A research update on the demography and injury burden of victims of New Zealand earthquakes between 2010 and 2014

Shewa Basharati[1],
Michael Ardagh[1,2],
Joanne Deely[1,3],
Nicholas Horspool[4],
David Johnston[5],
Shirley Feldmann-Jensen[6],
Alieke Dierckx[7],
Martin Than[1]

[1] Canterbury District Health Board, Christchurch, New Zealand
[2] University of Otago, Christchurch, New Zealand
[3] Lincoln University, Lincoln, New Zealand
[4] GNS Science, Wellington, New Zealand
[5] Joint Centre for Disaster Research, Massey University, Wellington, New Zealand
[6] California State University, Long Beach, California, USA
[7] Emergency Care Foundation, Christchurch, New Zealand

Author correspondence:
Joanne Deely,
Canterbury District Health Board,
Christchurch,
New Zealand.
Email: joanne.deely@cdhb.health.nz

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Abstract

This study compared the populations exposed to different shaking intensities of recent New Zealand earthquakes with injury burden, demography, and scene of injury. The population exposed to each earthquake was approximated by overlaying estimates of ground shaking with models of day and night population distributions. Injury data from all earthquakes and their aftershock periods were analysed for patient age and sex, location, scene of injury, and date of injury. An association was found between population exposed to shaking intensity and injury burden. The total injury burdens for each earthquake were: 2,815 (Darfield, 2010); 9,048 (Christchurch, February 2011); 2,057 (Christchurch, June 2011); 1,385 (Christchurch, December 2011); 106 (Cook Strait, 2013); 166 (Grassmere, 2013); and 49 (Eketahuna, 2014). All earthquakes injured approximately twice as many females as males. Most people who were injured were in the age range of 40-59 years. Two-thirds of injuries occurred at home, followed by 14% in commercial locations and 6.5% on roads and streets. This pattern was repeated within the data for each sex. The results suggest that the total injury burden was positively associated with both the intensity of shaking and size and density of the exposed population. The localities where most injuries occurred suggest that where people were at the time of shaking influenced their risk of injury. Potential explanations for the sex disparity in number of injuries are discussed.

Keywords: *earthquakes, sex and age, scene of injury, population exposed to shaking intensity, injury burden*

Identifying the causes of injury and understanding who is most at risk during an earthquake will help to inform interventions that reduce injury risk and improve rescue and medical strategies. New Zealand is a country of 5 million people, located in the south-western Pacific Ocean, consisting of two main islands which lie along a tectonic plate boundary that forms part of the "Pacific ring of fire". Both islands suffered some major earthquakes and aftershocks between 2010 and 2014 (see Figure 1).

Figure 1. Epicentres of New Zealand earthquakes from 2010 to 2014. M = Magnitude.

Table 1.
Summary of New Zealand earthquakes from 2010 to 2014.

	Earthquakes						
Details	Darfield	Chch-Feb-11	Chch-Jun-11	Chch-Dec-11	Cook Strait	Grassmere	Eketahuna
Locality	Darfield	Christchurch	Christchurch	Christchurch	Seddon	Seddon	Eketahuna
Date	4/9/10	22/2/11	13/6/11	23/12/11	12/07/13	16/8/13	20/1/14
Time	4:35	12:51	14:20	15:18	17:09	14:31	15:52
Day	Sat	Tues	Mon	Fri	Fri	Fri	Mon
Magnitude	7.1	6.2	6.0	5.9	6.5	6.6	6.2
PGA	1.26g	2.2g	2.13g	1.0g	0.2g	0.75g	0.26g
Depth	10.8km	5.9 km	7km	7km	13km	8km	34km
Aftershock Period	4/9/10 – 21/2/11	22/2/11 – 12/6/11	13/6/11 – 22/12/11	23/12/11 – 12/2015	21/07/13 – 15/08/13	16/07/13 – 12/2015	20/01/14 – 12/2016

Note. PGA = Peak ground acceleration; Dates are in day/month/year format.

