

Nonradiological Health Consequences from Evacuation and Relocation (NUREG/CR-7285)

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Project Background

- Evacuation and relocation are key protective actions recommended in a radiological release
 - PAGs are intended to weigh the risk of radiation against the risk of the protective action
- Despite being protective of the hazard, evacuation and relocation have inherent risks associated with them
 - The holistic risk has not been fully quantified, making it difficult for emergency managers to thoughtfully weigh the risks
- This project seeks to quantitatively and qualitatively evaluate the risks associated with evacuation and relocation

Definitions and Scope

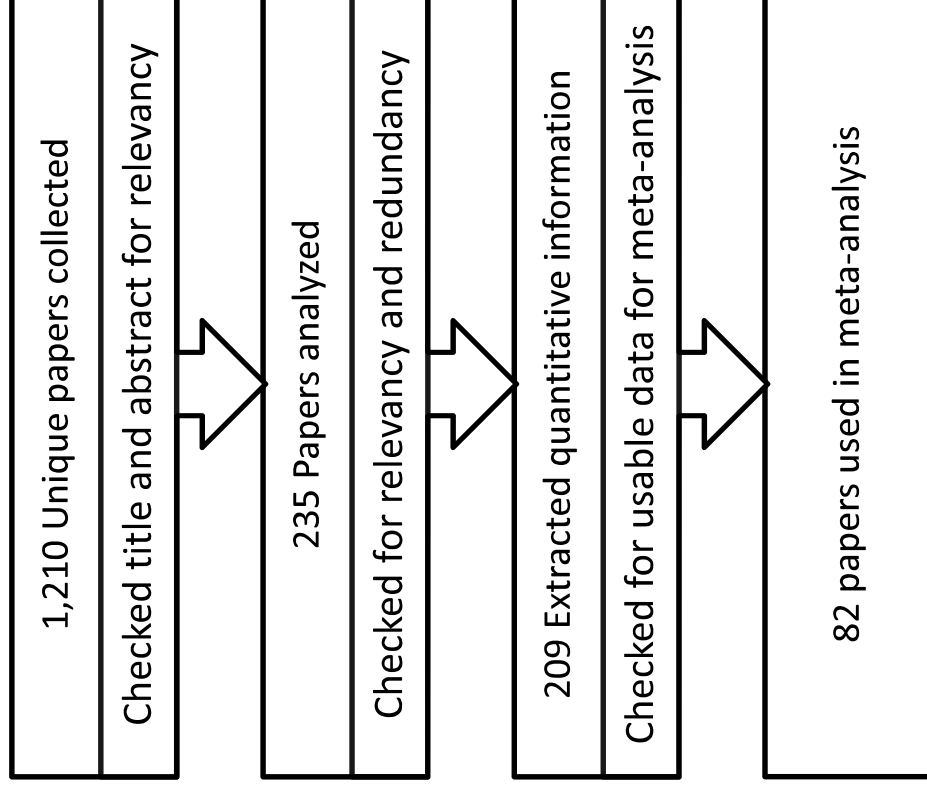
- Two groups examined:
 - Displaced populations
 - Evacuated populations typically return within 1 year
 - Relocated populations remained displaced for greater than 1 year
 - Nondisplaced populations
- Response to a range of emergency events, excluding:
 - Terrorism
 - Designed to create out-sized fear and anxiety in the population
 - Displacements due to armed conflict where populations were not evacuated to truly safe areas
 - During typical evacuations, populations are brought to safe areas
 - Populations still at risk complicates interpretation of findings

Non-Radiological Health Consequences from Evacuation and Relocation

LITERATURE REVIEW

Literature Review Methodology

- Collected papers covering a multitude of events and health outcomes
- Filtered based on:
 - Relevancy
 - Redundancy
 - Reliability
 - Newcastle-Ottawa Scale
- Excluded from meta-analysis if populations were conflated or ambiguous



Human Health Effects

- Fourteen different health effects were identified across all the studies from the literature review

Broad effects	# of papers in meta-analysis
General Health Effects	18
Healthcare Accessibility	5
Other miscellaneous effects	8
Psychological Distress	23
Substance Abuse	11

Specific effects	# of papers in meta-analysis
Anxiety	10
Depression	17
PTSD	32
Diabetes	10
Heart Disease	12
Mortality	8
Weight Problems	6
Respiratory	5
Sleep Problems	4

Emergency Events

- Nine different emergency event types were included in the dataset
 - Most nuclear power plant data from the Fukushima nuclear accident

Event	# of papers in meta-analysis
Hurricanes/Cyclones	19
Wildfires	6
Non-disaster relocation events	2
Nuclear power plant accidents	32
Earthquakes	9
Floods	6
Explosions	3
Earthquakes and Tsunamis	3
War	3

Non-Radiological Health Consequences from Evacuation and Relocation

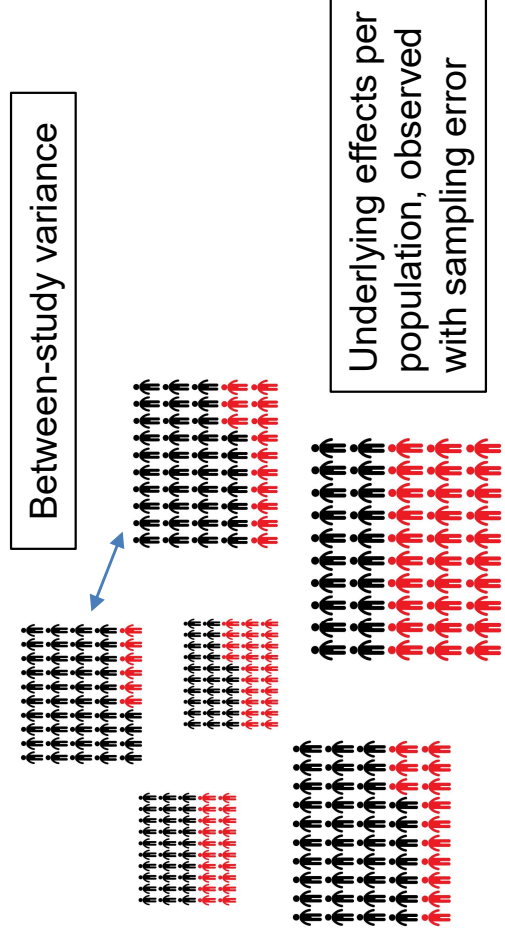
STATISTICAL METHODOLOGY

Overview of Statistical Method

- **Meta-analysis** – combining data from multiple papers
 - Most papers describe one health effect observed at a single event
 - To understand effect across all health effects and all disasters, results must be combined
 - Meta-analytical methods were used to combine study data and account for intra-study and inter-study variance
- **Meta-regression** – understanding how different factors affect the health effects measured
 - For the same health effect, different variables could influence the outcome
 - Event type, time between event and data collection, age of population, etc.
 - Meta-regression provides a tool to examine how different event characteristics influence the measured odds ratio

