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MORTALITY, THE FAMILY AND THE INDIAN OCEAN TSUNAMI

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Abstract

Over 130,000 people died in the 2004 Indian Ocean tsunami. The correlates of survival are examined using data from the Study of the Tsunami Aftermath and Recovery (STAR), a population-representative survey collected in Aceh and North Sumatra, Indonesia, before and after the tsunami. Children, older adults and females were the least likely to survive. Whereas socio-economic factors mattered relatively little, the evidence is consistent with physical strength playing a role. Pre-tsunami household composition is predictive of survival and suggests that stronger members sought to help weaker members: men helped their wives, parents and children, while women helped their children.

1. Introduction

The Sumatran-Andaman earthquake and the tsunami it spawned constitute one of the deadliest and most seismically powerful disasters in recorded world history. The geophysics of the event is well-documented, in part because of expansions in digital sensors before the event (Bilham, 2005; Park, 2005; Kanamori, 2006). It is estimated that over 160,000 people died in the tsunami. Yet, several years after the event, little is known about the factors that affected survival chances of the populations at risk.

We provide evidence on the correlates of tsunami mortality, based on data from Indonesia, the country in which loss of life was greatest. We draw on a longitudinal survey of 43,606 individuals living along the coast of Aceh and North Sumatra on the northern end of the island of Sumatra. The baseline survey, which was collected before the tsunami, is representative of the study population before the disaster. We conducted extensive fieldwork

after the tsunami to ascertain the survival status of the original survey respondents. In this paper, we focus primarily on 6,151 people who were living in communities heavily damaged by the tsunami.

Socioeconomic status, age, and sex are the stratifying characteristics most often examined in the context of understanding differential survival during a disaster. In many natural disasters, the poorest experience the greatest devastation both because the locations and conditions of their housing make them relatively more vulnerable to natural hazards and because they have greater difficulty marshalling resources to escape the disaster (Cutter, 1996). Studies of tsunami deaths in Sri Lanka and India based on cross-sectional data collected after the tsunami documented higher mortality among individuals from households relying on fishing. In India householders whose homes were close to the shore and those with no education were also more likely to lose their lives (Guha-Sapir *et al.*, 2006). In Sri Lanka, India, and Indonesia children and older adults died in greater proportions than prime age adults (Guha-Sapir *et al.*, 2006; Nishikiori *et al.*, 2006; Doocy *et al.*, 2007).

With respect to the tsunami, gender is the dimension that has received the greatest attention, because of the much higher rate of mortality for women than for men at prime ages. This phenomenon, which attracted the attention of media and NGOs, has been documented in post-tsunami surveys in all three of the countries discussed above (Oxfam, 2005; CNN, 2005).

Some of the explanation likely lies in sex differences in physical strength, stamina, and running and swimming ability. Yeh (2010) develops a physical model that combines flow characteristics of water during a tsunami with the physiological attributes of males and females of different ages to show that age-sex differences in vulnerability are substantial. But many have speculated that women's family roles may have contributed as well, with the gender difference in mortality arising because females died trying to save their children and other family members (MacDonald, 2005). Indeed, in Yeh's model the difference between men and women widens further when women's attributes are adjusted to incorporate evacuation with a small child. The potentially relevant social factors extend beyond caretaking norms. In Aceh (which is strongly Islamic) and South Asia, women wear more restrictive clothing than men and are less likely to know how to swim (Neumayer and Plumper, 2007).

Moving beyond simply identifying the factors that affect death, social scientists have a longstanding interest in understanding how human behavior plays out in the throes of a force that is sudden, lethal, and completely unexpected. In many cases social norms appear to hold in the sense that individuals behave in organized rather than chaotic ways (Quarantelli, 1989). Among passengers on the Titanic, for example, higher proportions of women and children survived than did men because they were given preferential access to lifeboats, as were passengers in first class cabins (Frey *et al.*, 2009).

The Titanic, however, is an example of an event in which the period between first warnings of a problem and the ship's submergence was sufficient to allow for some degree of organization in the evacuation procedures. Although earthquakes are relatively common in

Indonesia, the last major tsunami on the coast of mainland Aceh took place over 600 years ago, and so the retreating ocean was not interpreted as a sign of danger by the vast majority of the population (Monecke *et al.*, 2008).¹ Chances of survival hinged critically on an individual's proximity to the shoreline when the waves hit in combination with the water's path and geophysical land features that diminished the water's force. In the face of this threat, were people able to assist those around them, or did they even try? We infer an answer to this question from empirical patterns that emerge in the data.

In our analysis we examine the evidence for and against three general forces that differentiate survival outcomes: physical strength, socioeconomic status, and household composition. We compare mortality rates of male adults with same age females and we compare rates for these groups with rates for children and older people. We provide empirical evidence that confirms the importance of physical strength, suggests that socioeconomic factors mattered relatively little, and documents a role for both men and women in helping household members less able to survive on their own.

2. Data and Context

We draw on data from a study we have conducted, the Study of the Tsunami Aftermath and Recovery (STAR). Our study covers the northwestern half of the island of Sumatra, which lies between the Indian Ocean and the Straits of Malacca. A mountain range extends down the center of the region, bordered on each side by coastal lowlands in which rural population densities are relatively high.

The study communities are located in two provinces, Aceh (which occupies the northern tip of the island) and North Sumatra. For several decades Aceh was the site of a civil war between the Indonesian government and Islamic groups pushing for greater autonomy. This struggle ended with a peace agreement nine months after the tsunami. North Sumatra has had a more peaceful past.

On the morning of December 26, 2004, a strong earthquake shook the region. The tsunami wave reached Aceh approximately thirty minutes after the earthquake, engulfing communities along 800 kilometers of coastline. It is estimated that about 130,000 individuals perished and another 30,000 remain classified as missing (Rofi *et al.*, 2006; Doocy *et al.*, 2007).

