
Earthquakes and citizen science: Understanding human behaviour through GeoNet's Felt Detailed reports.

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ABSTRACT

This study examined behavioural and emotional responses of the public during seven earthquakes in New Zealand between 2016 and 2024, using 9,368 GeoNet Felt Detailed reports to assess the role of perceived shaking intensity. The analysis showed that passive behaviours, most commonly “stopped what I was doing but stayed where I was,” were the most frequent responses across all events. The use of the recommended protective action, “Drop, cover and hold,” increased as perceived shaking intensity increased; however, overall participation in this action remained low. A notable concern was the increase in reports of “moving to a doorway,” indicating the continued influence of an outdated belief that such an action might be useful. Undertaking this action is likely to actually increase risk of injury.

In contrast, the results showed a statistically significant but modest negative relationship between perceived shaking intensity and emotional responses. A higher proportion of respondents reported being “extremely frightened” during Light or Weak shaking (32.8%) than during Strong or Severe shaking (2.9%), which contrasts with conventional models that link stronger shaking with higher levels of fear. These findings emphasise the importance of taking recommended protective actions immediately at the onset of shaking, rather than waiting for shaking to intensify, and highlight the need for targeted risk communication to correct misconceptions about protective behaviours during earthquakes.

1 INTRODUCTION

1.1 Background

People's behaviour during earthquake shaking is highly likely to influence survival outcomes during such events (Lindell et al., 2016). Although it is well established that injuries and fatalities in earthquakes are largely associated with poor building standards and resulting structural damage (Mckenna, 2011; Rahman, 2018), existing research indicates that, despite improvements in building codes and structural safety, a substantial number of injuries continue to occur because of individual actions (Lindell et al., 2015; Horspool et al., 2020). Furthermore, studies have shown discrepancies between recommended protective actions and actual behaviour exhibited during earthquake shaking (Bernardini et al., 2019). Research has also found that

individuals frequently delay taking protective action, often waiting to assess whether the shaking will intensify or continue (Vinnell et al., 2023). This is particularly concerning because increasing shaking intensity reduces the feasibility of executing protective actions, thereby elevating the risk of injury. To minimise this risk, recommended action such as “Drop, cover and hold” (CDC, 2024; NEMA, n.d.-b; Tokyo Fire Department, n.d.) should be performed immediately once we feel the earthquake (Horspool et al., 2020). Therefore, to reduce injuries and fatalities resulting from behavioural actions, it is important to examine how individuals behave, respond, and react during earthquakes.

1.2 Behavioural response to earthquakes

Immediate behavioural responses during earthquake shaking are varied, encompassing protective actions, flight, prosocial responses, and remaining in place. The adoption of recommended protective measures, such as “Drop, cover, and hold” or seeking shelter, varies significantly across different events and contexts. While moderate sheltering levels were observed in earthquakes like Imperial County, Whittier Narrows, Loma Prieta, and Northridge (Arnold et al., 1982; Goltz & Bourque, 2017). Events such as the Ridgecrest sequence and studies in New Zealand and Japan based on “Did You Feel It?” (DYFI) data reported substantially lower adoption of “Drop, cover and hold” responses. (Goltz, Park, Nakano, et al., 2020; Goltz, Park, Quitoriano, et al., 2020) Conversely, actions like running outside or evacuating buildings are frequently reported, particularly in areas like Mexico and Israel (Prati et al., 2012; Shapira et al., 2018; Rapaport & Ashkenazi, 2019; Santos-Reyes & Gouzeva, 2020), compared to the United States (Goltz & Bourque, 2017).

Other consistently documented responses are protecting people/ helping others and remaining stationary. Prosocial responses have been reported across numerous earthquakes (Ohta & Ohashi, 1985; Lindell et al., 2016; Santos-Reyes & Gouzeva, 2020; Wang et al., 2022). Simultaneously, remaining in place or freezing is one of the most common immediate responses, with many respondents across various earthquakes reporting immobility or stopping and staying still (Arnold et al., 1982; Lindell et al., 2016; Goltz & Bourque, 2017; Ahn et al., 2021)

Fear is consistently identified as the dominant emotional response during earthquakes. Fear was the dominant emotional response during major earthquakes in Japan (Ohta & Ohashi, 1985). Similarly, Prati et al. (2012) found that fear emerged as the predominant emotional reaction during the 1997 Umbria–Marche earthquake, with 38.38% of respondents identifying it as their primary response. For the same earthquake, a broader category encompassing indicators of fear, including helplessness, worry, terror, and panic, was reported by 67.70% of respondents. Other emotional responses included surprise (13.10%) and sadness (12.10%), while a small proportion of participants reported emotions outside the predefined categories. In a study of emotional responses among Mexico City residents following the 2017 earthquake, Santos-Reyes and Gouzeva (2020) reported a range of emotional reactions, with more than half of respondents (51%) expressing fear.