In this paper, we present an overview of the seven most significant New Zealand earthquakes between September 2010 and February 2014 (see Table 1). The major Darfield earthquake (2010) caused extensive damage to many older brick and masonry buildings in the Canterbury region, including Christchurch City. There was a significant number of injuries associated with this event (Gledhill, Ristau, Reyners, Fry, & Holden, 2011; Johnston et al., 2014). The Darfield earthquake initiated a period of continuous local seismic activity, which included three other major earthquakes (aftershocks) close to Christchurch City. The most significant occurred on the 22nd of February 2011. This earthquake led to 185 deaths and thousands of injuries (Ardagh et al., 2012; Johnston et al., 2014). Destruction, including property damage and liquefaction, was widespread (Kaiser et al., 2012). The Christchurch central business district (CBD) was significantly damaged with two multi-storey buildings collapsing (Ardagh et al., 2012). The other two significant Christchurch-based earthquakes that caused injury in Canterbury occurred on the 13th of June 2011 and the 23rd of December 2011 (Table 1).

Later, on the 21st of July 2013, the Cook Strait earthquake (also known as the Seddon earthquake) struck 20 kilometres east of the town of Seddon in the Marlborough region of the South Island (Table 1; USGS, 2016a). This earthquake caused moderate damage in the wider Marlborough area and Wellington (the capital city, 55 kilometres north of the epicentre; see Figure 1). Six weeks later, the Lake Grassmere area was struck by an earthquake 10 kilometres south-east of Seddon (Table 1; USGS, 2016b).

On Monday the 20th of January 2014, an earthquake struck the Eketahuna area in the south-east of New Zealand's North Island (GeoNet, 2014) in the middle of the afternoon. This earthquake caused minor to moderate damage in Palmerston North, Eketahuna, and the wider Wellington region (EQC, 2018).

Johnston et al. (2014) and Ardagh et al. (2012; 2016) reported injuries from the Darfield 2010 and Christchurch (22nd February 2011) earthquakes. These three studies noted a disproportionate number of females injured compared with males, and that most people injured were in the age range 40-59 years. Although most injuries occurred at home (Ardagh et al., 2016), Johnston et al. (2014) also reported that most people were injured while moving during the Darfield earthquake, but most were injured while stationary during the Christchurch earthquake. These studies concluded that where people were, what they were doing, and their actions during earthquake shaking influenced their risk of injury. To build on this previous research, our study had two objectives. Firstly, we compared the Darfield and Christchurch (22nd February 2011) earthquake data over their total aftershock periods with similar data from the five more recent earthquakes presented in Table 1 to determine if the distributions found in the earlier studies are common phenomena. The other important objective of this study was to compare the populations exposed to different shaking intensities with injury rates, demography, and scene of injury. Such a comparison was not made in previous research but will contribute important information for understanding earthquake injury burden.

Methods

The population exposed to each earthquake was approximated by overlaying estimates of ground shaking from ShakeMap (Horspool, Chadwick, Ristau, Salichon, & Gerstenberger, 2015) with a model of population distribution for day and night populations within the RiskScape Multi-hazard Impact Modelling software (Schmidt et al., 2011). The injury data from all earthquakes and their aftershock periods were obtained from the "Researching the Health Impacts of Seismic Events" (RHISE) database (housed at the Canterbury District Health Board, Christchurch, New Zealand). The database was established after the 22nd of February, 2011, Christchurch earthquake with patient data from the Canterbury District Health Board (CDHB) live warehouses of patient data and the New Zealand Accident Compensation Corporation (ACC) client datasets (Ardagh et al., 2016). The CDHB provides free health care to the region while the ACC scheme provides free health care for people injured in accidents in New Zealand. Each episode of care requires the completion of details to progress funding for the claim. The RHISE database combines and links patient data from both sources and has continued to be updated following each new earthquake event. Consequently, a comprehensive database has been developed.

The RHISE database contained data from 15,697 patients injured on the day of each earthquake and during the aftershock periods presented in Table 1. Of the total patients, 71 were excluded from the study because they were not earthquake-related, leaving 15,626 people injured in the seven earthquakes. Each patient's data contain demographic information and a description of injuries. The following data were analysed: patient age and sex, scene of injury, and date of injury.

Results

Populations Exposed to Different Intensities of Shaking

The estimated populations exposed to different intensities of shaking are presented in Table 3 with definitions for the Modified Mercalli Intensity (MMI) scale given in Table 2. The results for populations exposed to shaking reflect severity of shaking and proximity of epicentres to large urban areas. The highest magnitude Darfield earthquake, with a rurally located epicentre 40 kilometres from Christchurch City, was felt over a wide area. More than 400,000 people experienced extreme and severe intensity shaking and about 50,000 people experienced moderate to strong intensity shaking.