Onshore there was considerable local level variation in impact. Tsunami waves reached some coastal communities only a few minutes after the quake. The height and inland reach of water from the tsunami was a complicated function of slope, wave type, water depth, and coastal topography (Ramakrishnan *et al.*, 2005). At the beachfront in Banda Aceh, water depths were approximately 9 meters, but further inland did not typically exceed the height of a two story building (Borrero, 2005). Along parts of the west coast of Aceh, the water removed bark from trees as high as 13 meters (Borrero, 2005). Where rivers emptied into the

¹Only residents of Simeulue island, where a smaller tsunami occurred in 1907, systematically relocated to higher ground, and, correspondingly, the survival rate in Simeulue was very high (Gaillard *et al.*, 2008).

ocean, the water moved inland as much as six to nine kilometers, versus only 3–4 kilometers in other locations (Kohl *et al.*, 2005; Umitu *et al.*, 2007).

Eyewitness accounts also shed some light on the experience. In our interviews with informants who saw the event, most described a sequence of three incoming waves, with the second typically characterized as the deepest and swiftest moving. Eyewitness accounts described some locations on points of land where water approached from more than one direction. (Post-tsunami scientific observation confirmed these accounts are accurate.) (Umitu *et al.*, 2007.)

The impact of the water on the land varied. In some areas it scoured the earth's surface, removing all buildings and almost all vegetation. In other areas the water left deposits of mud and sand but structures largely remained intact. The worst-affected areas were low-lying communities within a few kilometers from the coast, and these were largely destroyed. Further inland, uphill and in topographically sheltered areas, flooding damaged many structures and deposited enormous quantities of debris. In the latter areas a larger proportion of the population survived.

3. Methods

Death and displacement in the aftermath of a disaster complicate efforts to study the affected populations. Out of both choice and necessity people quickly relocate to other areas and it is difficult to ascertain with certainty who has died and who has moved. Transportation and communication systems are disrupted and provision of assistance is a higher priority for command of scarce resources. Most information on disasters comes from rapid-assessment style surveys conducted with a small number of respondents who remain relatively near the site of the disaster or who have relocated to obvious camps and refugee settlements. With these studies, it is difficult to know how completely those interviewed represent the underlying population exposed to the event, nor is one able to benchmark respondents' experiences during and after the disaster against their situations before the disaster or against individuals in communities that did not experience the event but are otherwise similar (see Checchi and Roberts, 2008, for a discussion of these issues).

We designed and collected the STAR data to address the limitations of surveys based only on post-disaster data from individuals identified as affected after the event. The baseline for our study is a large-scale household survey collected in February and March 2004, about nine months prior to the tsunami as part of the annual National Socioeconomic Survey (SUSENAS) which is conducted annually by Statistics Indonesia. SUSENAS is a broad-purpose survey that covers over 800,000 households across the whole of Indonesia and is representative of the population at the *kabupaten* (district) level in each province. A stratified sampling scheme is used, in which households are randomly selected from within census tracts.

Collaborating with Statistics Indonesia, we turned this baseline into a panel survey by following up respondents from the 2004 survey. We selected all respondents who were living in a *kabupaten* with a coastline along the north and west coasts of Aceh and North

Sumatra as well as the islands off those coasts. Some 43,606 respondents make up the STAR sample. They are drawn from 585 enumeration areas in 525 *desas* (villages, the lowest administrative unit in Indonesia) and represent a pre-tsunami population of about 4.3 million.

By design the study area includes people who were living in areas directly affected by the tsunami, people who were living in nearby areas that were not directly affected, and people living as much as several hundred kilometers away from tsunami-damaged areas. The third group are a comparison group to contrast with those directly affected by the tsunami.

STAR respondents have been followed annually for five years since the tsunami, with the first post-tsunami interview conducted between May 2005 and May 2006. In fielding the first re-survey we mounted an extensive effort to identify all the people who had died and to find people who moved, interviewing them in their new location. Many components comprised this work. We created preprinted household rosters from 2004, listing the name, age, sex, and relationship of the household head of all members of the 2004 household. Field teams first visited the site of the 2004 interview. If an original household member could be found, that member was interviewed and information was collected on the survival status and locations of all household members. If no original household member could be found a “mini-roster” book was used, which provided for as many as three informants within the community to report on the survival status and possible location of each household member. We also checked rosters of the dead and missing in each community which were compiled and maintained by community leaders.

We determined survival status for 95 percent of the study sample. Of these, almost 2,400 were confirmed to be dead at the time of the first follow-up. Among known survivors, about 93 percent were from pre-tsunami households in which at least one person was interviewed after the tsunami. Among those that we failed to interview, most had moved and were not relocated despite extensive tracking efforts, which included multiple visits to the origin site, and trips to potential destination areas reported by informants. Trackers, who were assigned cases from central bases of operations in the provincial capital cities of Banda Aceh and Medan, worked not only in Aceh and North Sumatra but also in Java and other provinces on the island of Sumatra. Less than 1 percent of original respondents refused to participate in the follow up.

A major methodological component of our study is the creation of measures of damage to each site. Categorizing the study sites by degree of damage is not straightforward. We have drawn on data from multiple sources to construct a robust classification in each of the 585 study sites of the extent of damage due to the earthquake and tsunami. We use several biophysical measures derived from satellite imagery, drawing on Global Positioning System (GPS) measurements that we conducted in the field during the follow-up survey in each of the study sites. One measure was constructed by comparing satellite imagery from NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS) for December 17, 2004, a week before the tsunami, to imagery for December 29, 2004, three days after the tsunami. The proportion of land cover that was changed by the tsunami to bare earth (through scouring or sediment deposition) was manually assessed for a 0.6 km² area centered over each GPS

point. These estimates were supplemented with estimates of damaged areas derived from remotely sensed imagery and prepared by the USGS, USAID, the Dartmouth Flood Observatory, and the German Aerospace Center (Gillespie *et al.*, 2009). Second, in each community we conducted interviews with local leaders who provided their own assessments of the extent of destruction to the built and natural environment due to the tsunami and earthquake. Third, our survey supervisors completed a questionnaire in each community that detailed damage due to the tsunami and earthquake based on their own direct observation.