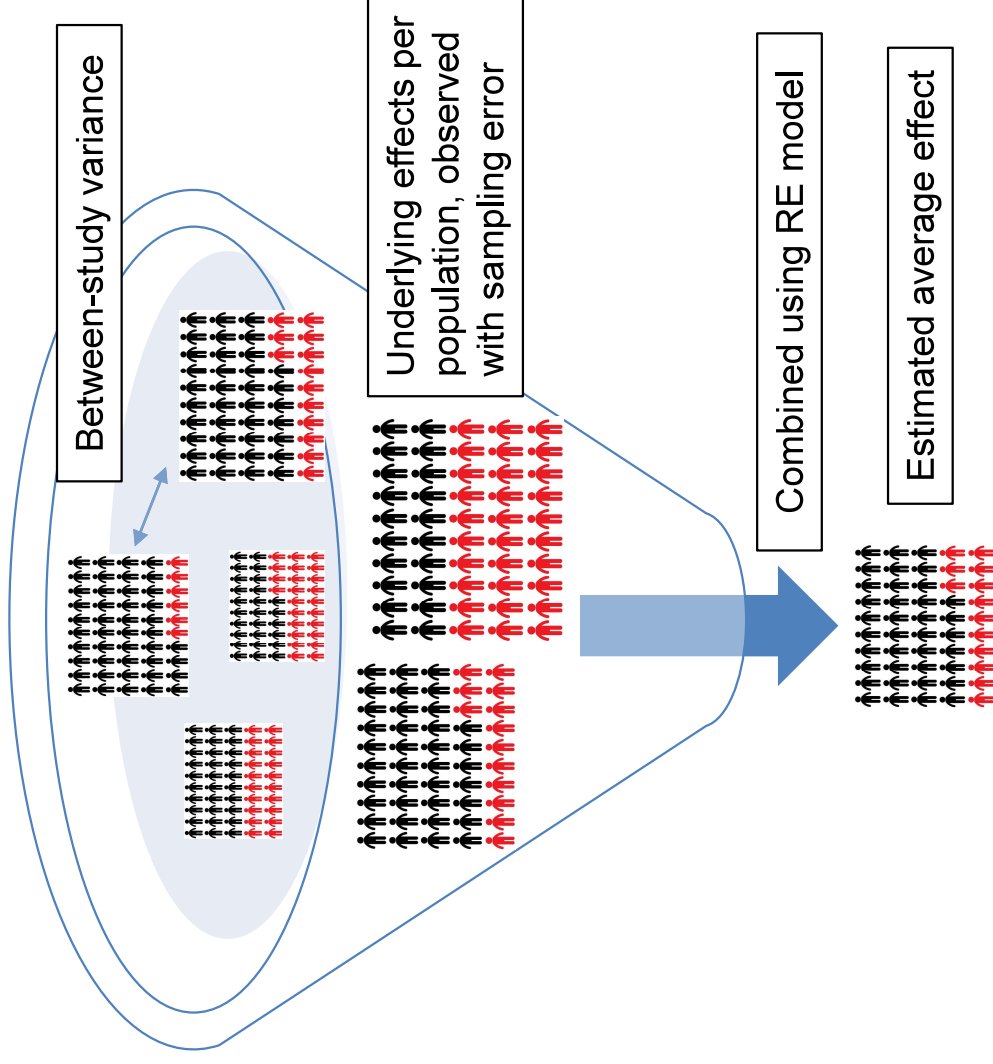
Meta-Analysis of Effect Sizes

- Effect size
 - Quantitative measure of a health effect for a general population under a given condition
- Meta-analysis estimates an average effect size across multiple studies
 - Using different studies increases statistical power and robustness of estimate
 - Combined evidence gets closer to some underlying “truth”
 - Identifies sources of disagreement between studies of different types



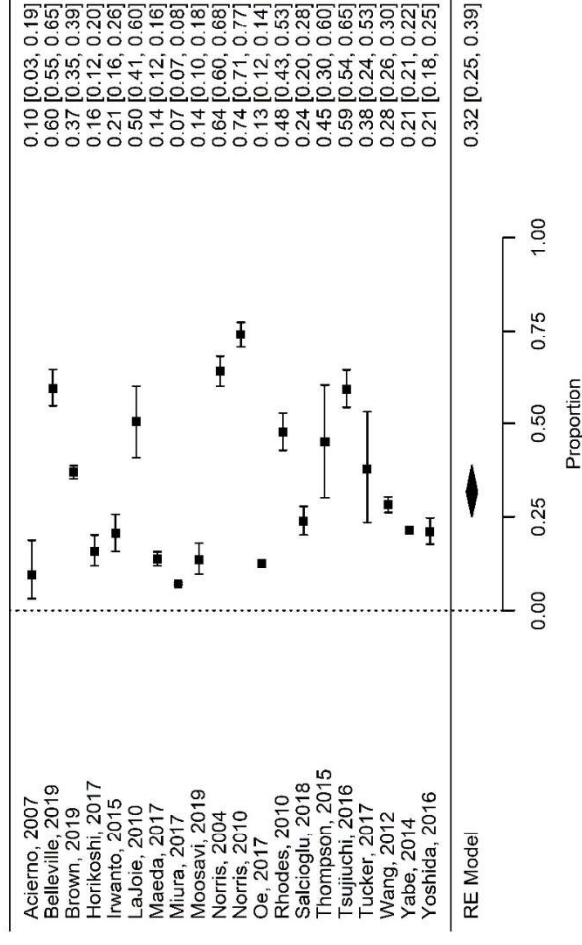
Random Effects (RE) Modeling

- Effect size
 - Population proportion or odds ratio
- Random Effects Model
 - RE models are used to combine individual study effect sizes into an average effect size
 - Accounts for differences between studies with different population demographics and emergency event type



Meta-Analysis of Proportions

- Study focused on estimating a **proportion** of the displaced and nondisplaced populations affected by each health condition following emergency events
 - Estimates a weighted average of the proportion in each population
- Proportions are visualized using a forest plot
 - Shows individual effect sizes
 - Individual-level variance of each study
 - Final pooled estimate and 95% confidence interval