Physical earthquake attributes, particularly shaking intensity, are consistently identified as key determinants of immediate behavioural responses. Stronger ground motion can limit the range of feasible responses by causing loss of balance and restricting movement (Lambie et al., 2016; Ohta & Ohashi, 1985). Higher intensities have been associated with increased adoption of protective actions, such as taking cover or holding onto furniture, whereas moderate shaking is more often linked to appropriate safety behaviours (Goltz, Park, Nakano, et al., 2020). Observational studies confirm systematic shifts in movement and protective actions as perceived intensity increases (Vinnell et al., 2022). Moreover, perceived intensity can initiate evacuation behaviour, a pattern evident during the Kaikōura earthquake, where stronger shaking increased the likelihood of leaving buildings (Bernardini et al., 2019; Blake et al., 2022).

Fear along with intensity, influences range of behavioural response. High levels of fear are associated with increased movement and evacuation, while lower fear is more commonly linked to remaining stationary.

Individuals experiencing high levels of fear are more likely to drop to the ground or run outside (Goltz, Park, Nakano, et al., 2020; Sun & Liu, 2023). Fear also influences evacuation decisions, as anxiety over aftershocks and fear of building collapse led many to evacuate during the 2016 Kumamoto and Kaikōura earthquakes (Kimur et al., 2017; Blake et al., 2022). Similar patterns, where fear and emotional stress triggered evacuation, were observed in earthquakes across Pakistan, China, Nepal, Mexico, and the United States (Goltz, Park, Nakano, et al., 2020).

Strengthening the evidence base for earthquake risk reduction strategies require a comprehensive understanding of human behaviour during and immediately after earthquake events (Lambie et al., 2016). Furthermore, identifying the factors that enable or constrain the adoption of appropriate protective actions during earthquakes is essential for informing targeted risk communication and the development of effective public education and awareness initiatives (Goded et al., 2021).

This study seeks to examine the principal behavioural and emotional responses reported by the New Zealand public during earthquakes between 2016 and 2024, and to investigate the role of shaking intensity in shaping immediate behavioural and emotional responses during earthquakes.

2 DATA AND METHOD

2.1 Citizen science approach in understanding immediate responses.

Citizen science approaches such as crowdsourced online macro seismic surveys facilitates the rapid, large-scale collection of self-reported data during earthquakes (Sbarra et al., 2010; Wald et al., 2011; Goded et al., 2018). This study analysed secondary data from GeoNet's Felt Detailed survey responses for seven earthquakes (magnitude > 5) occurred between 2016 and 2024. Table 1 provides a summary of these earthquakes, including the number of felt reports and key characteristics.

Table 1 : Overview earthquakes and submitted Felt Detailed Reports used in this study (GeoNet, n.d.)

Public ID/ Name*	Date and time	Shaking	Magnitu- de	Shaking Distribution	Depth (km)	No. of Reports* *	No. of Reports** *
2016p858000/ Kaikōura EQ	14/11/2016 12:02 AM	Extreme	7.8	Moderate – Severe	15	3514	1979
2018p816466/ Taumarunui EQ	30/10/2018 3:13 PM	Moderate	6.2	Weak- Light	207	930	590
2020p391429/ Levin EQ	25/05/2020 7:53 AM	Strong	5.8	Weak – Moderate	37	1519	873
2021p169083/ East Cape EQ	05/03/2021 2:27 AM	Severe	7.2	Light- Strong	33	6603	2940
2022p771854/ French Pass EQ	14/10/2022 3:03 AM	Light	5.7	Weak	146	1814	1207
2023p007281/ Te Aroha EQ	04/01/2023 5:39 AM	Strong	5.1	Not Felt – Moderate	7	1370	922
2023p122368/ Paraparaumu EQ	15/02/2023 7:38 PM	Strong	6	Weak – Light	54	1145	857

Based on the nearest geographic location , **Submitted through GeoNet , * After data cleaning and validation*

The Felt Detailed questionnaire (Goded et al., 2021) initially comprised 40 items; however, this study examined only three selected items :

- “How would you best describe the shaking?”
- “What was your first response while the earthquake was shaking?” and,
- “What was your reaction?”