These sources of information are used to construct a four-category indicator of damage to the enumeration area. This indicator is a strong and significant predictor of many tsunami-related outcomes derived from the household data including mortality, injuries, posttraumatic stress disorders, extent of damage to houses and land (Frankenberg *et al.*, 2008). By this measure 94 enumeration areas are classified as severely damaged. We link the measure to individuals based on their place of residence at the time of the pre-tsunami baseline.

In this paper we focus predominantly on individuals from the most heavily damaged communities, which are mapped in Figure 1. We determined survival status for over 98% of the baseline respondents in the most heavily damage zone. One quarter of them died in the tsunami. In 200 households every member perished. We have conducted face-to-face interviews with 93% of the survivors. We asked explicitly about deaths of household members at the time of the tsunami, as well as about deaths between the baseline and re-survey. Excluding deaths attributed to the tsunami, in the communities that were heavily damaged 1.85% (standard error=0.39%) of the population died between the baseline and re-survey. In the communities not directly affected by the tsunami, mortality between the survey waves is estimated at 1.60% (N=20,256, standard error=0.16%). Morality in the undamaged zone is not significantly different from non-tsunami mortality in the heavy-damage zone. In both community types, non-tsunami mortality varies with age in the usual pattern, being higher for very young than for older children, but highest among older adults.

4. Results

In the heavily damaged communities, tsunami mortality was extremely high. In about one quarter of these communities more than 70% of the population died. Although some deaths may have been falsely attributed to the tsunami, given the relative magnitudes of tsunami and non-tsunami mortality in the heavily damaged areas and the similar levels of non-tsunami mortality in heavily damaged versus undamaged areas, such mis-classification is unlikely to be important. In the regressions reported below, our conclusions do not change if we replace mortality from the tsunami with all-cause mortality.

Figure 2 displays the percentage of the population in the most heavily damaged zone who died during the tsunami, distinguishing age and gender. Mortality is lowest for adult males in their twenties. Within this age group males are about 10 percentage points less likely to die than females. Gender gaps are narrower among children (<15) and among adults 45 and older, who have the highest mortality. The mortality profile by age is U-shaped for males, which is consistent with the hypothesis that strength and swimming ability played a key role

in determining survival in the face of the tsunami. In contrast, the age profile for females is much flatter.

4.1. Mortality and Distance from the Coast

To provide evidence on the roles of physical strength, stamina and swimming ability (which we will refer to as ‘strength’ hereafter), Table 1 displays mortality levels by distance from the coast of the respondent’s community at the time of the pre-tsunami survey.² We interpret distance as a proxy for the water’s force and depth as the tsunami came ashore. Among those living at least 5 km from the coast, about 1 in 20 people died, regardless of age or gender. However, among those living within 1 km of the coast, where the tsunami surge was strongest, about half the children and prime-age females (age 15–44) died, and almost 7 out of 10 older women died. Among prime-age males about one-quarter died (half the rate for prime-age women and children). As distance from the coast increases, the age-gender gaps in mortality diminish. 2–5 km from the coast, the death rate among older women is roughly the same as the rate for prime-age males within 1 km of the coast. These results are broadly consistent with the physical model of vulnerability in Yeh (2010).³

4.2. Height of Survivors

Mortality patterns by age, gender and distance from the coast suggest that relative to prime-age men, women and children were at the greatest disadvantage in the areas where the tsunami hit the hardest. Because height is correlated with physical strength, those who survived the tsunami are likely to be taller than those who died (indeed, height is a key parameter in Yeh’s physical model). Heights were measured only in the survey after the tsunami, and so we draw inferences from the heights of survivors. If the women who are relatively short, and therefore relatively weak, are more likely to die in areas where the tsunami hit the hardest, then we would expect to see that in the areas closest to the coast, short women are under-represented among survivors. Table 2 presents heights of surviving females at the 20th and 80th percentiles of the distribution focusing on those people who were living within 1 km of the coast in areas that were heavily damaged (column 1) and areas not damaged (column 2). The difference is reported in column 3 and the associated asymptotic t statistic in column 4. In heavily damaged areas, a surviving woman at the 20th percentile is 147.0 cm tall which is 1.2 cm taller than a woman at the 20th percentile who was living in an area that was not damaged. This difference is significant at 10% size of test. In contrast, at the 80th percentile females are the same height regardless of location. We conclude that in the areas hit hardest by the tsunami, shorter females are missing from the distribution of heights of survivors presumably because these women died. Turning to men, a male at the 20th percentile of the height distribution is a little taller than a female at the 80th percentile. We find no differences in the height of surviving males by location, suggesting that men who were relatively short had no greater chance of dying than those who were taller.

²Distance is measured by the shortest straight-line distance in kilometers from the center of each enumeration area to the coast.

³Replacing distance from the coast with estimates of the fraction of people in the community who died in the tsunami, an alternative indicator of the force of the tsunami, yields the same patterns by age and gender.

In Indonesia, shorter people tend to be poorer and less well-educated. It is possible that taller and stronger people lived in more robust houses, were better able to move to a safer place or better understood the meaning of the receding water prior to the tsunami. We turn next, therefore, to an examination of mortality and socio-economic status (SES), measured in the baseline survey prior to the tsunami. Summary statistics of the covariates included in the models are reported in Appendix Table 1 which shows, for example, that 21% of respondents lived within 1 kilometer of the coast, 77% of respondents lived in houses owned by the household and 52% of the respondents lived in houses with brick walls.

4.3. Mortality and Socio-Economic Status

Results of models that relate mortality to SES are reported in Table 3. The models are estimated separately by gender for children (ages 0–14 years), for prime-age adults (ages 15–44), and for older adults (ages >45). In addition to indicators of SES, described in detail below, all models also control age of the respondent, distance to the coast, elevation of the land, whether the area was urban, and the district of residence. All of the covariates are measured prior to the tsunami and so do not reflect response to or impact of the tsunami. Coefficients are multiplied by 100 and interpreted as the (change in) the percentage in each demographic group who died. Standard errors, reported under coefficient estimates, take into account the clustered survey design and are robust to heteroskedasticity.⁴

Four classes of SES are included in the models. They are household resources, housing, occupation of the household head and education of the respondent (for adults). We discuss each in turn.