During the Christchurch, February 2011, earthquake, more than 300,000 individuals suffered extreme intensity shaking and more than 200,000 experienced moderate to severe intensity shaking. During each of the latter two Christchurch 2011 earthquakes, 500,000 people experienced moderate to severe shaking intensities, though none experienced the extreme shaking intensities felt during the earlier 2011 earthquake. In the case of the June earthquake, more than 300,000 individuals experienced severe shaking and more than 170,000 experienced strong shaking whereas the populations were more evenly spread over the moderate to severe shaking intensities during the December event.

During each of the three other earthquakes examined in this study (Cook Strait, Grassmere, and Eketahuna) with rurally-located epicentres, more than 2,000

Table 2.
Modified Mercalli Intensity (MMI) scale for New Zealand context.

MMI	Intensity	Description
1	unnoticeable	Barely sensed only by a very few people.
2	unnoticeable	Felt only by a few people at rest in houses or on upper floors.
3	weak	Felt indoors as a light vibration. Hanging objects may swing slightly.
4	light	Generally noticed indoors, but not outside, as a moderate vibration or jolt. Light sleepers may be awakened. Walls may creak, and glassware, crockery, doors, or windows rattle.
5	moderate	Generally felt outside and by almost everyone indoors. Most sleepers are awakened, and a few people alarmed. Small objects are shifted or overturned, and pictures knock against the wall. Some glassware and crockery may break, and loosely secured doors may swing open and shut.
6	strong	Felt by all. People and animals are alarmed, and many run outside. Walking steadily is difficult. Furniture and appliances may move on smooth surfaces, and objects fall from walls and shelves. Glassware and crockery break. Slight non-structural damage to buildings may occur.
7	severe	General alarm. People experience difficulty standing. Furniture and appliances are shifted. Substantial damage to fragile or unsecured objects. A few weak buildings are damaged.
8	extreme	Alarm may approach panic. A few buildings are damaged, and some weak buildings are destroyed.

Note. This table is adapted from Dowrick and Rhoades (2011).

Table 3.
Estimated population exposed (in thousands) to different levels of shaking.

	Shaking Intensity Level				
Event	MMI5 (Moderate)	MMI6 (Strong)	MMI7 (Severe)	MMI8+ (Extreme)	Total
Darfield-Sep-10	31	24	202	210	467
Chch-Feb-11	98	54	68	310	530
Chch-Jun-11	41	178	305	0	524
Chch-Dec-11	145	231	178	0	554
C. Strait-Jul-13	456	35	1	0	492
Grassmere-Aug-13	237	2	2	0	241
Eketahuna-Jan-14	98	157	1	0	256

Note. The MMI scale is defined in Table 2. Chch = Christchurch; C. Strait = Cook Strait.

individuals experienced severe intensity shaking, but none experienced extreme levels of shaking. In the case of the Cook Strait event, 35,000 people in rural towns of the Marlborough region experienced strong intensity shaking and more than 450,000 people in Wellington City (further from the epicentre) likely experienced moderate intensity shaking (Table 3). The pattern was similar for the Lake Grassmere earthquake except that approximately half the population size was affected by shaking. In the case of the deeper seated Eketahuna earthquake, more than 150,000 people felt strong shaking and more than 100,000 experienced moderate shaking.

Injury Burden

Figure 2 relates the maximum MMI intensity of earthquakes affecting populations of more than 150,000 to total injury burden. This figure suggests a relationship between the size of the population exposed to different shaking intensities and injury burden. The high intensity February Christchurch and Darfield earthquakes (MMI 8+) had the highest injury burdens, followed by the June and December Christchurch events which had maximum MMI intensities of 7. The populations which experienced MMI intensities of less than 6 had injury burdens an order of magnitude less than the Canterbury (Christchurch and Darfield) events.

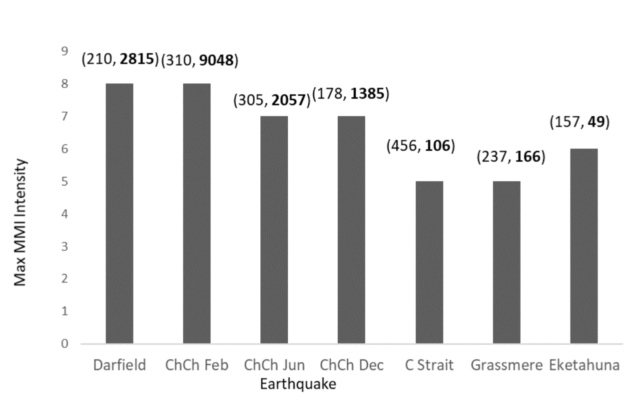

Figure 2. Comparison of the maximum MMI intensity (bars) that affected populations >150,000, and total injury burden; (population (thousands), **total injury burden**).