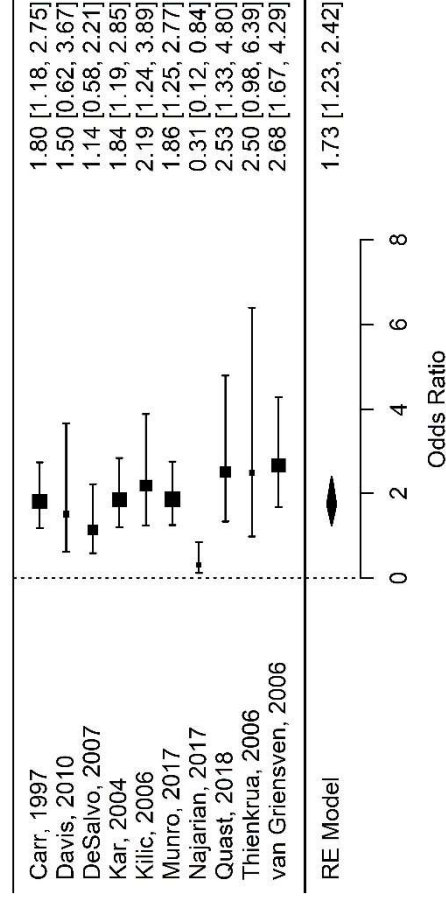
Example: Aggregated effect size for PTSD in evacuated or relocated groups following an emergency, $\hat{p} = 0.32$ (0.25, 0.39)

Meta-Analysis of Odds Ratio

- Study focused on estimating **the odds** that individuals may experience a health condition if displaced, compared to the odds if non-displaced, following an emergency event
 - Estimates are a weighted average of the odds ratio
 - Allows for an examination of the association between negative health outcomes (e.g., experiencing PTSD) and displacement

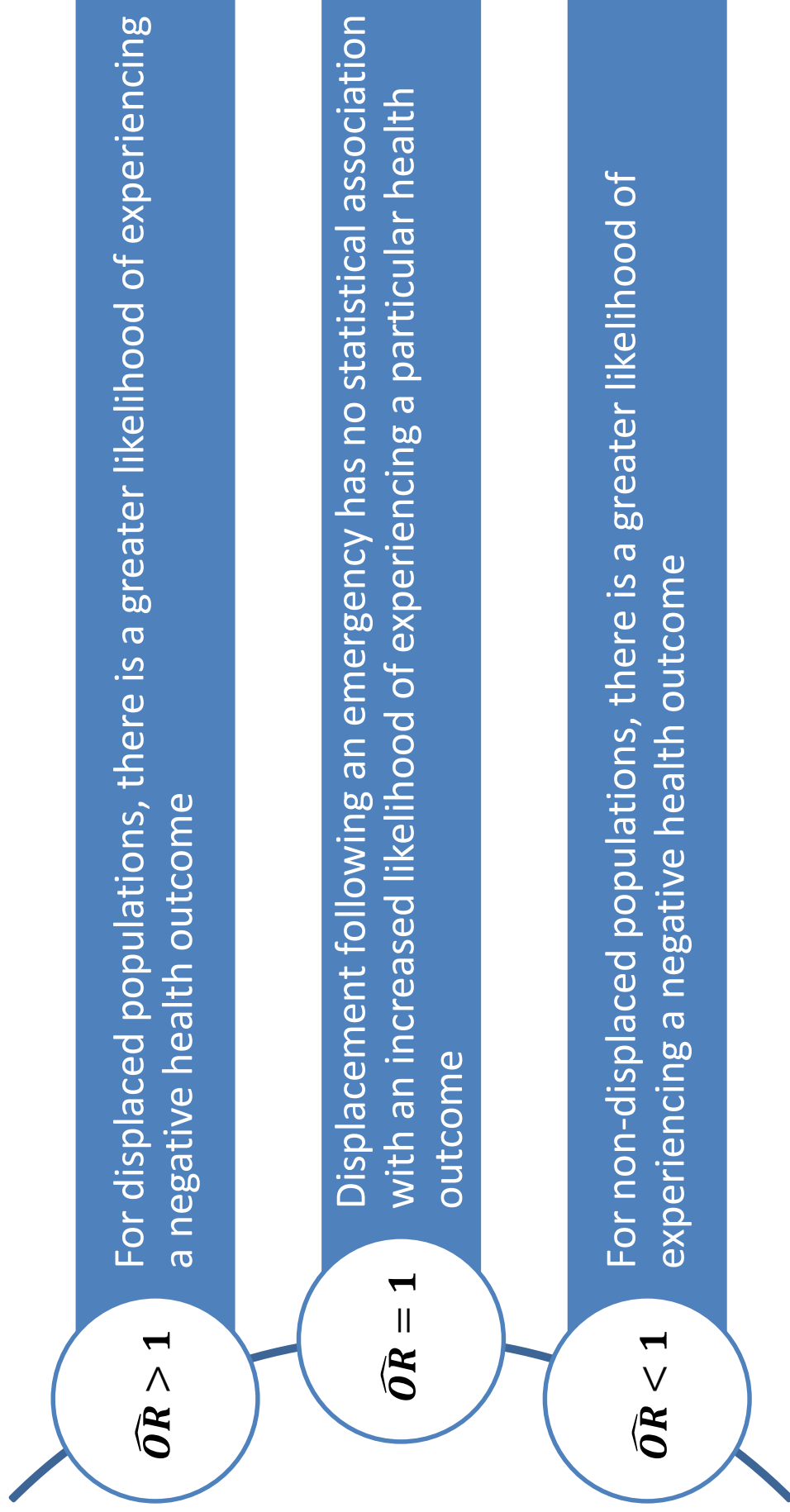
- Visualized using a forest plot

- Shows individual effect sizes
- Individual-level variance of each study
- Final pooled estimate and 95% confidence interval



Example: Comparative effect size for PTSD in evacuated or relocated groups following an emergency, $\widehat{OR} = 1.73$ (1.23, 2.42)