Household resources are measured with monthly consumption. Consumption is thought to be a better indicator of longer-run resource availability than income and, in any case, detailed income is not reported in the baseline SUSENAS survey. SUSENAS has a long history of measuring expenditure and includes a very detailed questionnaire about spending and consumption every three years. That module was not included in the baseline.

However, for almost 10 years, SUSENAS has included a shorter module that takes 30–40 minutes to administer and asks about 15 food sub-aggregates (such as ‘cereals’, ‘meat’ and ‘fish’) for the last week as well as 12 non-food sub-aggregates (such as ‘electricity, telephone, gas, kerosene, water, wood, etc.’) for both the last month and the last 12 months. For each sub-aggregate, the interviewer asks the respondent to include spending on the goods, consumption from own production and consumption from gifts and transfers including consumption at work. The interviewer aids the respondent by reading from a list of examples to be included in each sub-aggregate. As an example, for ‘cereals’, the interviewer mentions ‘rice, corn, wheat flour, rice flour, corn flour and similar items’. The interviewer works through these goods and helps the respondent estimate spending on the sub-aggregate.

⁴All the coefficient estimates reported in the regression tables are based on linear probability models which have the advantage of being easy to interpret in terms of changes in mortality rates. None of our substantive conclusions is changed if they are based on estimates from logit or probit models.

All expenditures have been converted to monthly amounts and the logarithm of household expenditure is our indicator of resources in the household. As a first step towards taking into account demographic structure, we also control the logarithm of household size. A fuller assessment of the role that household composition plays in affecting mortality is discussed below.

Children and prime-age females from households with fewer resources are more likely to have died in the tsunami although the association is significant only for male children. This pattern does not extend to prime-age males or older adults. There is little evidence in these models that household size is related to mortality.⁵

Houses that were better constructed would have provided some protection from the onslaught of the water. The second set of SES markers includes an indicator for whether the household owned its house and whether the walls were made of brick. Most other houses were made of wood.

There is no evidence that a brick house provided such protection. Indeed, residence in a house the household owns is associated with elevated mortality for all demographic groups. The estimated effect is largest and significant for children, prime-age females and older males. In these models, house ownership does not proxy for household resources. Although households with more resources are more likely to own their house, after controlling distance from the coast, urban location and kabupaten effects, home ownership is unrelated to household resources.

An indicator for whether the respondent has completed at least primary school is included in the models for adults. There is no evidence of a link between education and mortality due to the tsunami.

The baseline survey collected information on the occupation of the household head. We identify three types of workers: fisherman, farmers and government workers. Recall the tsunami hit at around 8 a.m. on Sunday, 26 December. Relative to later in the day or work days, families were likely to be together at home. However, fishermen may have been out on their boats, in which case they would have been protected from the tsunami. They may also be the strongest swimmers. The occupation of the head is likely to be the occupation of the adult male in the household. There is no evidence that adults males in households headed by a fisherman were less likely to die in the tsunami, suggesting they were not likely to be on the water that morning. If anything, children of fishermen are less likely to die, but this effect is not significant. Daughters of government workers are protected from the tsunami. It is not clear why and since this is the only coefficient that is significant among all 18 occupation covariates, this could be attributed to statistical chance.

Overall, this evidence suggests that SES is modestly associated with mortality and the effects are significant only for children and prime-age females.

⁵We have explored non-linearities in the associations between resources and mortality. Among those groups for whom resources are significantly associated with mortality in the linear models, the effects are greatest among the poorest. We find no evidence that resources are associated with mortality among prime-age males and older adults in models that are linear or non-linear in household resources.

If the primary benefit of being a fisherman is that one is a stronger swimmer or understood the warning signs as the water receded, then fishermen who were living close to the water should have a survival advantage relative to others living close to the water. To explore this idea we re-estimate the models, focusing on the households that were living within 1 kilometer of the coast at baseline. Although the sample sizes are small and some of the estimates are not well-determined, our main conclusions apply to this sub-sample but for two new results.

First, respondents in households headed by a fisherman are much less likely to die in the tsunami. The mortality rate is reduced by 28% for prime-age adult males. But, importantly, children and prime-age females are also significantly less likely to die. Possibly the entire household was on the water, but this is unlikely to be the explanation for two reasons. First, it is unusual for females to go out on fishing boats. Second, older males would be likely to be on the boats and therefore protected. But, older males and older females in households headed by a fisherman were not protected from the tsunami. Similarly, if the mechanism is that fishermen recognized the warning signs of receding water, we would expect that older adults would be most likely to recognize these signs and therefore also protected, but they are not. Perhaps the most plausible explanation for the result is that prime-age males who were fishermen were physically strong and relatively strong swimmers, and were therefore able to help children and prime-age females in their households. On average, older fishermen may not have had the strength to withstand the thrust of the water.

Second, among households living close to the water, larger household size at baseline is associated with elevated mortality among older males and, to a less extent, older females and prime-age males. This result suggests there may be a complex dynamic between household size and mortality risks.

Furthermore, recall that while the pattern of results in Table 1 are consistent with the hypothesis that strength was an important factor in explaining survival, the results also suggest that strength may be only part of the story. Specifically, despite the fact that prime-age females are likely to be stronger than children, prime-age females die at the same rate as children, regardless of distance from the coast. This phenomenon could arise if women died trying to save children suggesting household composition may be an important factor in mediating mortality risks. We explore this issue next.

4.4. Mortality and Demographic Composition of the Household

We extend the models above beyond the relationships between mortality, the physical location of one's home and SES, to consider the relationship between mortality and the composition of one's household. Table 4 presents results from multivariate linear regressions that relate death during the tsunami to the demographic composition of the household at the time of the pre-tsunami baseline survey. Each model includes the number of household members in the same six demographic groups (the index respondent is excluded from the count for his or her demographic group) as well as controls for the age of the index respondent, distance to the coast, elevation of the land, whether the area was urban, district of residence and the indicators of SES included in Table 3.

