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Health and housing consequences of climate-related disasters: a matched case-control study using population-based longitudinal data in Australia

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Summary

Background Understanding the role of how people are housed in reducing the long-term health and housing effects of climate-related disasters is crucial given our changing climate. We examine long-term health and housing trajectories and health effects of climate-related disasters in relation to housing vulnerabilities over a decade.

Methods We conducted a matched case-control study using longitudinal population-based data from the Household, Income and Labour Dynamics in Australia survey. We included data from people whose homes had been damaged by climate-related disasters (eg, flood, bushfire, or cyclone) between 2009 and 2019 and matched control cohorts with similar sociodemographic profiles who had not been exposed to disaster-related home damage during this period. We included data from de-identified individuals with at least 1 year of data before disaster and 3 years after disaster. One-to-one nearest neighbour matching was performed on the basis of demographic, socioeconomic, housing, health, neighbourhood, location, and climate characteristics 1 year before disaster. Conditional fixed-effects models for matched case-control groups were used to assess health trajectories, using eight quality-of-life domains on mental, emotional, social, and physical wellbeing, and housing trajectories, using three housing aspects of cost (ie, housing affordability and fuel poverty), security (ie, residential stability and tenure security), and condition (ie, housing quality and suitability).

Findings Exposure to home damage from climate-related disasters had significant negative effects on people's health and wellbeing at disaster year (difference between exposure and control groups in mental health score was –2·03, 95% CI –3·28 to –0·78; in social functioning score was –3·95, –5·57 to –2·33; and in emotional wellbeing score was –4·62, –7·06 to –2·18), with some effects lasting for 1–2 years after disaster. These effects were more severe for people who had housing affordability stress or were living in poor quality housing before the disaster. People in the exposure group had a slight increase in housing and fuel payment arrears following disasters. Homeowners had increased housing affordability stress (1 year after disaster: 0·29, 95% CI 0·02 to 0·57; 2 years after disaster: 0·25, 0·01 to 0·50), renters had a higher prevalence of acute residential instability (disaster year: 0·27, 0·08 to 0·47), and people who were exposed to disaster-related home damage had a higher prevalence of forced moves than did the control group (disaster year: 0·29, 0·14 to 0·45).

Interpretation Findings support the need for recovery planning and resilience building to consider housing affordability, tenure security, and housing condition. Interventions might require divergent strategies for populations in different precarious housing circumstances, and policies should target long-term housing support services for highly vulnerable groups.

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Introduction

Climate-related disasters, such as bushfires, flooding, and severe storms, have negative effects on health and wellbeing.[1] The International Panel on Climate Change assessment has concluded that climate-related disasters have increased in frequency and intensity, with this trend projected to continue throughout the century, and effects of these events on health and wellbeing will substantially worsen overtime.[2] Globally, the total number of extreme climate and weather events has increased, from less than 50 events per year in the 1960s to around 250 events per year in the 2010s.[3,4] Over the past decade, these extreme events have caused more than 410 000 casualties and affected 1·7 billion people.[4]

Australia is heavily affected by climate-related disasters. More than half of people affected by wildfire live in

Research in context

Evidence before this study

Climate-related natural disasters negatively affect people's health and wellbeing. However, little is known about housing affordability, security, and suitability after a disaster and their consequences for health recoveries. A search of PubMed and Google Scholar for journal articles published in English between Jan 1, 2012 and Sept 21, 2022 was conducted using the search terms "climate-related disaster", "health", and "housing". We identified that previous literature mostly measured housing consequences in terms of damage, destruction, reconstruction, and property values. Few studies addressed housing affordability, security, and suitability, which are crucial housing-based factors that shape health outcomes and health equity. Although five studies examined the long-term mental health impact of housing instability after climate-related disasters among subpopulations, the range of health-harming housing aspects examined in research was small. Previous studies predominantly had short follow-up times, were restricted to specific subpopulations, or focused on a specific disaster event.

Added value of this study

To address substantive and methodological research gaps identified in the existing literature, we used Australian population-based longitudinal data spanning a decade. To maximise the robustness of the study, we matched the exposed cohorts to control cohorts on the basis of their sociodemographic, health, housing, and geographical characteristics. We used conditional fixed-effects models for matched case-control data to examine the long-term effects of climate-related disaster events (ie, floods, bushfires, and cyclones) on health trajectories (ie, mental, social, emotional, and physical) and housing trajectories (ie, affordability, security, and suitability). We then examined the role of how people were housed (in terms of housing vulnerability) at baseline on health recovery after disaster.

Implications of all the available evidence

Our findings emphasise that housing is a crucial policy lever to provide disaster protection and assist in disaster recovery. Understanding the role of housing in disaster planning and recovery presents an opportunity to leverage housing for improving people's health and wellbeing. The right approach to housing assistance has the potential to greatly ameliorate the negative health effects. Interventions might require divergent strategies for populations in different precarious housing conditions, and policies should target long-term housing support services for highly vulnerable groups. Housing consequences according to varied disaster types and severity levels should be investigated in further research to support implementation of housing-based strategies.

Australia, rendering it in the top ten regions globally in terms of economic losses caused by natural disasters in 2020.[4,5] Natural disasters cause substantial damage to infrastructure and homes, destabilising disaster recovery. Some of the most catastrophic extreme climate events in Australia damaged or destroyed thousands of homes, including the Black Saturday bushfires in 2008–09 (ie, 173 fatalities and 2029 homes destroyed), Queensland floods in 2010–11 (33 fatalities and 28 000 homes damaged), and Black Summer bushfires in 2019–20 (26 fatalities and 2448 homes destroyed).

For more on the **extreme climate events in Australia** see https://knowledge.aidr.org.au

Housing is a crucial site for prevention and intervention in building preparedness for and adaptation to our changing climate.[6,7] The link between housing and health has been firmly established in the research literature[8] and in the *WHO Housing and Health Guidelines*.[9] Adequate housing is protective of health and wellbeing, whereas unaffordable, insecure, or unsuitable housing is a source of vulnerability and health harms.[8–13] Specifically, unaffordable, insecure, and unsuitable housing has been linked to poor mental health,[9,11,12,14] and energy poverty has been linked to increased risk of depression and hypertension and poor respiratory health.[9,13] By improving these features of housing through policy interventions, such as rental support, disaster resilience housing grants, and climate-adapted building codes, the chances of populations recovering their health and wellbeing following disasters will be improved.