Interpretation of Odds Ratios



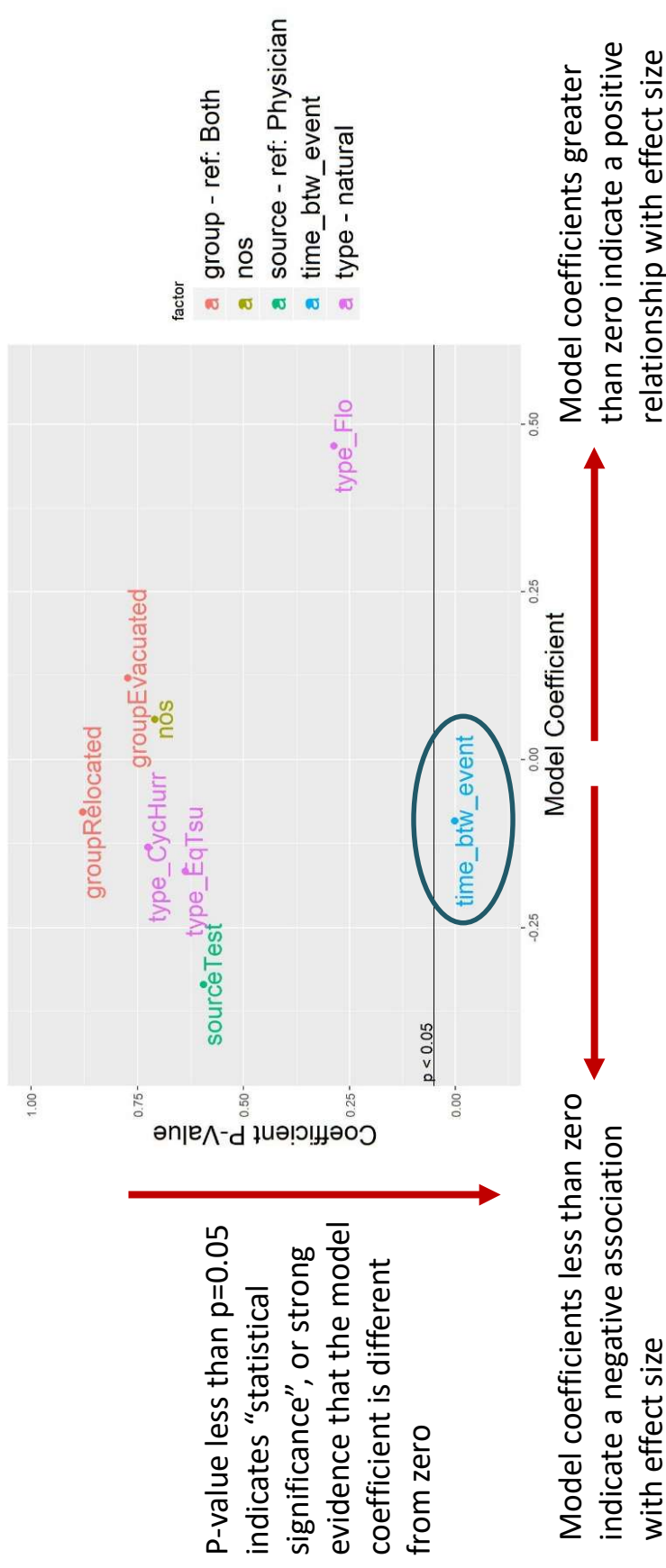
Meta-Regression of Emergency Factors

- Examined the individual study and emergency event characteristics that are associated with greater or lesser pooled effect sizes across each health outcome

Variable Short Name	Type of Variable	Variable Values
data_source	Categorical	Physician-diagnosed (reference), self-reported, test
group	Categorical	Both evacuated and relocated (reference), evacuated, relocated
NOS	Numeric	Ordinal NOS score values 2-8
time_between_event	Numeric	Years between event and effect measurement
type_CycHurr	Binary	Cyclone or hurricane emergency indicator
type_EqTsu	Binary	Earthquake or tsunami emergency indicator
type_Flo	Binary	Flood emergency indicator
type_Fire	Binary	Fire emergency indicator
type_NPP	Binary	Nuclear power plant emergency indicator

Meta-Regression of Emergency Factors

- The study characteristics were evaluated in individual models and results were aggregated across the health outcome to compare model coefficients and p -values



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RESULTS AND FINDINGS

Summary of Odds Ratio Findings

- Displaced individuals more likely to suffer from negative health effects
- “All Health Effects” is estimated at OR=1.49
 - Study aggregate across all disaster and health effect types
 - Evacuation and relocation are related to a greater likelihood of experiencing a negative health outcome

Outcome	Odds Ratio	Confidence Interval	Significant (95% level)
Anxiety	1.29	(0.84, 1.97)	
Depression	2.50	(1.87, 3.35)	Yes
Diabetes	1.19	(1.08, 1.32)	Yes
General Health Effects	1.94	(1.14, 3.30)	Yes
Healthcare Accessibility Problems	2.04	(0.81, 5.18)	
Heart Disease	1.07	(0.88, 1.31)	
Mortality	1.76	(1.49, 2.09)	Yes
PTSD	1.73	(1.23, 2.42)	Yes
Psychological Distress	1.68	(1.19, 2.38)	Yes
Respiratory Problems	1.48	(0.96, 2.30)	
Sleep Problems	1.63	(1.53, 1.74)	Yes
Substance Abuse	1.11	(0.97, 1.27)	
Weight Problems	1.43	(1.17, 1.75)	Yes
Other Effects	2.86	(1.81, 4.52)	Yes
All Health Effects	1.49	(1.24, 1.79)	Yes

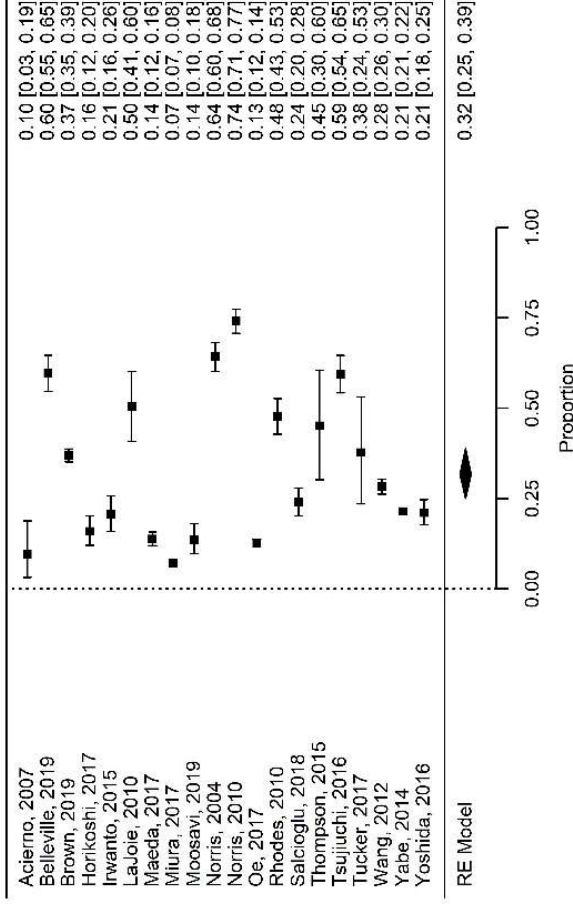
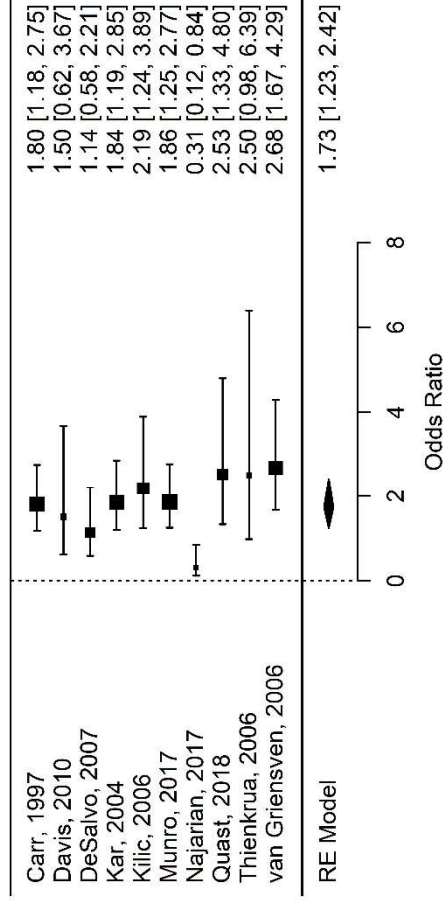
PTSD Meta-analysis