In the anecdotal descriptions of women who died trying to save their children, men are conspicuously absent, suggesting that men played no role helping other household members to survive. The evidence in Table 4 suggests a very different story. As shown in the first row, the number of prime-age males living in the household at the time of the baseline survey is associated with lower mortality for five of the six demographic groups. The protective effects are greatest for children and prime-age women, followed by older and prime-age men. The effects are statistically significant both for children and prime-age adults. For example, female children are 4.4 percentage points less likely to die with each additional prime-age male in the household.

Not only are the physically strongest the most likely to survive the tsunami, but so are prime-age women, children, and possibly older men who co-resided with them. The fact that prime-age men were also less likely to die if other prime-age men were in the household, suggests that the men shared the burden of helping other, more vulnerable household members, and that possibly they helped one another.

Evidence that is consistent with this interpretation is presented in the second row of the table, which indicates that mortality tends to be lower as the number of older males in the household increases. While this is true for five of the six demographic groups (but not for older men themselves), none of the estimates is significant.

More vulnerable demographic groups make up the remaining rows of Table 4. The presence of prime-age women is (marginally) protective for other prime-age women, but male children are significantly more likely to die if there are more prime-age women in the household. Among adults, older women are likely to be the weakest. Their presence in the household is associated with higher mortality for male children and prime-age women, and the effects are large and statistically significant. It is likely that older women, prime-age women, and children all competed for assistance from men and that as their numbers rose, they were less likely to survive. If this interpretation is correct, then prime-age women, who are probably the strongest among this group, were apparently able to help each other.

The claim that women died because they were trying to save their children is not consistent with any of this evidence. First, neither a male nor a female child is more likely to have survived the tsunami if the child was living in a household with more prime-age women. In fact, male children are more likely to die when there are more prime-age women present. Second, the presence of children in the household is not predictive of death of prime-age women (or men). Rather, there is suggestive evidence that the presence of female children is protective for older adults, an association that is significant for older men.

We re-estimated the models for respondents living within a kilometer of the coast. Generally speaking, the estimated coefficients are the same direction and broadly similar in magnitude. The presence of more prime age and older males is protective, and older females are associated with elevated mortality for other groups. However, the standard errors are much larger and none of the coefficients on household composition is significant. Nor are interactions between household composition and living within a kilometer of the coast significant in fully saturated models. We conclude that we do not have the power to detect

differences in the effects of composition among those who were living close to the water and bore the full brunt of the wave.

There are clearly important asymmetries in the demographic distribution of mortality and household membership. Taken together, the results suggest that the gender gap in mortality due to the tsunami cannot be entirely explained by the fact that males are stronger than females, or by the supposition that women died trying to save dependents. Rather, the presence of males in a household, particularly prime-age males, is protective for prime-age women and children, suggesting that men may have tried to save their wives and children.

4.5. Correlations in Mortality among Co-Residing Kin

As a step towards exploring the hypothesis that family members helped each other, we examine correlations in survival status among closely-related kin living in the same household at the time of the baseline interview. We construct log odds ratios that measure the strength of the association between the mortality outcomes of a pair of kin. Each dyad consists of a prime-age (15–44) adult and a closely related household member from another demographic group that is likely to be physically weaker than the adult. The log odds ratios for husbands and wives, for prime-age adults and their sons and daughters (age 0–14) and for prime-age adults and their parents are displayed graphically in Figure 3.

For each pair, if the mortality probabilities of the individuals that make up the pair are independent, the log odds will be zero. Independence in the probabilities could arise if the two individuals were apart at the time of the tsunami, or if one member was strong enough to survive the water while the other was not. For every pair, independence is rejected. Mortality outcomes are strongly concordant: when one family member is killed by the tsunami, the other member is also more likely to die, and when one lives the other is also more likely to survive.

This concordance is expected given the results in Table 3, which indicate that household demographic composition is predictive of mortality. However, the ordering of the log odds ratios is striking. If strength alone determined survival, concordance would be highest for the pairs most closely matched on degree of physical strength – prime-age males and their fathers, and prime-age women and their mothers. In fact, concordance in mortality outcomes is strongest among husbands and wives and weakest among prime-age males and their fathers. The log odds ratio for men and their wives is significantly greater than the log odds ratios for men and any of the other demographic groups in the figure (at a 1% size of test). A possible explanation for the link between the survival outcomes of husbands and wives is that men were either able to save their wives or that both died as he tried to help her.

4.6. Own Mortality and Mortality of Family Members

To provide evidence on this question, we unpack the correlations embodied in the log odds in Figure 3 and examine the gender-specific associations between own mortality and survival status (during the tsunami) of co-resident close kin. This approach allows for asymmetries within pairs of kin in the relationship between own and other mortality. To illustrate, assume that a husband and wife were together at the time of the tsunami. If the husband died, we infer that the water overpowered him and, since his wife is likely to be

weaker, she is more likely to have died. However, if the wife died, we know only that the water was strong enough to overpower her but do not know that it would have overpowered him. If the wife's death is a stronger predictor of her husband's death than vice-versa, the pattern cannot be explained by the difference in strength of the husband and wife. A more plausible explanation for this observation would be that the husband died trying to save his wife.

More generally, if the death of a family member who belongs to a physically weaker demographic group creates an excess mortality risk for the index person from a relatively stronger demographic group, we interpret it as evidence that the index person's death results from trying to save the relatively weaker family member. This argument depends on the assumption that family members were in close proximity to one another when the tsunami came ashore. That assumption is supported by the strong correlations in survival outcomes depicted in Figure 3, and the assumption is discussed in more detail below.

To assess empirically whether the hypothesized relationships hold, we regress mortality, for male and female prime-age adults, on an indicator for whether the spouse died (conditional on living with a spouse). The models also include death of a son under 15 (conditional on living with a son of that age) and death of a daughter under 15 (conditional on living with a daughter of that age). We control for the survival of the spouse and survival of male and female children, as well as the same indicators of household composition, SES, age, distance from coast, elevation and district of residence that are included in Table 4.

Results are reported in Panel A of Table 5. The first column of the first row provides an estimate of the association between a woman's death and the death of her husband. The association between a man's death and his wife's death is in the second column. The difference between them, which is the critical indicator of excess risk, is in the third column.