Although the evidence for the health effects of exposure to climate-related disasters is increasing, the role of housing adequacy in the health effects of and recovery from climate-related disasters has scarcely been researched.[6,7,15] Despite the important pathways between climate-related disasters, housing, and health, notable gaps exist in understanding housing and health inequities after disaster. This lack of knowledge greatly hinders capacity to prepare and respond to the challenges of the changing climate.

Previous studies on housing trajectories have largely focused on property damage or improvement as outcomes, showing that loss and recovery in assessed housing values varied by neighbourhood social vulnerability and housing type.[7,16,17] Furthermore, existing empirical evidence on disparities in health recovery across the dimensions of housing is scarce.[6,7,15] Research has mostly focused on housing instability as the exposure, showing that people whose residential properties were lost or damaged during climate-related disasters were particularly vulnerable to increased risks of psychological morbidity and wellbeing impacts,[18–20] and people who were displaced permanently or resided in unstable housing for extended periods were more likely to have poor emotional and mental health due to disrupted access to services and social networks.[20–22] To advance understanding of how climate-related disasters affect housing and subsequent disparities in health recovery following a disaster, a conceptual approach is required that considers the multidimensionality of housing, including affordability, security, and suitability.

Previous research on health and housing trajectories following natural disasters has also had methodological challenges, including short follow-up periods (eg, focused on the first few years following events), narrowly focused population groups (eg, older adults or mothers from low-income backgrounds), small samples, or a small range of locations affected by a single event.[18,21,23,24] Most study designs do not include baseline measures before disaster or matched counterfactual comparison groups, posing a challenge to isolating the effects of climate-related disasters from unobserved confounding.[17,19,20] Studies have also largely focused on mental health, whereas physical health over time has been understudied.[23,24]

To address these conceptual, empirical, and methodological research gaps, we aimed to examine the long-term effects of climate-related disaster events (ie, floods, bushfires, and cyclones) on health and housing trajectories using population-based longitudinal data spanning 2009–19 in Australia. Using matched case-control data, the study seeks to investigate the effect of climate-related disasters on health-related trajectories (ie, quality-of-life measures covering mental, emotional, social, and physical wellbeing); describe the effect of climate-related disasters on housing trajectories (ie, housing unaffordability, fuel poverty, residential instability, tenure insecurity, housing quality, and housing unsuitability); and examine the role of housing in health recovery disparities. To our knowledge, this is the first study that uses population-based longitudinal data to investigate multidimensional housing and health trajectories in the long term and assess health recovery patterns for people with different housing vulnerabilities.

Methods

Study design and participants

We conducted a matched case-control study using population-based longitudinal data from Australia. 10 years of annual data on sociodemographic status, personal wellbeing, and life events, including measures of climate-related disasters, health, and housing, were collected from 2009 to 2019 as part of the Household, Income and Labour Dynamics in Australia (HILDA) survey. The HILDA survey is a nationally representative longitudinal study of more than 10 000 Australians with a stratified multistage clustered sampling design and a low non-response rate, at around 2%.[25] The full survey was administered to household members 15 years and older who were interviewed face-to-face and followed up annually. We included data from de-identified individuals with at least 1 year of data before disaster and 3 years of data after disaster to allow for the control of baseline characteristics and sufficient follow-up.

To approximate what would have occurred in the absence of the disaster for affected cohorts, control cohorts were drawn from respondents who had never been exposed to a climate-related disaster that damaged or destroyed their home between 2009 and 2019. Each exposed cohort, defined by different disaster years, was matched to a control cohort (ie, people who reported never having housing damage or destruction from a climate-related disaster) with similar demographic, socioeconomic, housing, health, neighbourhood, location, and climate characteristics 1 year before the disaster. Affected and unaffected cohorts were dynamically matched on the basis of their similarity at 1 year before the disaster, using one-to-one nearest neighbour matching within a calliper of 0·2 of the SD of the logit of the propensity score[26] without replacement (appendix p 2). Specifically, the matching was performed on the following covariates: sex, age group, country of birth, Aboriginal and Torres Strait Islander status, education, remoteness, area deprivation quintiles, household structure, equivalised household income, employment status, long-term health condition, government payment status, tenure types, dwelling types, mean area housing prices, 13 region indicators (based on the Australian Statistical Geography Standard Greater Capital City Statistical Area[27]), eight climate zone indicators (using the National Construction Code[28]), and eight mental and physical health domain measures (definitions are shown in appendix pp 3–4). The matching outcomes were assessed by use of standardised mean differences, which show significant improvement and an effective balance of covariates between exposed and control cohorts (appendix pp 5–7).

See Online for appendix

Ethics approval of the HILDA survey was granted by the Human Research Ethics Committee of the University of Melbourne (identification number 1955879). Informed consent was obtained from participants for the HILDA study, and all data were de-identified for researcher access.

Procedures

The HILDA survey contains a binary variable to indicate whether a climate-related disaster (ie, flood, bushfire, or cyclone) had damaged or destroyed a respondent's home between 2009 and 2019. A total of 2003 people in the sample reported home damage from climate-related disasters between 2009 and 2019. Around 14% of the exposure group had more than one disaster during the study period and, for those cases, the exposure measure was centred around the first occurrence of disaster.

The primary outcome was the differences between health outcome scores of people who were exposed to home damage due to climate-related disasters and similar cohorts who reported never having housing damage from a climate-related disaster from 1 year before disaster to 8 years after disaster. These health outcomes were measured with the 36-Item Short Form Survey, a standardised and validated diagnostic tool for assessing functional health status and wellbeing across

	Control group (n=992)	Exposure group (n=992)
Sex		
Female	548 (55%)	529 (53%)
Male	444 (45%)	463 (47%)
Age group		
<30 years	218 (22%)	238 (24%)
30–39 years	169 (17%)	169 (17%)
40–49 years	182 (18%)	185 (19%)
50–59 years	212 (21%)	199 (20%)
≥60 years	211 (21%)	201 (20%)
Country of birth		
Australia	788 (79%)	819 (83%)
Countries with English as the main language	99 (10%)	92 (9%)
Other countries	105 (11%)	81 (8%)
Aboriginal and Torres Strait Islander status		
Yes	28 (3%)	33 (3%)
No	964 (97%)	959 (97%)
Remoteness		
Metropolitan areas	529 (53%)	531 (54%)
Regional or remote areas	463 (47%)	461 (46%)
Area socioeconomics by IRSAD		
Lowest quintile	209 (21%)	204 (21%)
Second quintile	236 (24%)	219 (22%)
Third quintile	207 (21%)	204 (21%)
Fourth quintile	163 (16%)	183 (18%)
Highest quintile	177 (18%)	182 (18%)
Household structure		
Couple without children	290 (29%)	299 (30%)
Couple with children	424 (43%)	424 (43%)
Lone parent	101 (10%)	83 (8%)
Lone person	125 (13%)	137 (14%)
Other	52 (5%)	49 (5%)

(Table 1 continues on next page)

various mental and physical quality-of-life domains that has been widely adopted and validated in Australia and internationally.[25,29] On a scale from 0–100 (with a higher score indicating better health), the 36-Item Short Form Survey measures eight mental and physical wellbeing constructs: mental health, social functioning, role limitations due to emotional problems, vitality, physical functioning, role limitations due to physical health, bodily pain, and general health. Multiplicity of primary outcomes was not accounted for.