3 METHOD

This study analysed 9,368 validated GeoNet Felt Detailed Reports from seven earthquake events (Table 1) to examine behavioural and emotional reactions, based on the questions outlined above. Quantitative methods were applied, using descriptive statistics and graphical summaries. Chi-square tests and effect size were calculated (Arthur & Clark, 2021) to examine associations between shaking intensity and both behavioural responses and emotional reactions. For bivariate analysis, shaking intensity was categorized into three groups:

- Weak/Light:** Reports of “Heard, but not felt,” “Gentle, hardly recognized as an earthquake,” and “A jolt or mild, but unmistakably an earthquake.”
- Moderate:** Reports describing moderate shaking.
- Strong/Severe:** Combined descriptions of strong and severe shaking.

4 RESULT

4.1 How would you best describe the shaking?

Reported shaking intensities for the seven earthquakes ranged from 'heard but not felt' to 'severe' (Figure 1). The 2016 Kaikōura event had the highest concentration of high-intensity reports, predominantly 'strong shaking' (54.9%). The 2021 East Cape, 2020 Levin, and 2018 Taumarunui earthquakes were mostly perceived as 'moderate shaking' (42.4-55.4%). The 2022 French Pass event was largely described as a 'jolt or mild but unmistakable shaking' (49.6%). Early 2023 events (Te Aroha and Paraparaumu) were characterised by mid-range intensities, mainly 'moderate' and 'strong' shaking.

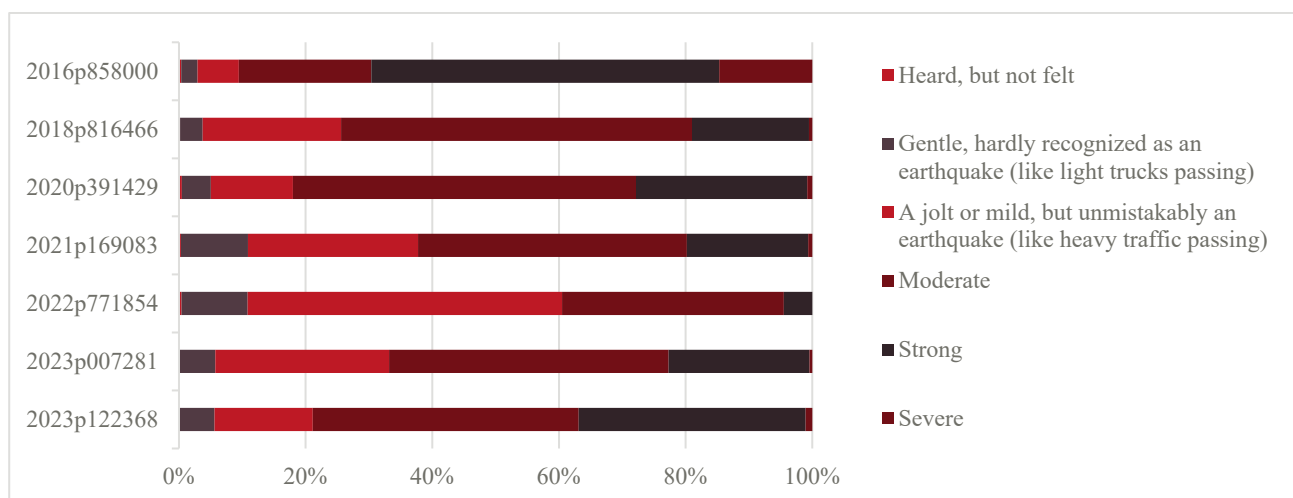


Figure 1 : Distribution of perceived shaking intensities.

4.2 What was your first response while the earthquake was shaking?

The most frequent first response across all events (Figure 2) was "stopped what I was doing but stayed where I was" (dominant in East Cape and Taumarunui, ~72%). Continuing previous activities was less consistent. Recommended protective action, "Drop, cover and hold," was reported by 3.9% overall, with the highest number of reports at 13.6% in the Kaikōura earthquake and the lowest 0.8% in the French Pass event. Moving to a doorway was highest during the 2023 Paraparaumu earthquake (18.3%). Immediate evacuation was highest in Kaikōura (4.2%) but declined in subsequent events. Protecting people was highest in Kaikōura (21.2%) and lower (2-6%) elsewhere. Protecting property was consistently low (under 2%).

