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A case-control study of the casualties associated with the Loma Prieta earthquake: County of Santa Cruz

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ABSTRACT: A case-control study was conducted in the County of Santa Cruz (SCC) to examine the risk factors for physical injuries associated with the Loma Prieta earthquake and how the physical environments and personal behaviors of residents of SCC contributed to their risk of being physically injured or killed in SCC during the shaking of the main earthquake and in the subsequent 72 hours. The risk factors (those features associated with an increased risk of sustaining an injury) examined included age of building, type of structure, occupant behavior and sociodemographic characteristics. This paper describes the data collection effort, and presents preliminary results from interim analyses of the data.

1 INTRODUCTION

A critical review of the scientific literature on the causes of earthquake-related deaths and injuries leads to the following general conclusions: 1. A paucity of epidemiological investigations of earthquakes, despite their great lethality; 2. Almost all of the published epidemiological studies on earthquake-related injuries are descriptive rather than analytical, precluding the ability to establish and quantify the magnitude of the relationship between significant risk factors and injuries; 3. Documentation of deaths and, in particular, non-lethal injuries is often incomplete in the aftermath of disaster; 4. Injuries are often vaguely and inconsistently defined in the previous epidemiological studies; 5. Most previous epidemiological studies of earthquakes have been conducted solely by health researchers, even though the topic calls for an interdisciplinary approach which draws on structural engineering, geology, architecture, epidemiology and emergency medicine.

The majority of studies on the risk factors for earthquake-associated injuries actually appear in the earthquake engineering literature. These studies have generally been executed along strict disciplinary lines without input from health professionals. Thus, despite their quantitative approach, these engineering studies do not employ standard epidemiologic methods or meet minimal criteria generally required by epidemiologists to accurately and reliably assess risks. For example, some surveys of earthquake victims are not based on random, probability based samples of a clearly defined study population (Arnold 1986; Durkin 1985); others do not report sufficient information to evaluate the sampling methodology (Mochizuki 1988; Miyano et al. 1988; Ohta et al. 1980; Ohta et al. 1977); still others sample highly select groups (Mochizuki et al. 1988), making it difficult to generalize the results to the rest of the population. Many of these studies either do not report or have unacceptably low case ascertainment or survey response rates. The survey instruments, when described, do not always appear to measure well the stated variables of interest (Ohta, et al., 1980; and Ohta et al. 1977), although this may be due, in part, to poor translations of the questionnaires published in the English-language scientific literature.

Despite these limitations, the literature has identified a number of potentially important risk factors for injuries associated with earthquakes (for a summary see, for example, Jones et al. 1989; Jones et al. 1990a). These include characteristics of the earthquake itself (e.g., magnitude, intensity, distance from the epicenter, time of day and season), geological and topographic conditions (e.g., soil type, cliffs or mountains), post-earthquake environmental conditions (e.g., rain which may cause landslides, extreme cold), the nature of the built

environment (e.g., the degree of seismic resistance of buildings and other human engineered structures, such as bridges), the presence or absence of secondary hazards (e.g., fires, hazardous materials spills, tsunamis), sociodemographic features of the affected population (e.g., population density, age, sex), and human behavior during and after the event (Stratton 1989; Tierney 1990). An extensive critique of the earthquake injury risk factor literature will be published later (Wagner et al. 1993).

1.1 *The Loma Prieta Earthquake*

On Tuesday, October 17, 1989 at 5:04 PM Pacific time, a magnitude 7.1 earthquake with an epicenter 10 miles northeast of Santa Cruz struck the northern California region. The quake caused extensive damage to the Marina district of the City of San Francisco, one span of the Bay Bridge fell from its support, a 1.5 mile section of Interstate 880 (Nimitz Freeway) in Oakland (Cypress Section) collapsed and major structural damage was reported from a number of locations in the County of Santa Cruz. The Loma Prieta event is regarded as the most financially destructive earthquake in the history of the United States.

The County of Santa Cruz (Figure 1) was hard hit by the quake though it did not get the media attention of San Francisco and Oakland. The damage sustained warranted the assignment of the second highest intensity level assigned to the earthquake, i.e., MMI VIII, to much of the County.