A woman was 23 percentage points more likely to die if her husband died than if she was unmarried or living separately from her spouse. However, a man was 44 percentage points more likely to die if his wife died than if he was unmarried or living separately from his spouse. The 21 percentage point difference between husbands and wives is not only large and positive. It is also statistically significant (at a 10% size of test). That is, the *extra* risk of one's own death when a coresident spouse dies is substantially greater for males than for females. As discussed above, this male disadvantage with respect to excess risk cannot be attributed to relative strength, since men are in fact systematically stronger than women.

Further evidence suggesting that strength alone did not determine an individual's death emerges from the associations between adults' deaths and deaths of their children. A prime-age female is likely to be bigger and stronger than her children. Yet her risk of death is higher if a son or daughter died than if she did not have children 0–15 years of age in the household. Moreover, a prime-age male is more likely to die if his young son died, although an adult male is surely stronger than his son. We attribute this excess mortality to parents dying while trying to save their young children.

Moreover, whereas there is no difference in the excess mortality of mothers and fathers that is associated with the death of a son, there is a large and significant difference of 20

percentage points if a daughter died. Mothers, it appears, were equally likely to die trying to help a son or a daughter while fathers were more likely to die trying to help a son (who would on average, have been heavier than a daughter). Again, the evidence suggests that parents' deaths are a function not solely of strength, but also of their behaviors in the face of risk to their young children.

Panel B of Table 5 reports results for mortality of children under age 15. The models include controls for death and survival of parents (conditional on living with the parent) along with the same indicators of household composition, SES, age, distance from coast, elevation and district of residence that are included in Table 4. Young girls are 32 percentage points less likely to die when their mother survived than when they did not have a mother in the household. For boys whose mothers survive the reduction in mortality is 27 percentage points. These relationships suggest that mothers actively tried to save their children. A surviving father, on the other hand, is not related to children's survival.

4.7. Location of Household Members at the Time of the Tsunami

This interpretation of the results in Table 5 depends crucially on the assumption that at the time of the tsunami, family members were relatively near one another, irrespective of age and gender. It is impossible, however, to know the exact location of those who died when the tsunami waves came onshore. The tsunami struck in the early morning on a Sunday and it is likely that household members were at home together, especially in urban areas. Is it possible that the men whose wives died were away from the home in locations that were less vulnerable relative to the locations of their wives? That interpretation is inconsistent with the results in Table 5. A woman is more likely to die if *either* a son died *or* a husband died, and a man is more likely to die if *either* a son *or* a wife died. If husbands were apart from their wives but with young sons, then the death of a son should be irrelevant for his prime-age mother. Instead the son's death is strongly predictive of his mother's death. The interpretation is also inconsistent with the results on household composition in Table 4, in which the presence of prime-age males in the household reduces the mortality of prime-age females, and with the particularly strong correlations between husbands' and wives' survival outcomes in Figure 3.

Although we do not know the precise locations of those who died during the tsunami, we did ask survivors a series of questions about their experiences at the time of the tsunami. We have examined these data, asking whether, within a household, experiences differ for husbands and wives. Among couples in which both members survived the tsunami, husbands were no more likely than wives to have heard the water, been caught up in it, or to have been injured by the tsunami. And wives were no more likely than husbands to have witnessed a family member struggle or disappear in the water. It is difficult to reconcile the within-household similarities in husbands' and wives' experiences at the time of the tsunami with the idea that husbands whose wives died were, along with their sons, in systematically more vulnerable locations than their wives.

4.8. Qualitative Evidence

In addition, we conducted in-depth interviews with survivors living in and around Banda Aceh in 2010 and the stories we were told are largely consistent with a picture in which families were together and sought to help each other when the tsunami came ashore. Informants talked about parents trying to help their children, especially the youngest, and husbands trying to help their wives.

The earthquake occurred just before 8 am on a Sunday, when children were not in school and many offices and shops were closed. For these reasons, in most instances parents and children were together at home when the tsunami struck. In some cases in which men had already left the home, they returned immediately after the earthquake to check on their family and their possessions.

Descriptions of the events when the water came ashore focus on several themes in the qualitative interviews: the terror the water caused, efforts to help family members, the importance of finding a high place or something, whether floating or stable, to cling on to and the key roles of physical strength and the ability to swim. Almost all the informants talked about their gratitude to God for their survival.

Several informants described trying to keep hold of their children as they were swept up in the water, with varying degrees of success. One man, for example, together with his wife and three children, tried to escape the water by jumping aboard a small van. At that point he was holding the middle child (a daughter) and his wife was holding their youngest child. The tsunami wave overtook the vehicle. The man struggled to keep his daughter in his arms as he was swept 4 km inland, only to tire and lose grasp of her before he eventually caught hold of a tree. Ultimately that daughter and the oldest child, a son, were rescued. His wife and youngest child were swept away by the wave and died. Another woman reported that she was not strong enough to keep hold of her son, and shortly after being caught in the water, he was swept first from her arms, then from her sight. A third informant, a middle-aged female, described sending her children to an upper story of their home, from whence they ultimately pulled her to safety after the water trapped her in a lower story of the residence.

5. Conclusions

The tsunami was a large, unanticipated disaster that caused unprecedented death and destruction. Based on longitudinal population-based survey data that we collected in areas heavily-damaged by the tsunami, some 10% of children age under 15 who survived the tsunami lost a parent, and 10% of survivors who were married at the time of the tsunami lost their spouse. In the 20 communities in our sample where mortality was the highest, more than 70% of the population died, including more than 80% of women and children. Overall, prime-age males were the most likely to survive the tsunami because they were the strongest. In general, stronger people were more likely to survive, particularly in the areas that were hardest hit by the tsunami when it came onshore. But the story does not end there.

Our examination of patterns of mortality as household composition varies indicates that death is less likely if a person from a physically stronger demographic group was available to help – such as a prime-age male – and that death was more likely in the presence of people in even more need of assistance – such as older women. Further, prime-age males were more likely to die if their wives or sons died. Within households, wives were the people prime-age males were the most able to help. We interpret our results as evidence that provide help is exactly what they tried to do. On the other hand, the comparative advantage of prime-age women lies in helping children. The picture that emerges is not one in which household members panicked blindly, but rather one of families in which stronger members sought to help those they could – in some cases successfully, in others not. To the extent these behaviors are instinctive, they may reflect the influences of social norms and evolutionary biology.