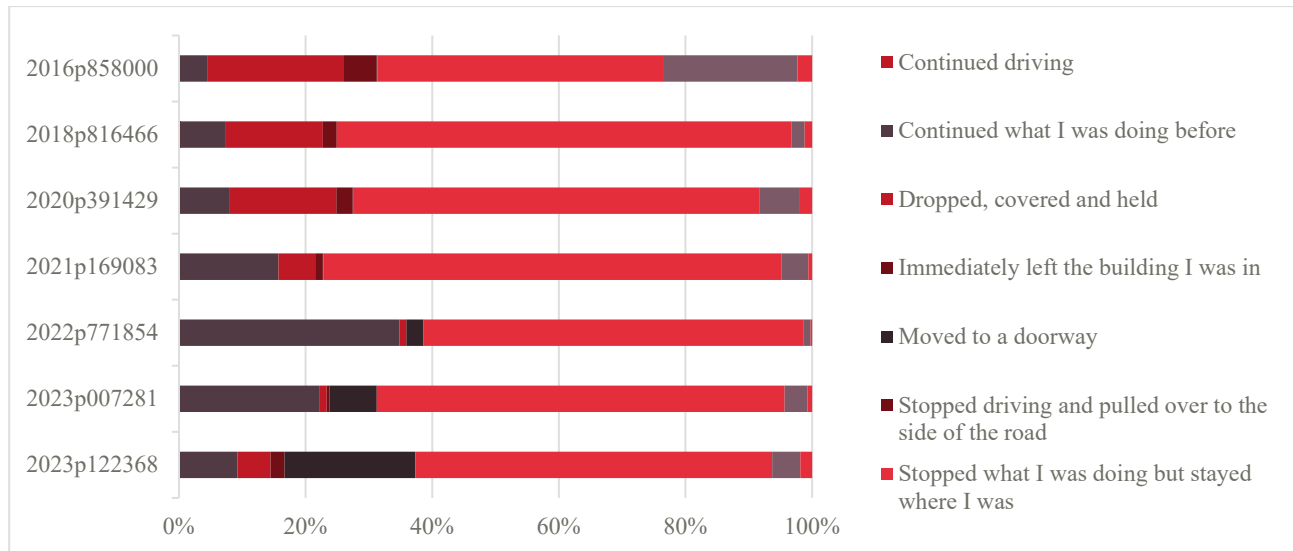


Figure 2: Proportion of reported behavioural responses.

4.3 What was your reaction?

Emotional reactions varied substantially (Figure 3). Most respondents reported no or minimal fear. "Extremely frightened" was highest in the 2022 French Pass (34.1%) and 2023 Te Aroha (22.5%) earthquakes, but only 2.9% for Kaikōura. Conversely, "very frightened" was most prevalent during Kaikōura (27.0%), remaining below 10% for the rest.