Displaced individuals were more likely to experience PTSD, with an overall average odds ratio of 1.73

Reflected in a large disparity in the overall prevalence of PTSD in the displaced (right) and nondisplaced populations ($p=0.15$, not pictured)

However, PTSD prevalence is high in both groups

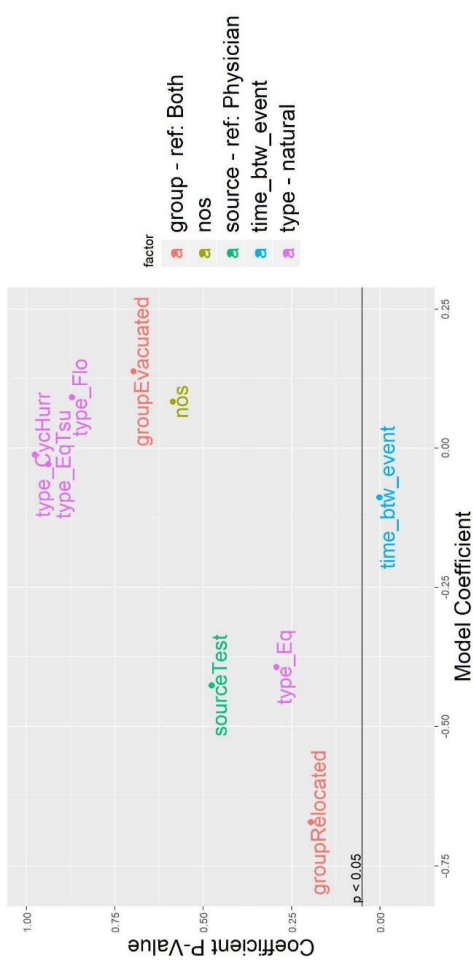
- PTSD is nearly inevitable among a population following man-made or natural emergencies whether or not there was an evacuation event (Neria, 2008)



PTSD Meta-regression

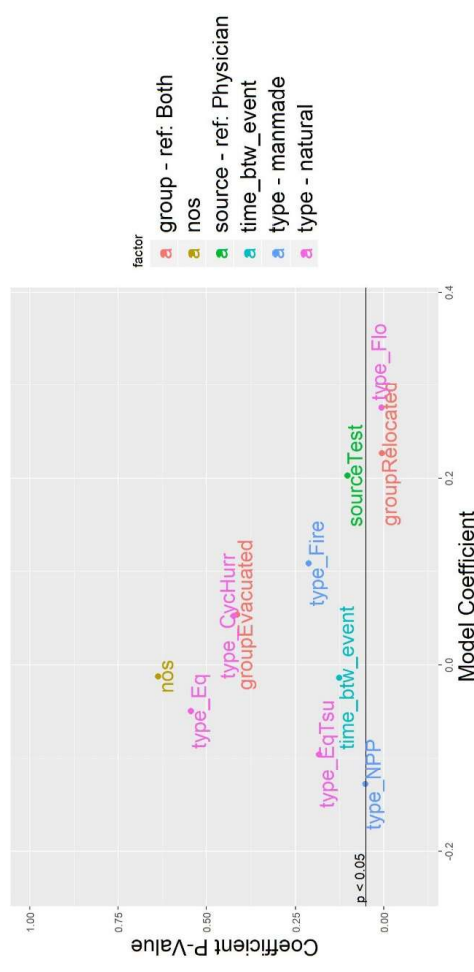
Only one statistically significant variable was identified in the odds ratio analysis

- Time between the emergency event and the data collection



Displaced population only—

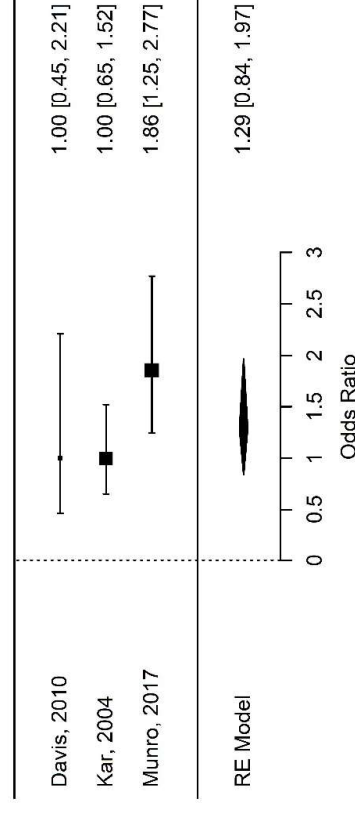
- Relocation and flood events both associated with higher prevalence of PTSD
- Nuclear power plant accidents were not significant at the p<0.05 level but were associated with lower prevalence of PTSD



Anxiety Results

Small number of studies directly compared displaced and non-displaced individuals with anxiety

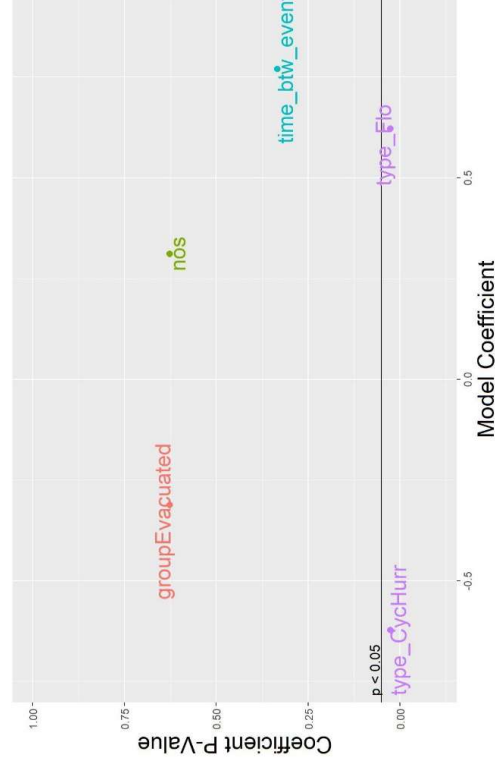
- Displaced individuals were more likely to experience anxiety
- Not statistically significant