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Appendix

Table 1

Summary statistics

	All	Age <15		Age 15 –44		Age 45	
		Females	Males	Females	Males	Females	Males
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
<u>Community characteristics</u>							
Distance to coast							
% living [...] from coast:							
<1 km	21	22	21	22	20	18	22
1–2 kms	24	23	23	24	23	25	25
2–5 kms	40	42	43	38	41	39	39
>5 kms	15	13	13	16	16	19	13
Average elevation (metres)	17.2	19.1	18.3	16.9	16.2	15.4	17.8
<u>Household characteristics</u>							

	All	Age <15		Age 15–44		Age 45	
		Females	Males	Females	Males	Females	Males
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
ln(HH expenditure)	7.4	7.4	7.4	7.5	7.4	7.4	7.4
ln(HH size)	1.6	1.6	1.7	1.6	1.6	1.4	1.5
HH composition: # of							
Age 0–14: Females	0.63	0.73	0.71	0.67	0.64	0.34	0.53
Males	0.72	0.80	0.85	0.74	0.73	0.37	0.58
Age 15–44: Females	1.22	1.30	1.28	1.14	1.26	0.98	1.32
Males	1.06	1.09	1.11	1.13	0.90	1.12	1.07
Age >45: Females	0.31	0.20	0.20	0.30	0.37	0.20	0.61
Males	0.37	0.33	0.33	0.43	0.37	0.64	0.08
% HHs own their house	77	75	75	73	75	86	86
% houses have brick walls	52	50	47	53	53	55	55
% HH head's occupation is							
Fishing	10	10	12	9	10	8	10
Agriculture	28	32	30	26	27	22	31
Government	8	10	9	9	7	6	9
<i>Individual characteristics</i>							
Age	27	7	8	28	28	57	56
% completed primary school				73	79	27	47
% married				55	49	58	93
<i>Survival and mortality of HH members</i>							
% spouse living in HH pre-tsunami				54	48	56	92
% spouse died				11	12	19	32
% spouse survived				43	36	38	60
% mother in HH pre tsunami	48	94	95	35	42	3	2
% mother died	15	28	26	13	15	2	1
% mother survived	33	66	69	22	27	2	1
% father in HH pre-tsunami	42	89	91	27	34		
% father died	10	17	18	8	9		
% father survived	33	72	73	19	24		
% males in HH age 0–14 died				10	8		
survived				26	23		
% females in HH age 0–14 died				10	8		
survived				23	20		
Sample size	6,151	855	955	1,681	1,571	524	565
Number of clusters	94	94	94	94	94	94	94

Fig. 1.
Location of Study Sites in Heavily Damaged Areas

Fig. 2.
Percent Dead by Age, Sex and Extent of Damage

Fig. 3.

Log Odds of Concordant Survival Outcomes for Pairs of Close Kin

Notes: Each pair consists of a male or female adult age 15-44 and a close family member living in the same household before the tsunami. Standard error bars indicate 95% confidence intervals. For each pair, null hypothesis survival outcomes are independent rejected, $p < 0.01$

% of population that died at time of the tsunami by age, gender and distance of pre-tsunami community from coast

Table 1

	Age <15		Age 15-44		Age >45	
	Females	Males	Females	Males	Females	Males
	[1]	[2]	[3]	[4]	[5]	[6]
<i>% died at tsunami</i>						
All respondents	30.4 [4.2]	26.9 [3.9]	29.2 [3.6]	17.4 [2.2]	38.2 [4.6]	29.7 [3.7]
<i>Distance of community from coast</i>						
distance < 1 km	54.5 [9.5]	45.7 [9.5]	48.1 [6.9]	24.3 [5.3]	66.0 [7.6]	43.4 [8.3]
1 km < distance < 2 kms	25.7 [8.1]	26.6 [8.0]	31.8 [8.0]	21.9 [5.6]	36.6 [10.0]	29.1 [8.9]
2 kms < distance < 5 kms	16.3 [6.5]	18.2 [6.2]	18.4 [5.2]	9.3 [3.3]	29.4 [8.1]	15.7 [6.2]
distance > 5 kms	5.5 [3.0]	3.3 [2.5]	4.1 [1.1]	3.6 1.3	6.1 [3.4]	6.6 [3.9]
Sample size	855	955	1,681	1,571	524	565

Notes: Standard errors in parentheses take into account clustering.

Table 2

Distribution of height of survivors
Among those living within 1km of coast prior to the tsunami

Height (cms)	Extent of damage to community		Difference (Heavy-Not heavy)	
	Heavy	Not heavy	Diff	t statistic
	[1]	[2]	[3]	[4]
<i>Female adults</i>				
20 %ile	147.0	145.8	1.2	[1.7]
80 %ile	155.5	155.7	-0.2	[0.2]
<i>Male adults</i>				
20 %ile	157.0	157.1	-0.1	[0.1]
80 %ile	167.9	167.6	0.3	[0.4]

Notes : Sample sizes are 887 female and 931 male adults age 19.

t statistics based on bootstrapped estimates with 300 replications.