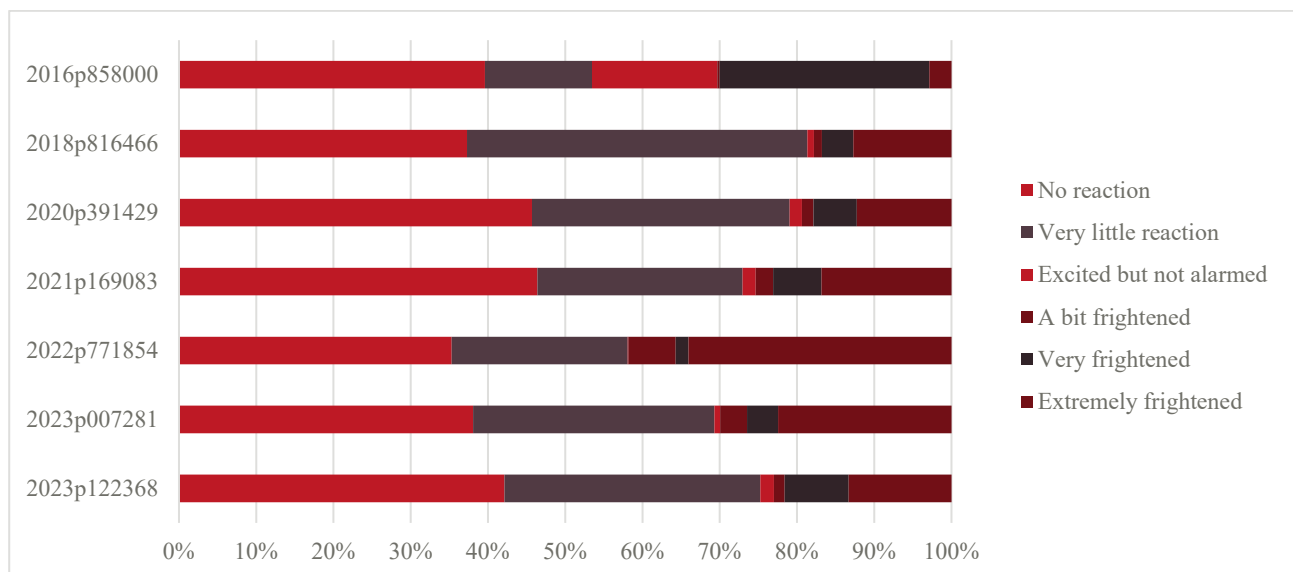


Figure 3: Proportion of reported emotional reactions.

4.4 Influence of intensity on behavioural response and emotional reaction

A statistically significant, yet moderate, association was found between behavioural responses and perceived shaking intensity $\chi^2(12,9363)=1666.254$, $p < .001$, Cramer's $V=.298$). The predominant behaviour across all intensity levels was : "Stopped what I was doing but stayed where I was," which accounted for most reports, specifically 66.9% at Light/Weak intensity, 68.5% at Moderate intensity, and 49.0% at Strong/Severe intensity. However, recommended protective actions and active mobility behaviours increased significantly with higher perceived intensity. For instance, "Dropped, covered and held" rose from 2.0% at Light/Weak to 19.3% at Strong/Severe, and active responses like "Immediately leaving the building" increased from 0.6% to 4.6% across the same range. Similarly, "Moved to a doorway" increased from 1.5% to 4.3%, and protective behaviours toward others, "Protecting people nearby," also showed a marked increase from 1.6% to 15.2%. This overall pattern indicates a shift from primarily passive responses at lower intensities to more frequent adoption of recommended protective and active behaviours as the perceived shaking intensity increased.

In contrast, the analysis of emotional responses and perceived shaking intensity revealed a statistically significant but modest and negative relationship $\chi^2(10,9363)= 2889.239$, $p < .001$, $\gamma = -.167$). This weak negative association suggests that a linear increase in perceived intensity was not consistently linked to a proportional increase in emotional reactions. A substantial proportion of respondents (44.7%) reported no emotional reaction even during Strong/Severe shaking. Furthermore, the proportion of respondents reporting being extremely frightened was higher in the Light/Weak category (32.8%) than in the Strong/Severe category (2.9%), further illustrating the absence of a linear relationship between perceived intensity and emotional reaction.

5 DISCUSSION

This study provides an overview of the immediate behavioural and emotional responses reported by individuals during earthquake events, with particular attention to the role of shaking intensity in shaping these responses.

The influence of shaking intensity on behavioural response is well established, with stronger ground motion associated with more reactive and urgent actions (Goltz, Park, Nakano, et al., 2020; Goltz, Park, Quitoriano, et al., 2020). At lower intensity levels, typically Modified Mercalli Intensity (MMI) I–V, individuals often delay protective actions while prioritising situation appraisal. Analysis of earthquake video footage also indicates that behavioural responses change as shaking progresses. In the study by Vinnell et al., (2022), during the initial P-wave phase most individuals remained standing or continued walking; however, with the onset of the stronger S-wave, the majority of individuals modified their behaviour, including the adoption of protective actions. This shift in action suggests that behaviours resembling “freezing” during the early stages of shaking are more likely to reflect periods of situational assessment and decision-making rather than behavioural paralysis.

This study, consistent with previous research, shows that across seven events, individuals first assessed the earthquake's nature and severity before acting. Movement-based responses, including protective and maladaptive actions (e.g., moving to doorways), increased with shaking intensity, aligning with findings that response delays decrease, and protective actions increase, as intensity rises (Zhou et al., 2018). Effective strategies like "drop, cover, and hold on" or evacuation to safe locations are typically adopted only at higher intensities (MMI VII or above) (Goltz, Park, Nakano, et al., 2020; Goltz, Park, Quitoriano, et al., 2020).