The secondary outcome was the probability of poor housing circumstances from 1 year before disaster to 8 years after disaster between the exposed and unexposed group. For housing measures, we used housing domains that have been well established and described in the most recent housing and health glossary[10] and the *WHO Housing and Health Guidelines*,[9] covering cost (ie, housing affordability and fuel poverty), security (ie, residential stability and tenure security), and condition (ie, housing quality and suitability). Housing affordability was measured using an indicator of housing affordability stress (ie, when a household is in the bottom 40% of national income distribution and spending more than 30% of household income in housing costs[10]) and an indicator of housing payment arrears (ie, not being able to pay rent or mortgage payments on time). Fuel poverty was measured using an indicator of fuel poverty (ie, spending more than 10% of household income on electricity bills, gas bills, and other heating fuel[10]) and an indicator of fuel payment arrears (ie, not being able to pay electricity, gas, or telephone bills on time). Residential stability was defined by whether a person had changed address since their previous interview. Tenure security was defined by whether a person was forced to move due to eviction, their property or government housing no longer being available, or inability to afford their mortgage or rent on time.[30] Housing quality was proxied by dissatisfaction about the home the person lived in (ie, categorised as poor condition if the home was self-rated as 0–4 on a scale from 0 [totally dissatisfied] to 10 [totally satisfied]). Housing suitability was assessed using an overcrowding measure based on the internationally adopted Canadian National Occupancy Standard (ie, categorised as overcrowding if at least one additional bedroom was required[30]). Details of variable definition are presented in the appendix (pp 3–4).

Statistical analysis

For descriptive analyses, visual inspections of trends in unadjusted health and housing outcomes (as previously described) over time, sample statistics for individuals who had been exposed to disaster-related home damage and individuals who had never been exposed, and sample statistics of baseline characteristics for matched exposure and control groups were presented. In the main analyses, conditional fixed-effect regressions for matched case-control data were used. Linear regression was modelled for health outcomes and logit regression was modelled for housing outcomes. Clustering robust SEs were applied. The model takes the following form:

$$\begin{aligned}\text{Health}_{ijt} = {} & \alpha\text{DisasterYear}^{k}_{ijt} + \gamma\text{Group}_{ij} \\ & + \delta\text{DisasterYear}^{k}_{ijt} \times \text{Group}_{ij} \\ & + \beta_1 x0_{ij} + \beta_2 x_{ijt} + \theta_t \\ & + \phi_j + u_{ijt}\end{aligned}$$

$$\begin{aligned}P(\text{Housing}_{ijt} = 1|\text{regressors}) = {} & f(\alpha\text{DisasterYear}^{k}_{ijt} + \gamma\text{Group}_{ij} \\ & + \delta\text{DisasterYear}^{k}_{ijt} \times \text{Group}_{ij} \\ & + \beta_1 X0_{ij} + \beta_2 X_{ijt} + \theta_t + \varphi_j)\end{aligned}$$

where Health_{ijt} and Housing_{ijt} measure health and housing outcomes of individual i for the matched pair j in wave t; $\text{DisasterYear}^{k}_{ijt}$ is a set of binary variables equal to 1 in the kth period before, at, or following the disaster year (eg, k=–1 indicates 1 year before disaster,

k=0 indicates the disaster year, k=1 indicates 1 year after disaster); $Group_{ij}$ indicates the exposure or control group; and $X0_{ij}$ and X_{ijt} are vectors of time-invariant and time-varying characteristics. Matched exposure and control groups with covariate adjustment enables double robustness estimation to address remaining imbalance. Estimates are presented as the difference in outcomes between the exposure and control group and 95% CIs.

To investigate whether people with different housing sensitivities and capabilities fared differently, analyses of health heterogeneity by predisaster housing vulnerabilities were conducted according to housing affordability, stability, and condition. These housing vulnerability factors as social determinants of health have been linked to inequalities in health outcomes,[7,11,31] and their interactions with exposure indicators were tested for statistical significance. A composite score of the average of all health domains was used as the outcome measure for the heterogeneity analyses.

Sensitivity analyses were performed using alternative matching schemes, modelling strategies, and sample restriction, including conditional fixed-effects models using nearest neighbour matching without calliper, conditional fixed-effects models excluding individuals who had been exposed to a disaster after 2015 (enabling follow-up of at least 4 years), conditional fixed-effects models with clustering adjusted at the area level, mixed-effects models using nearest neighbour matching with calliper, and mixed-effects models with one-to-two ratio matching.

Observations with missing data for the outcome variables were not included.

Data were analysed with Stata 16.0.

	Control group (n=992)	Exposure group (n=992)
(Continued from previous page)		
Highest education		
Graduate or postgraduate	226 (23%)	214 (22%)
High school or advanced certificate	485 (49%)	488 (49%)
Year 11 or below	281 (28%)	290 (29%)
Employment status		
Employed	636 (64%)	648 (65%)
Unemployed	38 (4%)	33 (3%)
Not in labour force	318 (32%)	311 (31%)
Long-term health condition		
Yes	310 (31%)	316 (32%)
No	682 (69%)	676 (68%)
Receiving government payment		
Yes	238 (24%)	225 (23%)
No	754 (76%)	767 (77%)
Housing tenure		
Owner	713 (72%)	717 (72%)
Private renter	221 (22%)	214 (22%)
Social renter	15 (2%)	21 (2%)
Other	43 (4%)	40 (4%)
Dwelling type		
House	914 (92%)	908 (92%)
Flat, unit, or apartment	68 (7%)	73 (7%)
Other dwelling types (eg, caravan)	10 (1%)	11 (1%)
Mean household income and area housing price (SD)		
Equivalised household income, weekly AUS$	1035·4 (575·5)	1047·1 (604·3)
Local area home values, AUS$	474 596·5 (469 534·7)	481 653·9 (507 820·5)

Data are n (%) unless otherwise stated. IRSAD=Index of Relative Socio-economic Advantage and Disadvantage.