Obtaining reliable and accurate estimates of casualties associated with earthquakes has posed serious challenges. Such estimates have varied, in part, because there is no universally accepted definition of earthquake-related deaths and injuries. Furthermore, documentation of injuries has generally taken a lower priority than rescue and treatment activities in the face of disaster. The Loma Prieta Earthquake was no exception. Initial press accounts put the total death toll in the hundreds (Shilts et al. 1989a; Shilts, et al. 1989b), an overestimate by a factor of 3 to 4, and even the scientific literature could not agree on a total count, offering a range of 60 to 67 deaths (e.g., Anon 1990; McNutt 1990; CDC 1989; and USGS 1989). One year after the event, there was still no reliable information on injury morbidity associated with the earthquake (Jones et al. 1990b). The work described below attempts to overcome these and other problems that have characterized previous research in this area.

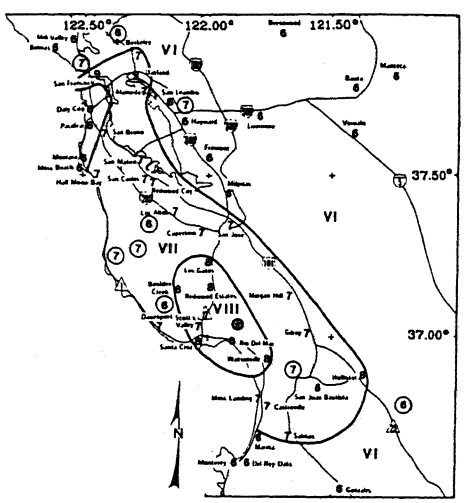

Figure 1: County of Santa Cruz

2 THE LOMA PRIETA CASE-CONTROL STUDY

A case-control study of the risk factors for sustaining physical injuries in the County of Santa Cruz (SCC) associated with the Loma Prieta earthquake was initiated to study how the physical environments and personal behaviors of residents of SCC contributed to their risk of being physically injured or killed in SCC during the shaking of the main earthquake and in the subsequent 72 hours.

2.1 *Specific aims*

The specific primary aims of this study are:

1. To assess the relative risk for physical injury associated with different physical environments (e.g., buildings, vehicles, outside), entrapment, and personal behaviors in the disaster and post-disaster phases of the Loma Prieta earthquake.

2. To assess the relative risk for other potential risk factors for physical injury including pre-existing medical conditions and mobility, drug and alcohol use, and sociodemographic characteristics.

3. To estimate the absolute risk of physical injury mortality and morbidity associated with the Loma Prieta earthquake in SCC.

4. To provide input data for casualty and loss estimation procedures for California (in particular the Bay Area), and other areas of the U.S.

A secondary aim of this study is to determine if physically injured cases who sought treatment at a

hospital were different from those who did not seek such care. For example, selection factors for treatment that will be examined include injury severity, possession of health insurance, and sociodemographic characteristics.

2.2 *Study methods*

The case-control study examines how the physical environments and personal behaviors of SCC residents contributed to their risk of being physically injured or killed in SCC by the Loma Prieta earthquake.

Physical environments are characterized broadly as being inside a building; in or on a vehicle; or outside (in close proximity to a building or away from buildings entirely). Risk factors specific to each environment are also being explored. Buildings are broadly classified as residential, commercial, industrial/farm, and public/institutional. For practical reasons (e.g., knowledge limitations of laypersons), the only attempt made through the questionnaire to infer structural type was through material description; this aspect is likely to require field follow up after preliminary data analyses. Within the building environment, hazards from structural and nonstructural components of buildings are distinguished from dangers posed by building contents. Behaviors of interest include the protection and rescue of oneself and other people, pets, or things, as well as clean-up activities in earthquake-damaged areas. Sociodemographic characteristics examined include age, sex, level of education, occupation, access to health insurance, etc.

The outcomes of interest are earthquake-related physical injuries that occurred during the shaking of the main earthquake (the disaster phase) and the subsequent 72 hours (the post-disaster phase). Injuries are characterized by their type, affected body parts, cause, and level of severity. Injury outcomes are defined in two ways: 1) presence or absence of injuries of any severity level; and 2) injury severity level using the Injury Severity Score (Baker et al. 1974).

Information on both injuries and risk factors was obtained through a structured interview of cases and controls, or their proxies if necessary. Injury information on cases was also obtained from medical records and autopsy reports. Interviews were generally conducted by telephone. They were administered in English and Spanish.

Interviews are a standard tool in epidemiology (Schlesselman 1982). They provide unique advantages over other methods of data collection for certain classes of information. For example, interviewing individuals is the best method currently available to investigate human behaviors during an unanticipated event (such as an earthquake) in a large-sized sample.