Emergency event type was significantly association with the anxiety outcome

- Floods associated with higher anxiety
- Hurricanes associated with lower

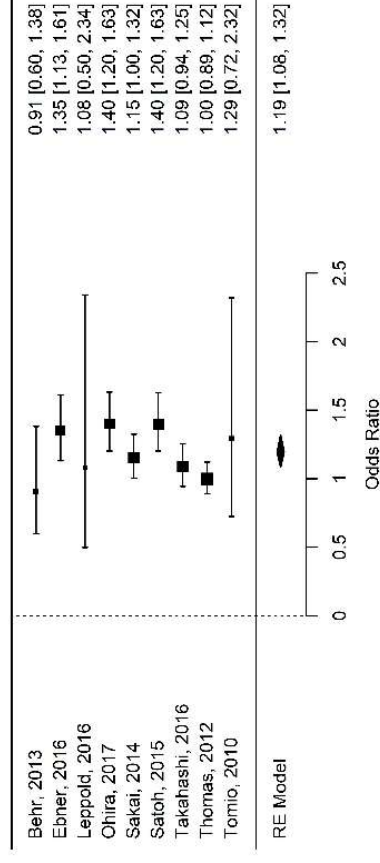
Anxiety following emergency events is mediated primarily by exposure to the traumatic event itself, rather than to factors related to evacuation (Davis, 2010)



Diabetes Results

Small but statistically significant result

- Displaced populations more likely to suffer diabetes after a disaster
- Studies did not necessarily distinguish new cases of diabetes from diabetes that predated the emergency event

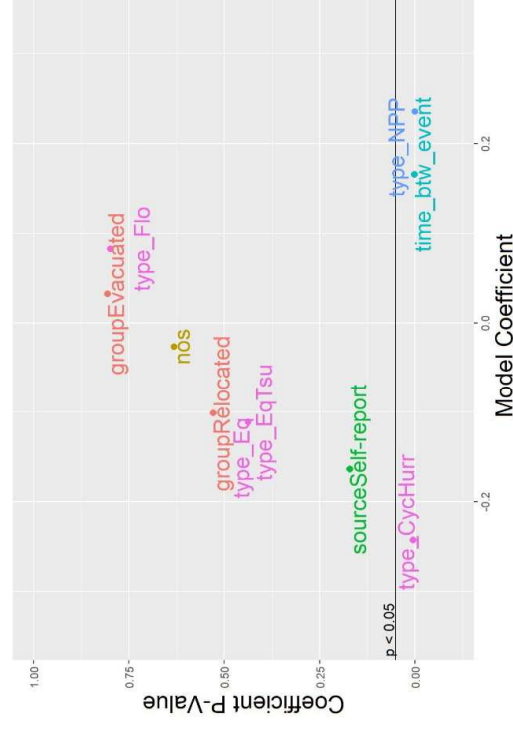


A higher odds ratio was associated with two factors:

- Greater times between the event and when the data was collected
- Nuclear power plant disasters

Nuclear power plant disaster data came from 2011 Fukushima incident

- Increased incidence of diabetes in evacuated groups could be caused by changes in diet and lifestyle that accompanies prolonged displacement



Sleep Problems

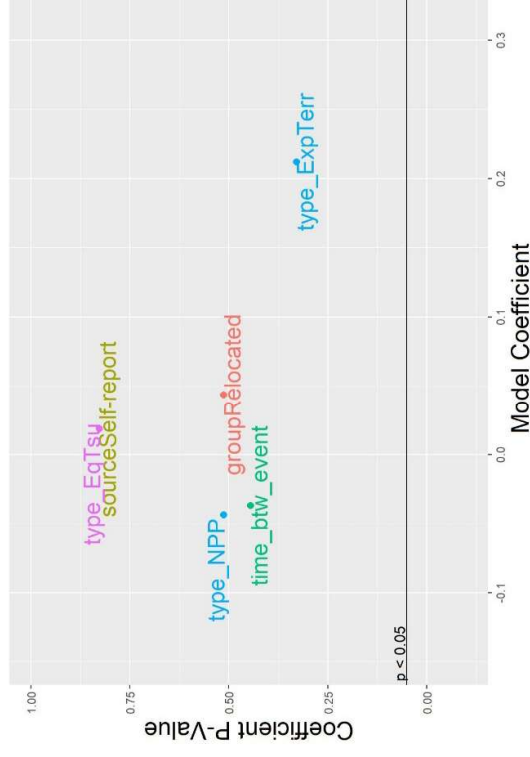
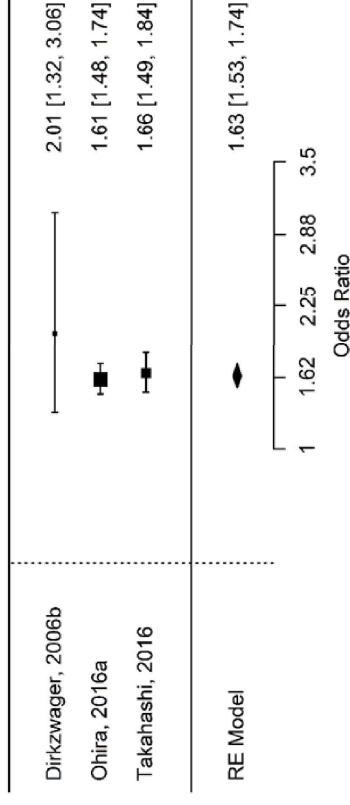
Displaced populations reported more sleep problems

- Likely a causal relationship between displacement and sleep problems as evacuees cope with the stress reactions and are anxious to return home

No individual variables were significantly associated with observed sleep problems

- Several at-risk groups or other potential factors that could be driving sleep problems
- Children between 4 and 12 had the largest increase in sleep problems

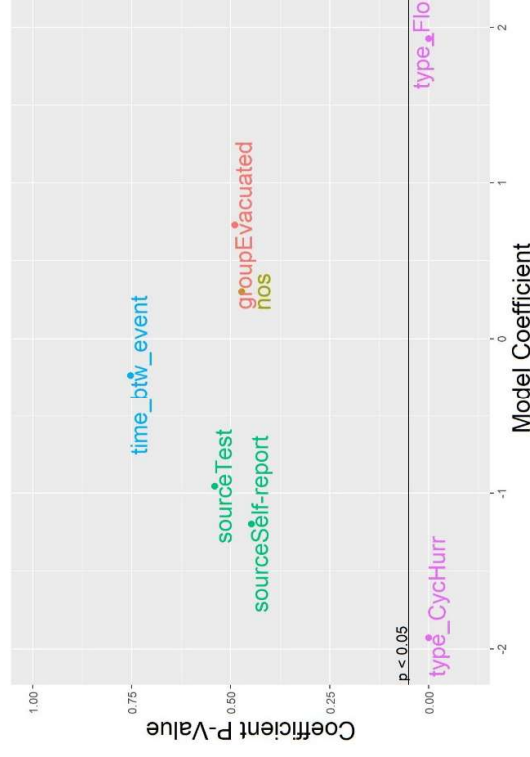
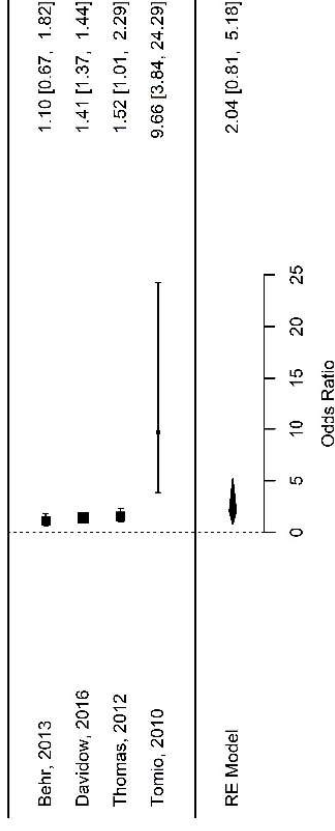
Analysis of sleep problems difficult because people cannot reliably report the quality of their sleep