Table 1: **Descriptive summary for exposure and control groups at baseline**

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

We included data from 1984 participants, collected between Aug 20, 2009 and Feb 9, 2020. Of 2003 people who reported home damage from climate-related disasters during 2009–19, those with at least 1 year of data available before the disaster were included to allow for the control of baseline characteristics, giving a sample of 1443 exposed individuals. After nearest neighbour matching, the analytical sample at baseline comprised 1370 people from the exposure group and 1370 from the control group. Individuals who were exposed to disaster after 2016 were excluded to enable follow-up of at least 3 years after disaster and reasonable sample sizes for later years. 992 individuals who were exposed were matched with 992 people who were unexposed (appendix p 1). Around 90% of individuals are observed for at least 8 years in the sample. Baseline characteristics (after matching) show balanced profiles between groups (table 1).

Comparing respondents who were not exposed to disaster-related home damage with those who were (before matching), the groups that were more at risk were people older than 30 years, people born in Australia, people located in regional or remote regions, people in employment, people receiving government payments, and people with long-term health conditions (appendix p 8).

Health outcome scores, measured across eight domains from 1 year before the disaster to 8 years after the disaster, declined sharply by 2–3 points at the year of disaster, particularly in mental health domains (in the order of 11–16% of 1 SD; unadjusted changes; figure 1).

When examining housing circumstances from 1 year before disaster to 8 years after disaster, we identified that the prevalence of residential instability and forced moves peaked at disaster year for the exposed group (unadjusted changes; figure 2). Housing affordability stress remained high after disaster in those exposed to disaster-related home damage.

Table 2 shows the results from conditional fixed-effects models for the effects of disaster-related home damage on mental and physical health over time. Although there were no significant differences in health outcome scores between exposure and control groups before the disaster, disaster-related home damage had significant effects on mental health, social functioning, and role limitations due to emotional problems, and these effects remained 1 year and 2 years on, with role limitations due to emotional problems present only at 2 years on. People exposed to disaster-related home damage also reported significantly lower levels of general health, physical functioning, role limitations due to physical health, and bodily pain at time of the disaster and a protracted effect on bodily pain 2 years on compared with people of similar characteristics without exposure. Sensitivity analyses showed similar results (appendix pp 9–13).

Table 3 shows the effects of disaster-related home damage on the prevalence of housing affordability stress, fuel poverty, residential instability, tenure insecurity, poor housing quality, and housing unsuitability over time. The difference in housing affordability stress for homeowners with a mortgage in the exposure group compared with matched controls was significant, and at 2 years after disaster the difference remained sizeable (0·25, 95% CI 0·01 to 0·50). The probability of not being able to pay rent or mortgage payments on time significantly increased for a few years following a disaster compared with matched controls. People who were exposed to home damage from disasters were slightly more likely to have fuel poverty and fuel payment arrears following the disaster compared with those who were not exposed. The effect of disaster-related home damage on residential relocation appeared to be more pronounced for renters than owner occupiers. The probability of forced moves (ie, eviction, property no longer available, and relocation due to inability to afford rent or mortgage) for people in the exposure group was also significantly increased at the disaster year compared with the control group, and the majority of forced moves were made by renters. There was a temporary small increase in the probability of poor housing quality proxied by home dissatisfaction measures at the disaster year, and no significant difference in housing suitability measured by overcrowding was observed between the exposure and control group.

We analysed the differential trajectories of health outcomes over time by housing domains, with significance tests on the interactions with exposure indicators of p=0·091 for housing affordability, p=0·024 for housing security, and p=0·0003 for housing quality (figure 3). The health-related quality of life of people who did not have housing affordability stress before disaster had a smaller decrease at the disaster year (–1·97, 95% CI –3·22 to –0·72) than the health of those who had housing affordability stress before the disaster (although insignificant with high variability among this group; –4·20, –8·91 to 0·51). Although the exposure group had worse health than the control group at the year of the disaster regardless of their residential mobility, respondents who moved home following the disaster at the disaster year reported a greater decrease in health (–5·13, 95% CI –8·71 to –1·54) than those who remained in their homes (–2·30, –3·62 to –0·98). However, over the long term, the health of people who relocated seemed to take less time to recover (within 2 years after the disaster). Households living in poor quality housing before disaster experienced a larger health impact (–3·58, 95% CI –7·07 to –0·09) than those satisfied with their home before disaster (–2·03, –3·23 to –0·82).