Despite this, delaying protective action until shaking becomes more intense represents a maladaptive response that substantially elevates the risk of injury or fatality. Stronger shaking can restrict mobility, increase the likelihood of falls, and reduce the feasibility of effective evacuation once shaking subsides

(Zhang et al., 2024). Although higher intensities appear to prompt more decisive behaviour, postponing action until this point may exacerbate adverse outcomes (Vinnell et al., 2022). Immediate adoption of recommended protective actions, such as “Drop, cover and hold,” at the onset of shaking is therefore critical for reducing injury risk and improving safety outcomes during earthquakes.

Analysis of earthquake behaviour reports from the GeoNet data shows concerning inconsistencies, notably a decrease in “Drop, cover, and hold” and an increase in people “Moving to a doorway.” While the decrease in “Drop, cover, and hold” might be due to lower shaking intensity in recent events, the increasing use of doorways is problematic. Standing in a doorframe is an outdated, dangerous practice that offers no structural protection and increases injury risk from swinging doors (CUSEC, n.d.; NEMA, n.d.-a). Since the GeoNet reports don’t ask why people chose their actions, the exact influence is unknown, though moving through a doorway might be an step towards evacuation (Dacey, 2021).

While examining emotional responses across the seven earthquakes, substantial variation was observed in the intensity of fear reported by respondents. The results indicate a modest but negative relationship between perceived shaking intensity and reported “extreme fear,” with extreme fear being proportionally more prevalent during weak shaking than during strong shaking. This finding contrasts with conventional models that associate higher shaking intensities with increasing levels of fear and suggest that elevated fear motivates active responses (Goltz, Park, Quitoriano, et al., 2020).

One possible explanation for this contrasting pattern is that much of the earlier research examined behaviour in relation to single earthquake events (Prati et al., 2012; Lindell et al., 2016; Santos-Reyes & Gouzeva, 2020), whereas this study analysed combined responses across seven earthquakes. As a result, the aggregated findings may differ from those reported in event-specific studies. Furthermore, among the seven earthquakes analysed, only the Kaikōura earthquake was widely perceived as severe, while the remaining events were predominantly perceived as moderate or strong. This distribution may explain why the proportion of respondents reporting higher emotional valence, such as being very frightened or extremely frightened, was relatively low, thereby weakening the linear relationship between perceived intensity and extreme fear.

This research studied emotional response independently of behavioural response. However, further investigation is required to determine the influence of the emotions on behavioural response. During earthquakes the shift from emotional appraisal to behavioural response decision occur very quickly, thus understanding whether emotion moderates or mediates the behavioural response is crucial. Further analysis of the Felt Detailed data will explore the relationship of emotional reaction and behavioural response during the earthquake.

6 LIMITATIONS

There are a few limitations to be considered for this study. Firstly, online survey data sets may not demographically represent the affected population and could exclude certain groups (Haklay, 2013). Secondly, analytical issues may arise from combining data across multiple, heterogeneous earthquake events. Immediate behavioural and emotional responses are highly event-specific, influenced by factors like magnitude, intensity, context, and prior experience (Lindell & Perry, 2012; Prati et al., 2012). Pooling data from distinct earthquakes may obscure event-specific patterns.

7 CONCLUSION

This study, drew on 9363 GeoNet Felt Detailed survey reports collected through a crowdsourced approach immediately following earthquakes, for seven earthquakes between 2016- 2024. The analysis demonstrates that passive behaviours were predominant, particularly “Stopped what I was doing but stayed where I was”. Although the likelihood of adopting recommended protective actions such as “Drop, Cover, and Hold”

increased with perceived shaking intensity, overall adoption remained limited, especially during lower-intensity events. A key finding is the continued adoption of non-recommended actions, such as “Moved to doorways”, which represents an unsafe behavioural response. In addition, the results reveal a modest but unexpected negative association between shaking intensity and reports of extreme fear, indicating that increasing intensity is not consistently associated with a proportional increase in emotional response, particularly fear. Overall, the findings underscore the importance of the immediate adoption of appropriate protective actions to enhance personal safety. Future research should therefore prioritise identifying the underlying reasons for the persistence of behaviours such as moving to doorways, as well as further examining the complex role of emotional responses in shaping immediate behavioural choices. A more comprehensive exploration of the relationship between the physical characteristics of earthquakes, including intensity, and the influence of additional contextual and individual factors on behavioural responses will be essential for informing targeted awareness and educational programmes aimed at further reducing earthquake-related injuries.

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