Healthcare Accessibility Results

Odds ratio > 2 but not statistically significant

- Displaced populations suffer from significant accessibility problems
- General awareness about this issue may lead to mitigation efforts
- Both displaced and non-displaced populations struggled with healthcare accessibility after major emergency events



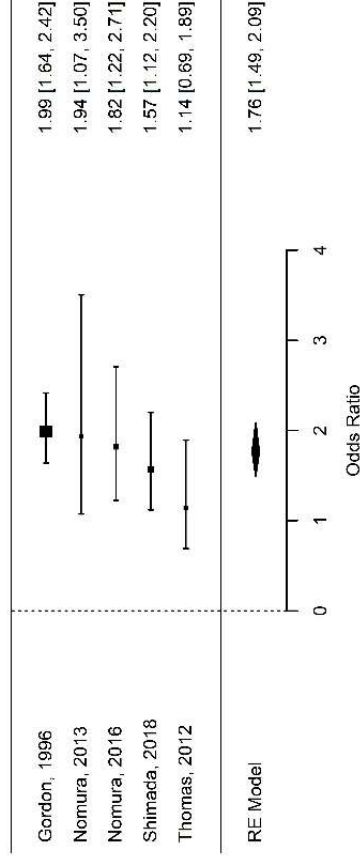
Floods were associated with higher odds ratios while hurricanes and cyclones were associated with lower odds ratios

- Result fairly expected as hurricanes typically have longer notice periods, giving emergency managers time to prepare
- Floods are typically no-notice or short-notice events, may not see same effect

Mortality Results

Displaced populations suffered higher mortality, particularly in the first 60-90 days after displacement

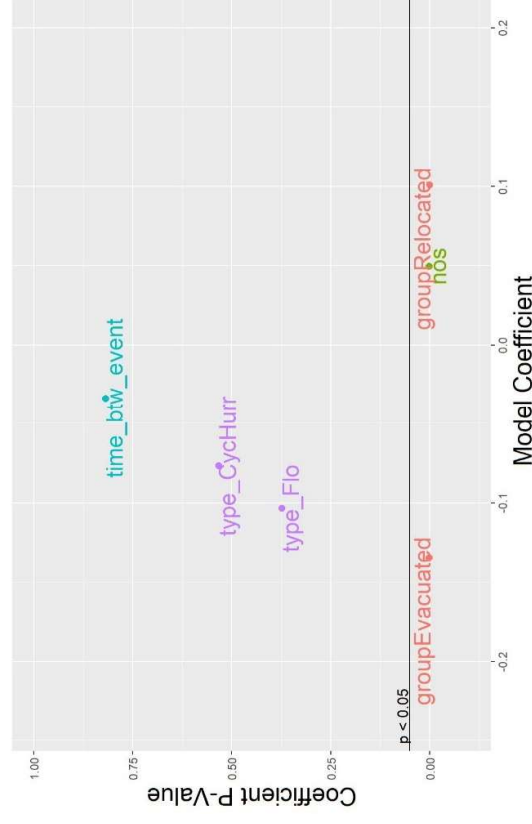
- Data includes deaths during evacuation of hospitals, elderly care or nursing facilities, and at admittees at a hospital



Meta-regression of the odds ratio effect size found no significant factors associated with mortality

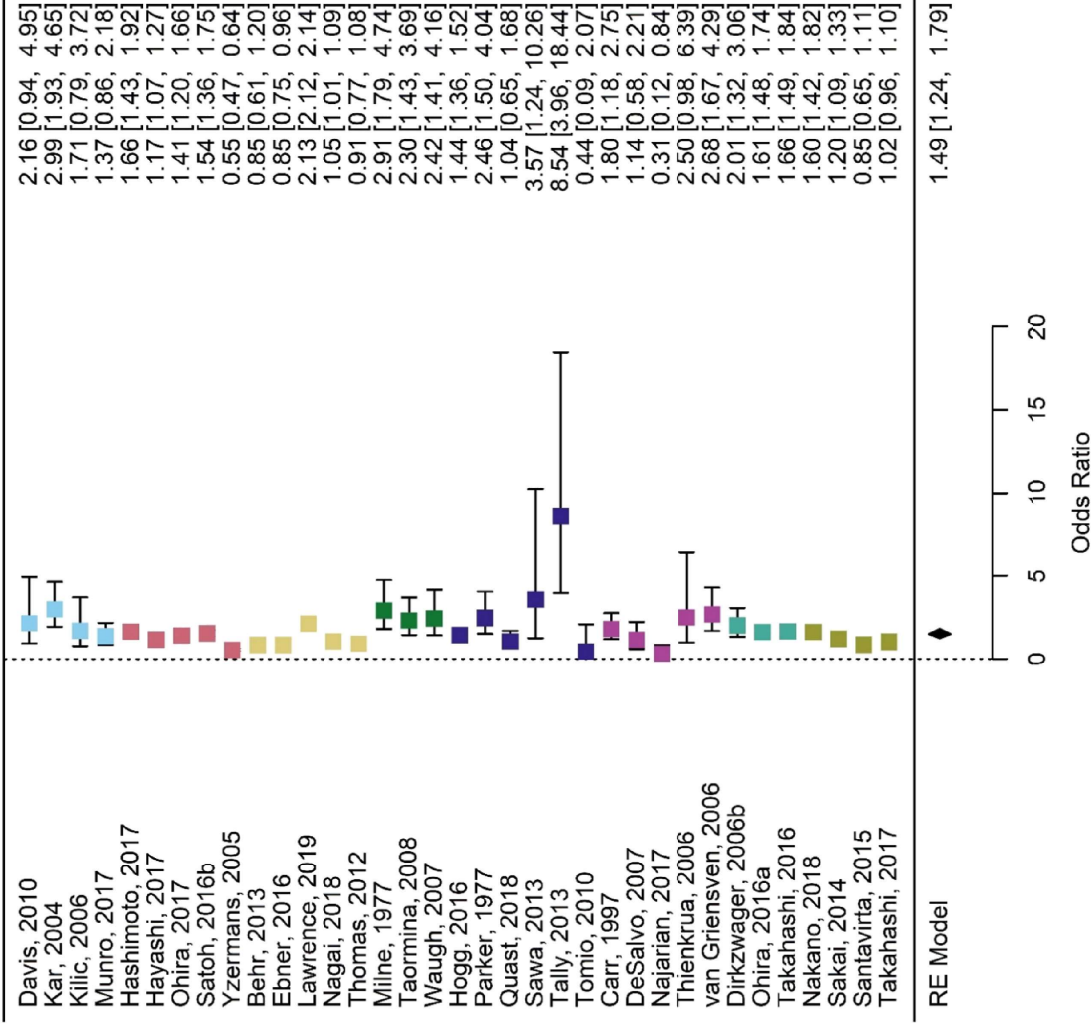
Meta-regression of the prevalence effect size:

- Evacuation score associated with slightly lower mortality
- Relocation associated with slightly higher mortality



* Meta-regression on the prevalence of mortality

Overall Health Effects



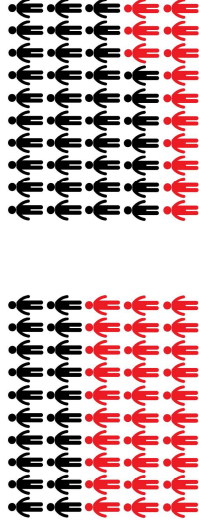
Analysis of Estimated Magnitude of Effect

- There are limitations to the real magnitude of each health effect –

- Directly comparing odds ratios tells us little about the total number of people who might be adversely affected by an ordered evacuation

- A risk difference analysis was performed to examine and compare the magnitude of the aggregate effect sizes across all the different health outcomes

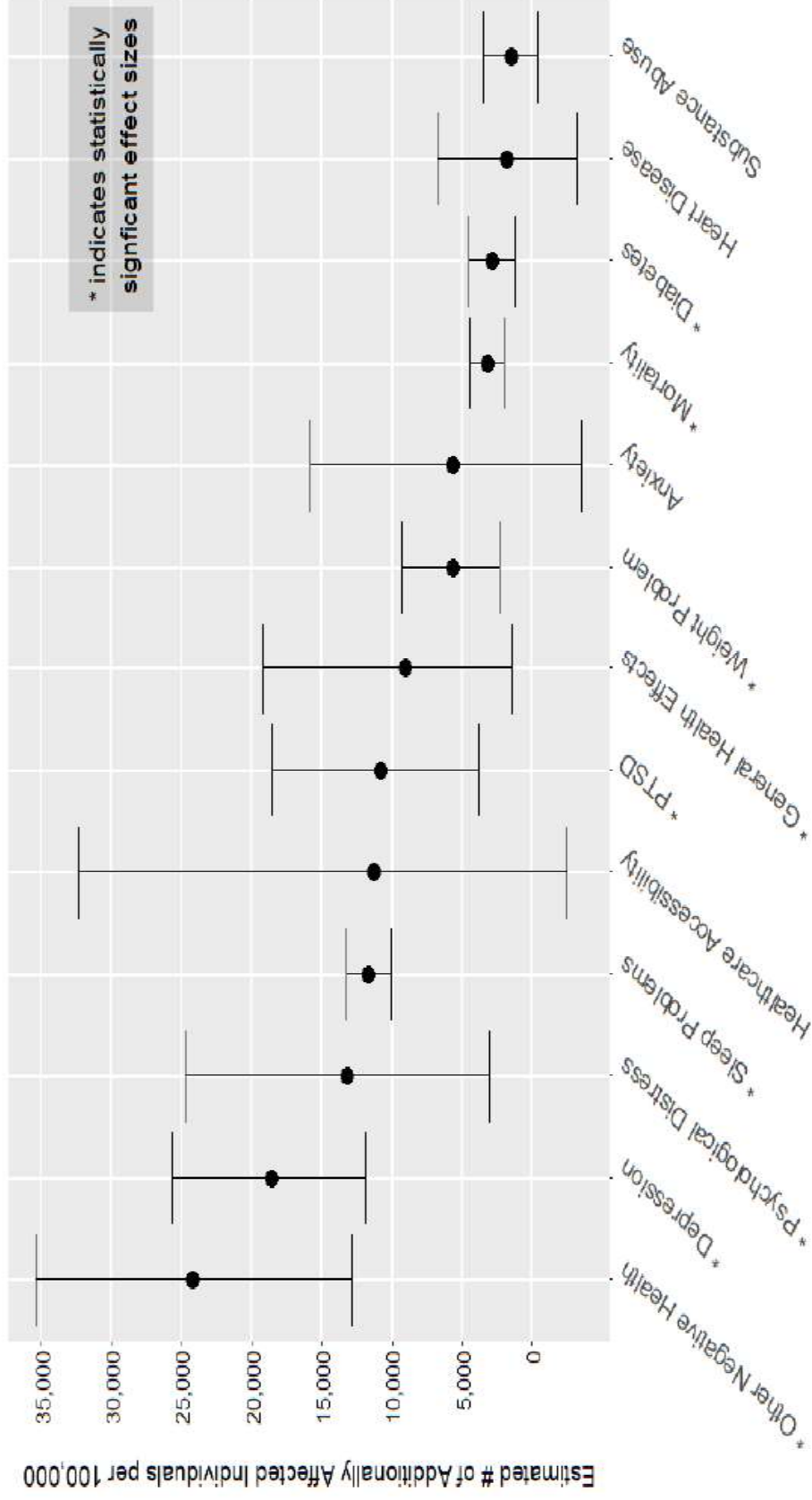
Use estimated effect sizes to solve for estimated number of individuals reporting the health effect after displacement



Estimate difference between displaced and nondisplaced affected individuals



Analysis of Estimated Magnitude of Effect



Effects

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CONCLUSIONS

Major Conclusions

- Data demonstrates a clear relationship between evacuation/relocation and an increase in expected deleterious health effects
 - Both physical and behavioral/psychosocial
 - Correlated, but causation has not been established for all effects
- Nearly 25,000 additional people per 100,000 displaced suffer from ‘other health effects’
 - Disruption of social support networks, increase in domestic abuse, memory problems in children, etc.
- Evacuation and relocation results in substantial and statistically significant increases in PTSD, depression, psychological distress, sleep problems, and mortality.
 - All health effects showed an increase among displaced populations, and most were statistically significant

Acknowledgement

Nonradiological Health Consequences from Evacuation and Relocation

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Questions

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