The earthquakes where more than 300,000 people experienced severe (MMI7) or extreme (MMI8+) shaking intensities had the highest injury burden rate proportional to the estimated population exposed to shaking (Table 4). These included the Darfield and February Christchurch events. The February Christchurch extreme earthquake shaking occurred during the middle of the day, affecting 310,000 people and injuring approximately 9,000. Although severe and extreme shaking affected more than 400,000 people in the Darfield event, this earthquake happened in the early hours of the morning and fewer than 3,000 were injured in total. In line with the February event, the injury rate for the June and December Christchurch earthquakes reflects the high numbers of people affected by strong and severe shaking intensities during the daytime.

The much lower total injury burden from the lower intensity Cook Strait and Grassmere events compared to the higher intensity Darfield and Christchurch earthquakes (see Figure 2) suggests a relationship between population size/shaking intensity and total numbers injured. This relationship did not hold for the deep epicentre Eketahuna earthquake, which had a similar total affected population size to that of Grassmere (256,000 vs 241,000), but had the smallest injury burden (N = 49) of the earthquakes considered here.

Demographic Distribution

Gender. The data suggest that most earthquakes injured approximately twice as many females as males. In the case of the Cook Strait and Eketahuna earthquakes, which had the lowest injury burdens of 106 and 49 respectively, the disparity between females and males was largest. The total injury burdens were: Darfield, 1,863 females versus 952 males; Christchurch (February), 5,960 females versus 3,088 males; Christchurch (June), 1,417 females versus 640 males; Christchurch (December), 978 females versus 407 males; Cook Strait, 82 females versus 24 males; Grassmere, 112 females versus 54 males; and Eketahuna, 39 females versus 10 males.

Age. Table 4 also presents the injury rate in the estimated population exposed to shaking stratified by age. Where the total injury rate for an earthquake was lower than 250 people per 100,000 exposed to shaking (i.e., the Darfield and three Christchurch events), most people who were injured were in the age ranges 40-49 years and 50-59 years. Older people had the next highest percentage of injuries (60-69 years and 70+ years). Children between the ages of 0-9 years were the least injured, followed by teenagers, young adults, and finally adults 30-39 years (Table 2). These trends held for the Grassmere earthquake, but the lower injury burdens in the Cook Strait and Eketuna earthquakes means that trends were not clear. In the Darfield, Christchurch, Grassmere, and Eketahuna earthquakes, the sex disparity held for all age groups except children. However, more female than male adults over the age of 40 were injured during the Cook Strait event.

Scene of Injury

The scenes of injury for all the earthquakes under study combined are presented in Table 5. Approximately two-thirds of injuries occurred at home, followed by 14% in commercial locations and 6.5% on roads and streets. This pattern was repeated within the data for each sex. Twice as many females as males were injured in all locations, except industrial places, farms, and data with no scene of injury.

Table 4.
Injury rate per hundred thousand of the total estimated population exposed to shaking.

		Age range							
	Total	0–9	10–19	20–29	30–39	40–49	50–59	60–69	70+
Darfield-Sep-10									
Male	204	3	8	15	31	51	45	28	23
Female	399	3	15	25	65	95	85	60	52
Total	603	6	23	39	96	146	129	88	75
Chch-Feb-11									
Male	583	12	27	57	88	123	125	80	71
Female	1125	11	45	114	165	233	233	158	166
Total	1707	23	72	171	253	356	357	238	236
Chch- Jun-11									
Male	122	2	5	10	17	28	25	19	16
Female	270	3	10	22	37	54	58	45	42
Total	393	5	15	32	54	82	83	64	57
Chch-Dec-11									
Male	73	1	3	5	7	14	17	13	13
Female	177	2	4	11	18	37	38	34	34
Total	250	3	7	16	25	50	55	47	47
C. Strait-Jul-13									
Male	5	0	0	1	0	1	1	1	1
Female	17	0	1	3	3	3	3	2	2
Total	22	0	1	3	3	4	4	3	3
Grassmere-Aug-13									
Male	22	1	2	2	3	4	5	2	3
Female	46	0	4	2	5	12	12	6	5
Total	69	2	6	4	8	16	17	8	8

Note. Data for Eketahuna not included as the low injury burden means injury rates per 100,000 are typically below 1.