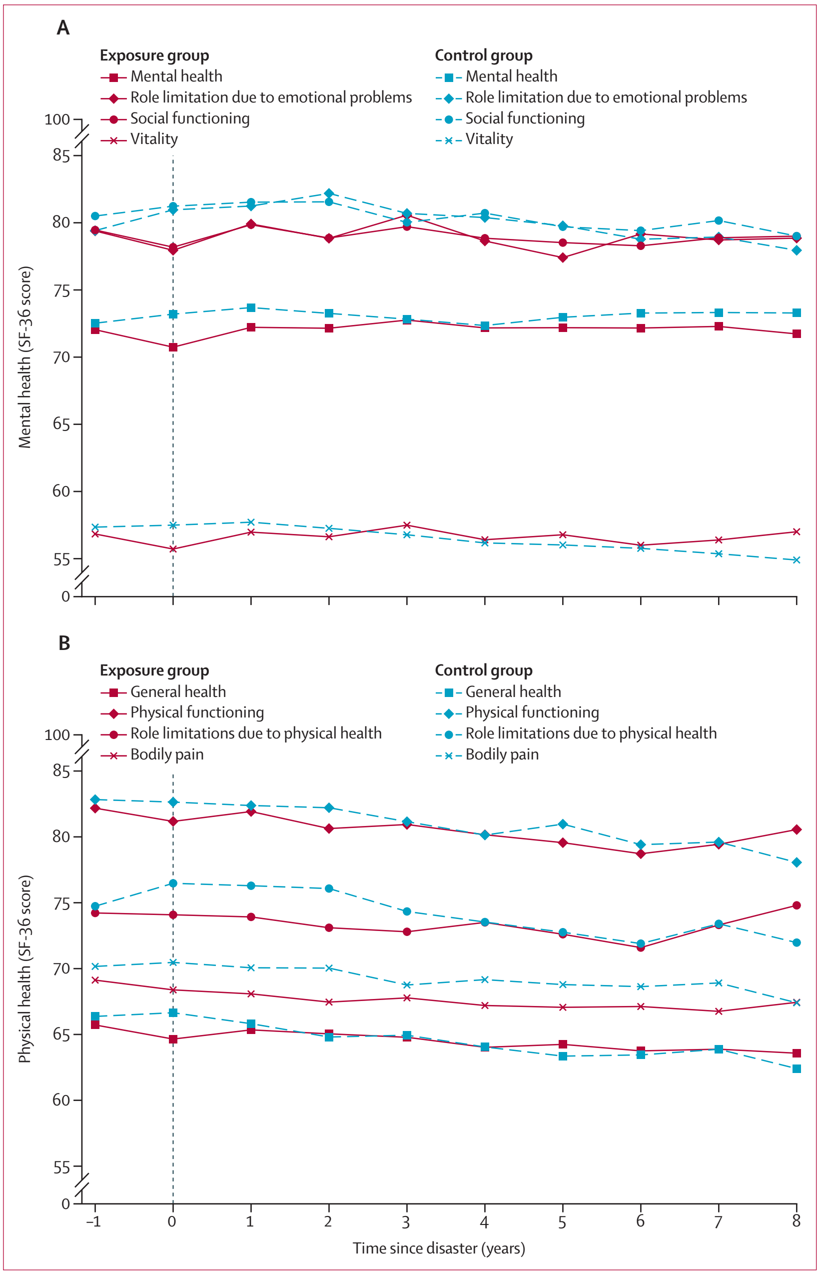

***Figure 1:* Health trajectories following climate-related disasters**
Health trajectories in mental health domains (A) and physical health domains (B). The SF-36 health domains (on a scale 0–100) are used. The unadjusted mean scores of health measures are presented. SF-36=36-Item Short Form Survey.

Discussion

This study investigates the effect of climate-related disasters on health and housing circumstances over time, and health recovery relative to housing vulnerabilities before disaster. The study design aimed to obviate confounding, selection, and endogeneity bias that was largely unaccounted for in previous studies.[17,19,20] We incorporated information from affected individuals before their exposure and obtained counterfactual cohorts of similar individuals, while exploiting within group variation and controlling for an array of confounders through matching using nationally representative longitudinal data. We identified evidence of negative mental, emotional, social, and physical health effects in the short term. These results were consistent with previous disaster studies showing that the prevalence of mental and physical illness increased for at least 1 year after single disaster events.[32,33]

This study describes people's housing circumstances (and recovery) following climate-related disaster events using a multidimensional conceptual framing of housing. To the best of our knowledge, this is the first study to examine long-term trajectories of housing affordability, security, and suitability following climate-related disaster events. We identified that housing affordability stress was significantly increased in the first 2 years after the disaster year for homeowners with a mortgage. Renters appeared to be most affected by residential instability and forced moves, with an increased prevalence of relocation and forced moves due to eviction, unavailable properties, or rental payment arrears. Populations who were exposed to home damage from climate-related disasters also had increased risks of fuel payment arrears for years after disaster and poorer housing conditions at disaster year to a lesser degree, and no significant changes were observed in the prevalence of overcrowding.

Unaffordable and insecure housing has been strongly linked to adverse mental and physical health outcomes.[10,11,13] These results emphasise housing affordability stress and tenure insecurity as determinants of recovery for homeowners and rental tenants after disaster and the need for differential disaster support programmes according to people's housing circumstances. The delayed risk of housing affordability stress for mortgaged homeowners might be due to the provision of short-term relief measures. The increased residential instability and forced moves for renters were likely to be related to insecure features of tenure rights and short rental market supply in Australia. Studies have shown that rental properties suffer

