'duck, cover and hold' and structural reinforcement may not be the best use of mitigation money. One clear outcome of

these three studies is that, contrary to some expert opinion, we do *not* know all there is to know about the causes or consequences of injuries in earthquakes.

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Notes

1. A sample created by random digit dialing is based on a randomly generated set of phone numbers. The telephone codes for the area under study are selected. Then random numbers are generated for the remaining four digits for phone numbers to be used in the sample. With this approach, every possible number in the area has a chance to be included in the sample (Aday, 1996).
2. Following the Northridge earthquake, ATC-20 Procedures for Post-earthquake Safety Evaluation of Buildings was used to identify buildings that are unsafe for occupancy. One of three coloured tags may be posted based on the result of the inspection. Red tags signify that the building is 'unsafe' for entry. Yellow tags signify that 'limited entry' is permitted but the building is not safe for general occupancy. Green tags indicate that the building is safe for occupancy (Ranous, 1995).
3. Modified Mercalli Intensity (MMI) areas are determined by reports from US Post Office employees who estimate the amount of shaking in the area around their offices and the extent and type of damage sustained by nearby major structures (roads, motorways, apartments and commercial buildings). Damage and intensity are classified using a scale from I–XII, where I represents 'not felt except by a very few under especially favorable circumstances', and XII represents 'Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air' (Dewey et al., 1995: 40–43). Following the Northridge earthquake, MMIs in southern California varied from less than VI to IX according to EQE International (EQE International and The GIS Groups of the Governor's Office of Emergency Services, 1995). Mercalli Intensities for the Loma Priesta earthquake ranged from less than VI to IX with the highest intensities in the Santa Cruz/Santa Clara area. In the Whittier Narrows earthquake, MMIs were VII/VIII in the highest intensity area and VI or less in the rest of Los Angeles County.
4. Peak Ground Acceleration is a physical measure of the amount of vertical and lateral movement of the earth as measured on seismographs as a ratio of that force of gravity (e.g. a PGA of 0.25g represents a force that is one-fourth the force of gravity or 0.25: 1). A contour map overlain on to the LOG (PGA) contour map developed by EQE and OES/GIS. For each mapped postcode, the areal amount of the code falling between the LOG (PGA) contours was tabulated, and assigned the mean value between the two contours ... ' (EQE International and The GIS roups of the Governor's Office of Emergency Services, 1995).

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Address for correspondence: Dr Kimberley I. Shoaf, Research Director, UCLA Center for Public Health and Disaster Relief, School of Public Health, PO Box 951772, Los Angeles, CA 90095-1772, USA. E-mail: <<kshoaf@ucla.edu>>