Table 5.
Scene of injury for all patients across all earthquakes.

Claim Scene	Total n (%)	Female n (%)	Male n (%)
Home	10,076 (64.5)	6,846 (65.5)	3,230 (62.3)
Commercial Location	2,229 (14.3)	1,542 (14.8)	687 (13.3)
Road/Street	1,012 (6.50)	648 (6.20)	364 (7.06)
Industrial Place	358 (2.30)	159 (1.52)	199 (3.86)
School	235 (1.50)	175 (1.67)	60 (1.16)
Place of Recreation and Sport	196 (1.30)	139 (1.33)	57 (1.11)
Place of Medical Treatment	64 (0.40)	51 (0.49)	13 (0.25)
Farm	15 (0.10)	8 (0.08)	7 (0.14)
Other	1,394 (8.90)	857 (8.20)	537 (10.4)
Not Obtained	245 (0.30)	26 (0.25)	219 (4.25)
Total	15,824 (100)	10,451 (66.1)	5,373 (34.0)

Discussion

This study found a positive association between population exposed to shaking intensity and the total injury burden of each of the seven earthquakes. Although most of the earthquakes considered in this study had shallow epicentres, the size of the populations affected by different intensities of shaking varied depending on proximity of the epicentres to major cities or towns.

The high injury burdens of all Christchurch earthquakes largely reflect daytime shaking. The February Christchurch event exposed the largest population to extreme shaking and led to the highest number of injuries, consistent with the findings of the ShakeMap Atlas which demonstrated a strong link between population exposed to extreme shaking and injury and mortality rates (Allen et al., 2009). However, although it was the highest magnitude earthquake with the second largest population exposed to extreme shaking, the night-time Darfield event caused approximately one-third the number of injuries as the February Christchurch event and no deaths. The data in this study therefore suggest that the time of day at which an earthquake occurs also impacts injury burden, supporting some existing evidence (Johnston et al., 2014). Considering this, the Darfield earthquake would likely have resulted in many more injuries if it had occurred during day-light hours when more people were active. However, some of the credit for the low injury burden from the Darfield earthquake can also be attributed to the Canterbury region's high proportion of flexible timber-framed houses (Quigley et al., 2010). Research demonstrates a positive association between shaking-induced building damage, which tends to be less in flexible-framed houses, and injuries (So & Spence, 2013).

The similar injury rates within the age groups of each sex suggests that males and females of the same age had the same risk of injury during all the events. Nonetheless, the injury disparity between the sexes and absence of it in children aged under 10 years need further consideration. Ardagh et al. (2016) reported similar age distributions of injuries during the first 24-hours of response to the February Christchurch earthquake as that of our study which considered all reported injuries following the event. In Ardagh et al.'s paper, the largest proportions of casualties were in the 40-49 years age group (21%) and 50-59 years age group (20%). While Johnston et al. (2014) reported similar age distributions for casualties of the Darfield earthquake (40-49 years, 24%; 50-59 years, 21%), they reported that injury burden of the February Christchurch earthquakes was relatively evenly spread across the 10-year age groups (0-59 years; 12.3%-14.7%). This discrepancy may be due to differences in the periods over which the data were assessed in each study. Ardagh et al. (2016) assessed the injury burden during the first 24 hours of response and Johnston et al. (2014) assessed burden (including casualties who incurred injuries during clean-up) in the following five months.

The most likely place to be injured during the earthquakes and aftershocks was at home. Ardagh et al. (2016) reported that about 50% of total casualties during the first 24 hours after the Christchurch earthquake were injured at home. In the current study, this increased to more than 60% when looking at all seven earthquakes and their aftershocks periods together. Two-thirds (6,659) of the total injury burden from the February Christchurch earthquake occurred in the first 24 hours (Ardagh et al., 2012). Ardagh et al. (2012) found slightly more people injured in the commercial and services industries during this one specific event compared with our study looking across multiple earthquakes; this difference is likely due to differences in proximity of earthquake epicentres to cities.