Table 3

Mortality and pre-tsunami socio-economic status by age and gender
Regression coefficients and [standard errors]

Indicators of socio-economic status	Age <15		Age 15-44		Age 45	
	Females	Males	Females	Males	Females	Males
A. ALL RESPONDENTS	[1]	[2]	[3]	[4]	[5]	[6]
ln(HH expenditure)	-9.4 [5.3]	-12.8 [5.4]	-8.1 [4.5]	-0.8 [3.9]	3.0 [5.6]	2.2 [4.7]
ln(HH size)	3.8 [5.4]	6.6 [5.6]	0.1 [4.3]	-1.1 [3.7]	0.1 [5.9]	-6.4 [4.8]
(1) if >primary education		.	-3.0 [3.7]	1.3 [2.3]	-1.2 [6.0]	6.0 [4.2]
(1) if own house	10.2 [4.1]	11.2 [4.4]	11.5 [4.0]	5.0 [2.8]	6.7 [5.9]	11.9 [5.6]
(1) if walls made of brick	5.5 [4.1]	-0.2 [3.9]	5.0 [3.0]	-1.5 [2.4]	4.2 [4.5]	3.3 [4.2]
(1) if head is fisherman	-11.5 [7.6]	-10.2 [7.1]	-0.4 [5.2]	-3.4 [4.3]	2.8 [7.8]	7.9 [7.7]
(1) if head is farmer	1.9 [5.0]	-6.6 [5.8]	-1.9 [4.4]	0.7 [3.6]	6.6 [8.0]	5.0 [5.8]
(1) if head is govt worker	-11.7 [5.2]	0.2 [5.3]	-2.1 [4.3]	-6.3 [3.2]	3.7 [9.0]	-10.3 [6.4]
X ² statistics for joint significance (p-values)						
lnPCE, lnHHsize	0.21	0.06	0.04	0.86	0.74	0.42
Own house, brick walls	0.01	0.04	0.00	0.15	0.32	0.10
Occupation of head	0.09	0.49	0.92	0.25	0.81	0.17
All SES indicators	0.00	0.05	0.02	0.34	0.80	0.19
Sample size	855	955	1,681	1,571	524	565
Number of clusters	94	94	94	94	94	94
B. RESPONDENTS LIVING < 1Km FROM COAST						
ln(HH expenditure)	-9.7 [8.6]	-7.1 [12.4]	-1.9 [6.9]	-11.6 [8.9]	-12 [10.9]	-13.1 [10.2]
ln(HH size)	9.0 [9.7]	0.3 [10.5]	9.1 [7.8]	13.5 [7.1]	15.9 [9.7]	29.3 [9.0]

Indicators of socio-economic status	Age <15		Age 15-44		Age 45	
	Females	Males	Females	Males	Females	Males
A. ALL RESPONDENTS	[1]	[2]	[3]	[4]	[5]	[6]
(1) if own house	7.1 [6.1]	6.2 [6.7]	7.7 [7.0]	0.2 [7.7]	11.0 [6.8]	13.6 [18.0]
(1) if walls made of brick	-4.8 [6.0]	2.0 [8.6]	1.1 [6.5]	1.0 [5.6]	7.3 [13.0]	5.4 [10.7]
(1) if >primary education			5.8 [6.0]	-2.2 [7.3]	3.2 [12.3]	3.1 [11.7]
(1) if head is fisherman	-39.2 [9.6]	-25.0 [12.4]	-13.6 [6.1]	-28.2 [7.1]	2.0 [11.3]	-8.2 [13.8]
(1) if head is farmer	11.1 [8.6]	7.5 [13.1]	7.2 [6.1]	5.4 [7.5]	-14.2 [9.7]	7.1 [11.8]
(1) if head is govt worker	-6.9 [14.7]	-10.6 [10.7]	-0.2 [10.5]	-10.5 [7.7]	7.5 [10.1]	-10.5 [15.7]
Sample size	190	200	364	319	93	126
Number of clusters	20	20	20	20	20	20

Notes: Standard errors in parentheses take into account clustering. Regressions also include age, distance from coast, elevation, urban location and district of resident. All covariates measured at baseline.

Table 4

Mortality and pre-tsunami household composition
By age and gender
Regression coefficients and [standard errors]

Pre-tsunami household composition # household member by gender and age group	Age <15		Age 15-44		Age 45	
	Females		Females		Females	
	[1]	[2]	[3]	[4]	[5]	[6]
# males age 15-44	-4.4 [2.2]	-4.3 [1.9]	-4.2 [1.4]	-2.3 [1.1]	0.4 [1.9]	-2.5 [1.7]
# males age >=45	-2.7 [3.7]	-3.3 [3.3]	-1.9 [2.9]	-3.6 [3.2]	-1.4 [7.1]	4.7 [5.0]
# females age 15-44	0.9 [1.9]	4.4 [1.8]	-1.5 [0.8]	0.6 [1.3]	1.7 [1.9]	2.7 [1.8]
# females age >=45	3.6 [3.7]	6.5 [3.3]	5.8 [2.6]	0.0 [1.9]	-0.4 [3.9]	0.6 [3.8]
# females age <15	-1.6 [1.9]	-3.5 [2.0]	-0.3 [1.1]	-0.1 [1.1]	-4.7 [2.8]	-4.1 [2.0]
# males age <15	-1.1 [1.9]	-2.3 [1.6]	-0.4 [1.4]	0.2 [1.2]	4.3 [2.6]	1.3 [2.1]
Sample size	855	955	1,681	1,571	524	565

Notes: Standard errors in parentheses take into account clustering. Regressions also include all covariates listed in Table 3.

Table 5

Own mortality and mortality of family members
Regression coefficients and [standard errors]

A. % prime-age adults died if other family member died			
Age 15–44	Females	Males	Diff
	[1]	[2]	[3]
(1) if spouse died in tsunami	23.4 [8.9]	44.0 [9.5]	20.6 [12.5]
(1) if son age 0–14 died in tsunami	14.6 [4.1]	10.2 [5.0]	–4.5 [6.4]
(1) if daughter age 0–14 died in tsunami	19.2 [4.3]	–1.2 [5.7]	–20.4 [7.6]
Sample size	1,681	1,571	3,252
B. % children died if parent survived			
Age <15	Daughters	Sons	Diff
	[1]	[2]	[3]
(1) if mother survived tsunami	–32.0 [8.9]	–27.1 [11.3]	4.9 [12.0]
(1) if father survived tsunami	10.1 [5.4]	–2.6 [4.3]	–12.7 [5.5]
Sample size	855	955	1,810

Notes. Standard errors in parentheses take into account clustering. Models include survival and presence of spouse and children in A; death and presence of parents in B. All models also control age of respondent, household composition, SES, distance to coast, elevation, urban location and district of residence as in Table 4. All covariates measured at baseline apart from death and survival of family members which are measured at time of tsunami.