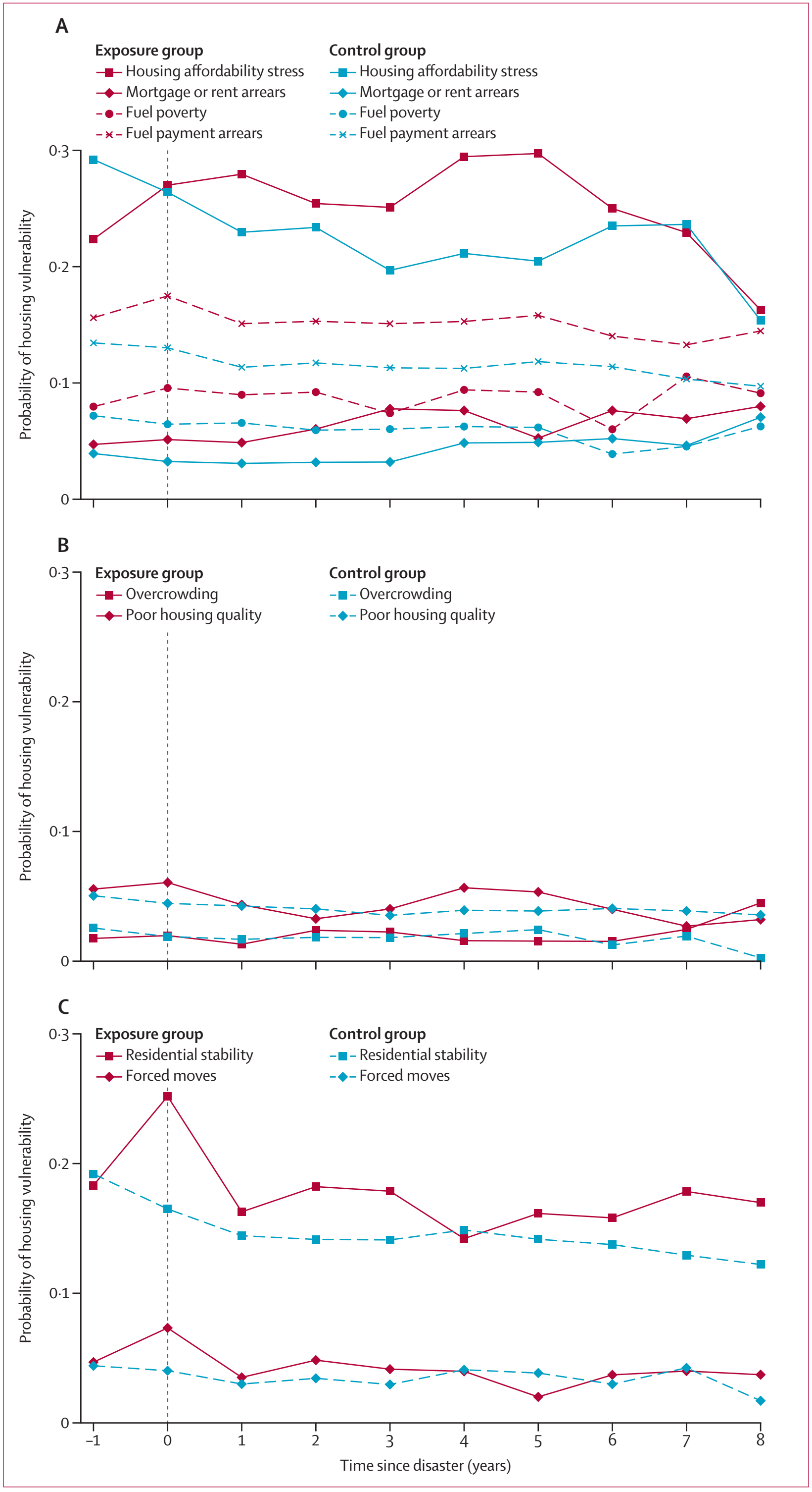

Figure 2: **Housing trajectories following climate-related disasters**
Trajectories of housing costs (A), security (B), and condition (C). Housing outcomes are binary variables that measure the prevalence of a housing vulnerability domain (ranging from 0–1). Housing affordability is measured using an indicator of housing affordability stress and an indicator of housing payment arrears. Fuel poverty is measured using an indicator of being fuel poor and an indicator of fuel payment arrears. Residential stability is defined by whether a person changed address since last interview and whether a person was forced to move. Housing quality is proxied by participant dissatisfaction about the home. Overcrowding is measured on the basis of the internationally adopted Canadian National Occupancy Standard. Detailed definitions are described in the Methods and the appendix (pp 3–4). The unadjusted mean probabilities of housing outcomes are presented.

	Mental health domains				Physical health domains			
	Mental health	Social functioning	Role limitations due to emotional problems	Vitality	General health	Physical functioning	Role limitations due to physical health	Bodily pain
1 year before disaster	0·02 (–1·23 to 1·26)	–0·87 (–2·53 to 0·79)	–0·11 (–2·58 to 2·36)	–0·14 (–1·56 to 1·27)	–0·97 (–2·38 to 0·45)	–1·07 (–2·51 to 0·37)	–1·62 (–4·31 to 1·06)	–1·34 (–2·94 to 0·27)
Disaster year	–2·03 (–3·28 to –0·78)	–3·95 (–5·57 to –2·33)	–4·62 (–7·06 to –2·18)	–1·07 (–2·44 to 0·30)	–2·17 (–3·58 to –0·75)	–2·13 (–3·65 to –0·62)	–2·69 (–5·23 to –0·14)	–3·39 (–5·03 to –1·75)
1 year after disaster	–1·36 (–2·59 to –0·13)	–1·81 (–3·57 to –0·06)	–1·37 (–3·84 to 1·11)	–0·35 (–1·74 to 1·04)	–0·35 (–1·77 to 1·07)	–1·32 (–2·79 to 0·15)	–2·61 (–5·30 to 0·08)	–2·46 (–4·08 to –0·84)
2 years after disaster	–1·14 (–2·39 to 0·11)	–2·20 (–3·95 to –0·45)	–2·86 (–5·39 to –0·33)	–0·64 (–2·04 to 0·76)	0·24 (–1·21 to 1·69)	–1·27 (–2·77 to 0·23)	–2·58 (–5·25 to 0·09)	–2·82 (–4·48 to –1·16)
3 years after disaster	–0·56 (–1·84 to 0·72)	–1·04 (–2·83 to 0·76)	–0·79 (–3·44 to 1·86)	0·35 (–1·04 to 1·74)	–0·09 (–1·53 to 1·35)	–0·41 (–1·94 to 1·12)	–1·89 (–4·65 to 0·87)	–1·09 (–2·82 to 0·64)
4 years after disaster	–0·41 (–1·76 to 0·95)	–2·35 (–4·22 to –0·48)	–2·17 (–5·03 to 0·68)	0·08 (–1·43 to 1·59)	–0·57 (–2·07 to 0·93)	–0·30 (–1·95 to 1·34)	–0·88 (–3·84 to 2·08)	–2·40 (–4·16 to –0·64)
5 years after disaster	–1·15 (–2·72 to 0·41)	–1·62 (–3·81 to 0·57)	–3·13 (–6·40 to 0·14)	0·49 (–1·25 to 2·24)	0·63 (–1·09 to 2·35)	–1·26 (–3·03 to 0·51)	–1·17 (–4·53 to 2·18)	–1·53 (–3·58 to 0·52)
6 years after disaster	–1·58 (–3·16 to 0·00)	–1·70 (–3·99 to 0·59)	–0·21 (–3·61 to 3·19)	–0·16 (–2·03 to 1·70)	–0·23 (–2·04 to 1·58)	–0·84 (–2·76 to 1·08)	–1·57 (–5·14 to 2·01)	–1·53 (–3·59 to 0·54)
7 years after disaster	–1·61 (–3·46 to 0·23)	–2·58 (–5·00 to –0·15)	–1·53 (–5·34 to 2·27)	0·63 (–1·38 to 2·64)	–0·57 (–2·58 to 1·45)	–0·57 (–2·67 to 1·54)	–0·56 (–4·37 to 3·25)	–2·13 (–4·51 to 0·26)
8 years after disaster	–1·89 (–4·07 to 0·29)	–1·13 (–4·20 to 1·94)	–0·45 (–5·17 to 4·26)	1·44 (–1·03 to 3·90)	0·94 (–1·39 to 3·27)	2·00 (–0·33 to 4·33)	3·33 (–1·27 to 7·93)	–0·88 (–3·66 to 1·90)

Data are mean differences in health outcome scores between exposure group and control group (95% CI). Conditional fixed-effect linear regressions for matched case-control data were estimated.