To be eligible for the case-control study, participants had to have been living and present in SCC at the time of the earthquake. The case group consisted of those killed by the earthquake and those seen at an SCC hospital or flown by helicopter out of County for treatment of earthquake-related injuries. For comparison, a population-based random sample of current SCC residents was selected using a random digit dial of listed and unlisted residential telephones. The sample was divided into two groups: non-injured controls; and, injured controls, i.e., individuals who incurred an earthquake-related injury but were not treated at a SCC hospital or flown by helicopter to a hospital outside SCC. The non-injured controls were frequency matched to hospital and dead cases on general area of residence at the time of the earthquake. Three residential strata were defined by aggregates of contiguous zip codes in the County. Stratum 1 is the northern mountainous region of the County, stratum 2 is the coastal northern area of SCC (including the City of Santa Cruz) and stratum 3 is the southern part of the county (including the City of Watsonville).

The goal was to interview two non-injured controls for each hospital or dead case.

The injury status of the individuals from the population sample was not determined in advance of the interview. Injury information collected in the interview was used to assign persons post-hoc to the appropriate category. Based on the results of the pilot testing, 20 percent of the population sample was expected to have incurred an earthquake-related injury and thus qualify as injured controls. With such a background injury rate, it would be necessary to interview 2.5 members of the population sample for each hospital or dead case to achieve the desired 2:1 ratio of non-injured controls to hospital/dead cases. Injured controls will be studied separately from hospital and dead cases.

The relationship between risk factors and earthquake-associated injuries and deaths is being evaluated for each of two time periods: 1) the disaster phase, the 15 second shaking period of the main shock, and 2) the post-disaster phase, defined as the next 72 hours.

Hospital and dead cases or their proxies were interviewed from July 19, 1990 to March 31, 1991.

Non-injured and injured controls were interviewed over the period of March 24, 1991 to August 31, 1991.

The collected data are currently being coded for data entry. Three basic types of analyses will be performed. First, hospital and dead cases will be compared to non-injured controls to assess the significant risk factors for injury. Second, hospital and dead cases will be compared to injured controls to evaluate the selection factors for seeking medical care among the injured. Third, several descriptive studies will be undertaken to assess the total morbidity and mortality in SCC associated with the earthquake.

3 RESULTS

The hospital/dead case population consisted of 580 persons (or their proxies) targeted for interview. Of these attempted interviews, 483 (83%) were successfully completed, 31 (5%) were refusals, and 66 (11%) were lost to follow up. Of the 483 successful interviews, 357 were eligible for the case-control study.

In obtaining the random population sample, contact was attempted with 1823 households. Of these, only 7.5% refused to cooperate with the study. This low refusal rate among hospital/dead cases and the population sample is important, as it indicates that both study groups are likely to be representative of the populations from which they came. In all, 701 households were eligible for the case-control study.

Table 1 shows a summary of the injury status of the population sample i.e., those not in the initial case series, for the three strata. The data indicate that a significant proportion (106/701) of the sample actually sustained some form of injury associated with the earthquake, even though they did not visit one of the SCC hospitals. This background rate of injury not reported to a hospital is of importance for disaster preparedness, as it must be factored into overall casualty estimates. Table 2 gives a more detailed breakdown of that part of the population sample injured by time period of injury and by stratum.

Table 3 compares the breakdown of time of injury

Table 1: Population sample: Injured vs. non-injured controls by stratum

	Total	Inj'd.	Non-inj'd.	Unk.
Stratum 1	138	25	112	1
Stratum 2	318	39	278	1
Stratum 3	245	42	200	3
All Strata	701	106	590	5

Table 2: Population sample: Injured controls by time of injury and stratum

	Only During	Only After	During & After	Total
Stratum 1	10	13	2	25
Stratum 2	17	17	5	39
Stratum 3	23	16	3	42
All Strata	50	46	10	106

for the hospital/dead cases to that in the population sample. It is evident that while most of the injuries occurred during the main shock, a reasonable number also sustained their injury after the event.

Table 3: Earthquake-related injury by time period

Time Period	Hosp/dead Cases	Injured Controls
During mainshock	219	50
72 Hrs after mainshock	114	46
Both time periods	24	10
Total	357	106

Table 4 presents the first detailed data from the study which form the basis for initial estimates of risk factors. The table summarizes the numbers of hospital/dead cases and non-injured controls by location and stratum.