Ardagh et al. (2016) reported that in the first 24 hours of the February 2011 earthquake approximately twice as many females as males were injured at home (2,390 versus 1,002) and close to three times as many females as males injured in the commercial/service industries (1,105 versus 444) and schools (106 vs 34). International reports of earthquakes causing high mortality and injury numbers have found that the most important risk factors are the degree of damage to buildings and the location of individuals within buildings at the time of shaking (Ellidokuz, Ucku, Aydin, & Ellidokuz, 2005; Ramirez & Peek-Asa, 2005). While our findings support Ardagh et al.'s conclusion that where people were and what they were doing influenced their risk of injury during earthquake shaking, as well as an apparent sex disparity in reported injuries, Canterbury's high proportion of flexible timber-framed houses likely contributed to the low number of serious injuries and fatalities incurred during the Darfield and Christchurch events (excluding the February event) compared to similar international earthquakes (Ardagh et al., 2016; Ardagh et al., 2012; Johnston et al., 2014; Quigley et al., 2010).

The high proportion of injuries that occurred at home and in commercial localities may also relate to what happened during shaking (Johnston et al., 2014). Close to half of the total injuries in the Darfield earthquake occurred when people rushed about in darkness in their homes during shaking in the early hours of the morning. In contrast, during the February Christchurch midday earthquake, less than 20% of people were injured this way. Johnston et al. (2014) found that approximately 25% of both sexes tripped or fell during shaking and approximately 10% were hit by projectiles. Most of the hospitalised patients who were injured during the February Christchurch earthquake came from the central business district (Ardagh et al., 2016).

If more adult females than males were at home, working in commercial areas, and teaching at schools, this may partly explain the sex disparity. Many reports on earthquake injury and mortality data evaluate samples of patients treated in hospitals, including field hospitals, without including the multitude of minorly injured patients (Amundson et al., 2010; Bozkurt, Ocguder, Turktas, & Erdem, 2007; Kreiss et al., 2010; Sami et al., 2009). Many reports also focus on subsets of injury types or disease processes (Etienne, Powell, & Faux, 2010; He et al., 2011; Hu et al., 2012; Mahue-Giangreco, Mack, Seligson, & Bourque, 2001; Rathore et al., 2007). Consequently, some studies report higher injury and mortality rates for females than males (Armenian, Melkonian, Noji, & Hovanesian, 1997; Chan et al., 2003; Etienne et al., 2010; Liang et al., 2001; Peek-Asa, Kraus, Bourque, & Vimalachandra, 1998; Peek-Asa, Ramirez, Seligson, & Shoaf, 2003; Tanaka et al., 1998) and some report the rate as equal for both sexes (Bozkurt et al., 2007; Ellidokuz et al., 2005; He et al., 2011; Hu et al., 2012; Mahue-Giangreco et al., 2001; Mulvey, Awan, Qadri, & Maqsood, 2008; Rathore et al., 2007; Sami et al., 2009; Xie et al., 2008; Zhang, Li, Carlton, & Ursano, 2009), while males tend to suffer more non-disaster related injuries than females (Udry, 1998).

It is possible that the lower rates of injuries for males could be due to under-reporting of injuries among this demographic, an aligned tendency for females to seek treatment more often than males (e.g., general practice visits in New Zealand: Jatrana & Crampton, 2009), or that a general, well-established difference in average physical size and strength could mean that the same impacts which injured females sufficiently that reporting was necessary would not injure males to the same extent (Blue, 1993). Finally, the disparity in our study could also have been influenced by differences in behaviour between the sexes during earthquake shaking. For example, it might be that males are more likely to undertake protective actions during shaking. Future research could explore this idea to support more education regarding securing objects to walls and other surfaces, and self-protective actions such as drop, cover, and hold (see e.g., getthru.govt.nz). In particular, if there is a sex difference in use of self-protective actions then tailoring education campaigns to be more effective for females may help to lower the injury rate for this demographic in future earthquakes.

Conclusion

This study found a positive association between population exposed to shaking intensity and the total injury burden from each of the seven earthquakes. Across the seven earthquakes, the size of the total injury burdens appeared associated with the severity of shaking experienced, which in turn could relate to the proximity of epicentres to major cities or towns as well as the time of day at which the earthquake occurred. As an extension of this study, current work led by author NH aims to develop a model that will predict the total injury burden and short- and long-term social impacts of future major earthquakes. The model is being developed by combining data from Statistics New Zealand on baseline populations with social and health data from the RHISE database. Our findings also align with those of Ardagh et al. (2016) and Johnston et al. (2014) whereby more females than males were injured in all events, most people were injured in the age range 40-59 years, and the most likely place to be injured during the earthquakes and aftershocks was at home. Future work specifically educating females on protective action during shaking could reduce the proportion of females injured in future events and therefore also meaningfully reduce the overall injury burden of earthquakes.

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