Table 2: **Health effects of home damage from climate-related disasters**

	Housing costs					Housing security			Housing condition	
	Housing affordability: mortgage affordability stress	Housing affordability: rental affordability stress	Housing affordability: housing payment arrears	Fuel poverty: fuel poor	Fuel poverty: fuel payment arrears	Residential stability: residential mobility of owners	Residential stability: residential mobility of renters	Tenure security: forced moves	Housing quality: home dissatisfaction	Housing suitability: overcrowding
1 year before disaster	0·04 (–0·62 to 0·69)	–0·17 (–0·63 to 0·30)	0·11 (–0·19 to 0·40)	0·02 (–0·29 to 0·32)	0·04 (–0·28 to 0·37)	–0·04 (–0·17 to 0·10)	–0·01 (–0·30 to 0·29)	0·01 (–0·37 to 0·39)	0·06 (–0·31 to 0·43)	–0·10 (–0·55 to 0·35)
Disaster year	0·04 (–0·21 to 0·29)	–0·10 (–0·29 to 0·09)	0·16 (0·01 to 0·30)	0·11 (0·00 to 0·22)	0·10 (0·04 to 0·17)	0·05 (–0·08 to 0·18)	0·27 (0·08 to 0·47)	0·29 (0·14 to 0·45)	0·10 (0·00 to 0·20)	–0·01 (–0·17 to 0·14)
1 year after disaster	0·29 (0·02 to 0·57)	0·04 (–0·16 to 0·24)	0·17 (0·05 to 0·28)	0·13 (–0·06 to 0·32)	0·10 (0·03 to 0·16)	0·01 (–0·09 to 0·10)	0·17 (–0·33 to 0·68)	0·20 (0·00 to 0·39)	0·01 (–0·11 to 0·12)	–0·06 (–0·23 to 0·10)
2 years after disaster	0·25 (0·01 to 0·50)	–0·05 (–0·23 to 0·14)	0·14 (0·04 to 0·24)	0·15 (–0·24 to 0·54)	0·11 (0·03 to 0·18)	0·07 (–0·11 to 0·24)	0·12 (–0·18 to 0·42)	0·17 (–0·02 to 0·37)	–0·04 (–0·16 to 0·09)	0·08 (–0·08 to 0·23)
3 years after disaster	0·36 (–0·03 to 0·75)	–0·03 (–0·21 to 0·15)	0·12 (0·01 to 0·22)	0·06 (–0·34 to 0·46)	0·10 (0·01 to 0·20)	0·05 (–0·06 to 0·16)	0·16 (–0·20 to 0·52)	0·17 (–0·03 to 0·38)	0·04 (–0·08 to 0·17)	0·07 (–0·09 to 0·23)
4 years after disaster	0·33 (–0·07 to 0·72)	–0·09 (–0·28 to 0·11)	0·08 (–0·02 to 0·18)	0·10 (–0·25 to 0·46)	0·10 (–0·03 to 0·23)	–0·07 (–0·18 to 0·05)	0·00 (–0·11 to 0·11)	0·01 (–0·17 to 0·19)	0·16 (0·00 to 0·23)	–0·07 (–0·25 to 0·11)
5 years after disaster	0·33 (–0·13 to 0·80)	0·04 (–0·20 to 0·29)	0·05 (–0·07 to 0·16)	0·10 (–0·30 to 0·51)	0·10 (–0·05 to 0·26)	0·02 (–0·10 to 0·13)	0·08 (–0·14 to 0·30)	–0·06 (–0·27 to 0·15)	0·10 (–0·03 to 0·24)	–0·11 (–0·31 to 0·08)
6 years after disaster	0·21 (–0·19 to 0·61)	–0·16 (–0·42 to 0·10)	0·07 (–0·05 to 0·19)	0·10 (–1·13 to 1·33)	0·08 (–0·05 to 0·22)	–0·02 (–0·15 to 0·12)	0·13 (–0·10 to 0·35)	0·15 (–0·08 to 0·38)	–0·01 (–0·16 to 0·14)	0·06 (–0·17 to 0·30)
7 years after disaster	0·15 (–0·21 to 0·51)	–0·10 (–0·35 to 0·15)	0·12 (–0·03 to 0·27)	0·24 (–0·69 to 1·16)	0·08 (–0·05 to 0·22)	0·08 (–0·07 to 0·24)	0·14 (–0·04 to 0·32)	0·02 (–0·23 to 0·26)	–0·09 (–0·27 to 0·08)	0·08 (–0·14 to 0·31)
8 years after disaster	0·02 (–0·13 to 0·18)	–0·07 (–0·31 to 0·16)	0·04 (–0·12 to 0·21)	0·10 (–0·13 to 0·32)	0·12 (–0·08 to 0·32)	0·00 (–0·16 to 0·17)	0·17 (–0·11 to 0·44)	0·20 (–0·10 to 0·51)	–0·03 (–0·24 to 0·18)	0·59 (0·26 to 0·91)

Data are mean differences in probabilities of housing outcomes between exposure group and control group (95% CI). Conditional fixed-effect logistic regressions for matched case-control data were estimated. Housing outcomes are binary variables that measure the probability of experiencing a housing vulnerability domain.

Table 3: **Housing effects of home damage from climate-related disasters**

more damage and have less access to recovery resources than do owner-occupied homes, such as insurance, loans, and assistance programmes,[7,16] and the leases of renters were likely to be terminated following the disaster,[16] contributing to their tenure insecurity.

We also identified that the health consequences of climate-related events varied by housing vulnerabilities. The negative health effects of climate-related disasters were greater for people who had housing affordability stress before disaster (although with large variation), resided in poorer quality housing before disaster, and relocated following the disaster at the disaster year. Our findings support the need for post-disaster recovery planning and community resilience building to consider housing tenure, housing affordability, rental security, and existing housing quality. Interventions might require divergent strategies for populations in different precarious housing circumstances, and policies should target long-term housing support services for highly vulnerable groups. Evidence on housing patterns following climate-related disasters is crucial to guide effective planning, development, and modification of policies and programmes and to mobilise housing as a prevention and intervention point to mitigate the negative health effects of climate-related disasters and ensure equitable access to service and support where needed.