Table 4: Respondent location (when main shock began) for hospital/dead cases injured during main shock and non-injured controls

Loc. @ t_{eq}	Hosp./dead cases				Non-inj'd controls			
	Stratum				Stratum			
	1	2	3	Tot	1	2	3	Tot
Bldg	22	76	120	218	73	200	146	419
Vehic	0	1	0	1	18	39	12	69
Neith	2	13	9	24	21	39	42	102
Total	24	90	129	243	112	278	200	590

4 DISCUSSION

From the data in Table 4, the odds ratios (which represent the relative odds of being injured during the mainshock associated with being in a building when the shaking began) can be computed. These ratios, and their 95% confidence intervals are presented in Table 5. The "odds ratio" ψ, defined as the ratio of the odds of injury in exposed individuals to the odds of injury in the unexposed, and is closely related to the relative risk (Schlesselman 1982), can be represented

$$\psi = \frac{P(I|E)/P(\bar{I}|E)}{P(I|\bar{E})/P(\bar{I}|\bar{E})} = \frac{P(E|I)/P(\bar{E}|I)}{P(E|\bar{I})/P(\bar{E}|\bar{I})}$$

Table 5: Relative risk of being injured or killed during main shock associated with being in a building when main shock commenced

Strtm	Odds ratio, ψ	95% Conf. Interval	χ^2_{mh} *	p-value
1	5.88	(1.24,38.2)	6.54	0.0106
2	2.12	(1.08,3.04)	5.65	0.0174
3	4.93	(1.70,5.87)	20.25	6.81e-6
All	3.32**	(2.11,5.53)	28.72	8.0e-8

* χ^2_{mh} is the Mantel-Haenszel χ^2 statistic.
** Mantel-Haenszel weighted odds ratio.

where E represents exposure (in this case to a building), $\bar{E}$ nonexposure, and I, $\bar{I}$ represent injury and non-injury, respectively. The first term is the odds ratio sought, while the second represents quantities measurable in a case-control study. The two can be shown to be equal by the use of Bayes' Theorem. For example, for stratum 1,

$$\psi = \frac{22/24 \times 39/112}{2/24 \times 73/112} = \frac{22 \times 39}{2 \times 73} = 5.88$$

Table 5 shows that SCC residents in a building when the main shock began had a 3.32 times greater risk (adjusted for residential stratum) of being injured during the main shock than those not in a building when the earthquake began. It is important to note that since the confidence intervals are rather wide e.g., stratum 1, it is not possible to definitively state that the actual risk in stratum 1 is higher. Further analysis is necessary to investigate the possibility of an interaction between stratum, presence in a building, and injury severity.

It is also important to note that because of the relatively few (5) earthquake-related fatalities in the County among SCC residents, the results presented are weighted heavily toward non-fatal injury. It is expected, therefore, that future analyses will reveal causative agents for injury other than total building collapse or severe damage which have shown in the past to have played a major role in fatality.

5 CONCLUSIONS

This paper describes recent efforts made, since the Loma Prieta Earthquake, to assess, both qualitatively and quantitatively, the morbidity and mortality associated with that event. When complete, this study will not only provide useful information relative to this specific event, but will also augment substantially the literature available in disaster – specifically earthquake – epidemiology. While being in a building seems an obvious risk factor for injury, this study provides quantitative risk information for use in improved casualty estimation models. As the research is still in progress, the material and data presented herein must be considered preliminary only (some subjects are still being reviewed for possible inclusion in the study). Since most of the efforts to date have focussed on study design, data collection and coding, few quantitative data are available for presentation at this stage, but those which are available are still of significance. It is anticipated that more complete, definitive data will be available within the next twelve months.

This study is the first case-control study of earthquake-related injuries in a region in which many buildings have been designed or retrofitted to resist seismic forces. Thus, in contrast to the few earlier studies which have concentrated on lesser developed nations, the results of this investigation are likely to be generalizable to future earthquakes in California, the U.S. in general, and industrialized nations, such as Japan, which have well-conceived and enforced seismic building codes. This information should be valuable since there is a probability of approximately two-thirds that an earthquake at least as strong as the Loma Prieta earthquake will strike California in the next 30 years (USGS 1990).

Ongoing work is investigating other factors relative to casualty in earthquakes, such as the magnitude of the risk posed by non-structure hazards, e.g., building contents, sociodemographic-related vulnerability, and inappropriate personal behaviors.

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