This study has several limitations. First, the exposure measure is operationalised as home damage from a flood, bushfire, or cyclone, and the specific type and severity of the disaster are not assessed. This method hinders the ability to disentangle the health and housing effects by different disaster types, durations, or severities. It is possible that the controls had been exposed to some of the non-housing-related effects of the disaster, such as pollution from a bush fire. The effect size estimates should be considered a midway point between severe indicators of exposure, such as bereavement, and indicators of mere exposure to disasters. Second, because of the nature of longitudinal data, fewer observations are available for later years after disaster overall (ie, respondents who were exposed to disaster in later years contributed fewer years of data to be examined in this analysis), leading to larger variation in the estimates, although sample restrictions were applied to ensure sufficient follow-up. Further years of data would allow analyses to be extended. Third,

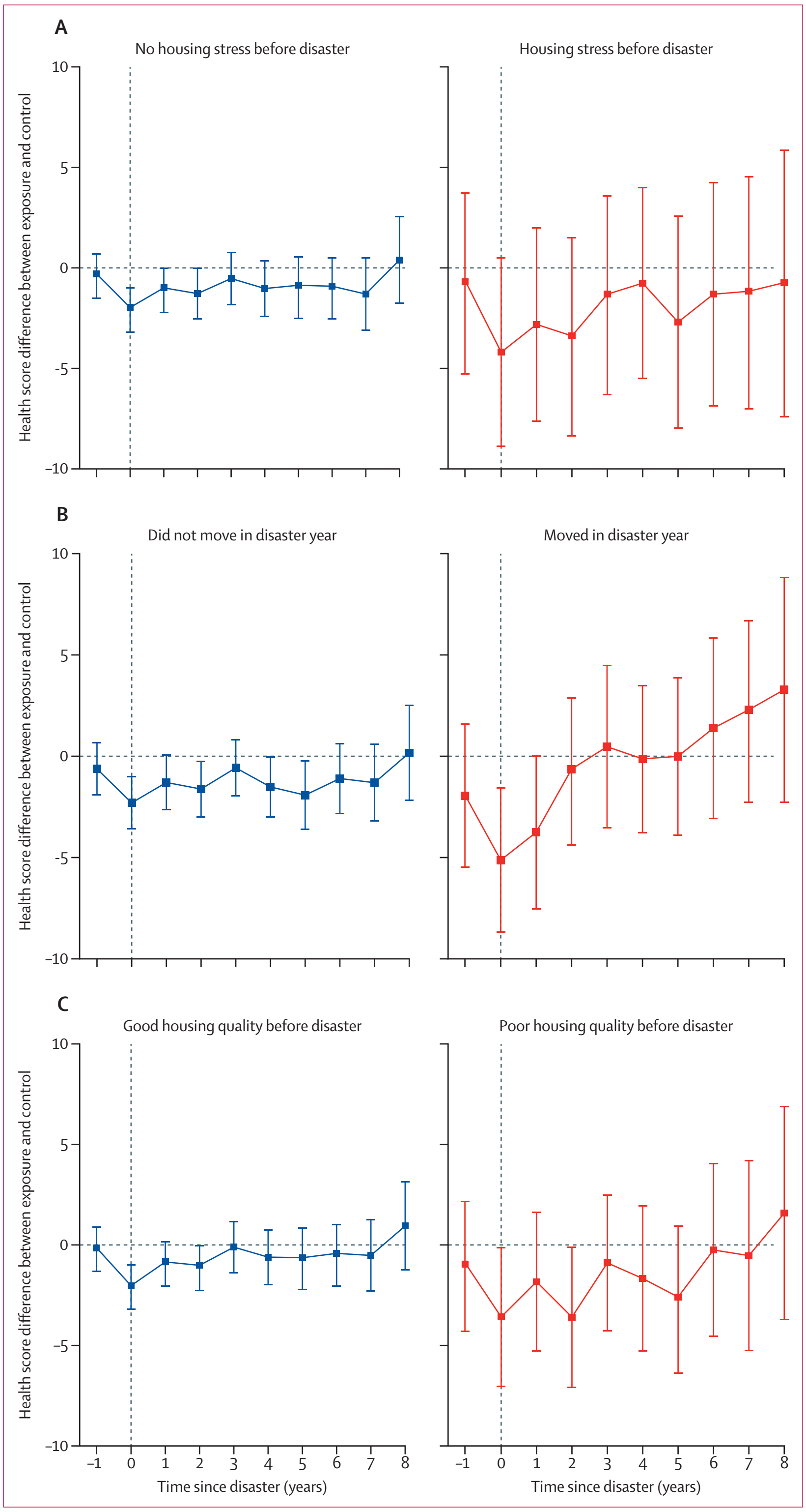

Figure 3: **Health disparities by housing vulnerabilities**
Health differences between exposure and control groups in housing affordability before disaster (A), housing security in the disaster year (B), and housing condition before disaster (C). Differences in the composite SF-36 score points (the mean score across 8 domains) between the exposure and control group and 95% CIs (dashed lines) at each disaster year are presented. Poor housing affordability is measured by spending more than 30% of household income on housing costs, and significance tests on the interactions with exposure indicators give p=0·091 (>0·050, >0·017 as Bonferroni correction). Housing security is measured by residential mobility, and significance tests on the interactions with exposure indicators give p=0·024 (<0·050, >0·017 as Bonferroni correction). Housing quality is proxied by low rating of home satisfaction, and significance tests on the interactions with exposure indicators gives p=0·0003 (<0·050, <0·017 as Bonferroni correction). SF-36=36-Item Short Form Survey.

as with most observational studies, unmeasured residual confounding probably remained despite matching, adjustment, and control for within group variation. Some self-reported measures, such as home satisfaction, might incur measurement bias. Fourth, further research could use a group-based approach to characterise recovery patterns or area-level data to identify neighbourhood vulnerabilities.

The evidence suggests that housing damage from climate-related disaster had significant mental, social, emotional, and physical health effects. People with pre-existing housing vulnerabilities had more severe health consequences than did people without pre-existing housing vulnerabilities. Climate-related disasters significantly affected housing affordability and security, and appropriate housing is essential for health recovery and capabilities to cope with disaster effects. Understanding the role of housing in disaster recovery presents an opportunity to leverage housing as preventive and interventive measures for improving people's health and wellbeing and to guide adaption, mitigation, and disaster risk management, especially for vulnerable populations. The right approach to housing assistance has the potential to ameliorate the negative health effects of climate-related disasters.

Contributors

AL conceptualised the study and analysed the data. All authors contributed to the study design and the interpretation and presentation of the results. AL and MT accessed and verified the data in the study. AL wrote the manuscript draft, and MT and RB revised the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

Data supporting this study are available from DSS Longitudinal Studies Dataverse. Requests to access the data should be directed to the Australian Government Department of Social Services at https://dataverse.ada.edu.au/dataverse/hilda.

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