Estimating mortality from external causes using data from retrospective surveys: a validation study in Niakhar (Senegal)

Gilles Pison(*) (1, 2), Bruno Masquelier (2, 3),

Almamy Malick Kante (4), Cheikh Tidiane Ndiaye (5), Laetitia Douillot (6),

Géraldine Duthé (2), Cheikh Sokhna (7), Valérie Delaunay (6), Stéphane Helleringer (8)

(1) French National Museum of Natural History, Paris, France

(2) French Institute for Demographic Studies (INED), Paris, France

(3) Centre for Demographic Research, Louvain University, Louvain-la-Neuve, Belgium

(4) Mailman School of Public Health, Columbia University, New-York, USA

(5) Agence Nationale de la Statistique et de la Démographie, Dakar, Sénégal

(6) Unité mixte de recherches Lped, Institut de recherches pour le développement, Marseille, France

(7) Unité mixte de recherches Urmite, Institut de recherches pour le développement, Dakar, Sénégal

(8) Bloomberg School of Public Health, Johns Hopkins University, Baltimore, USA

Abstract

In low and middle-income countries (LMICs), data on causes of death are either inaccurate or limited to small and highly selected populations. In this paper, we tested whether adding a few questions on injuries and accidents to mortality questionnaires currently used in nationally-representative surveys would yield accurate estimates of the extent of mortality due to external causes (accidents, homicides or suicides). We conducted a validation study in Niakhar (Senegal), during which we compared reported survey data to high-quality prospective records of deaths collected by a health and demographic surveillance system (HDSS). Survey respondents more frequently listed the deaths of their adult siblings who had died of external causes, than the deaths of those who died from other causes. The specificity of survey data was high, but sensitivity was low. Among reported deaths, less than 60% of the deaths classified as due to external causes by the HDSS were also classified as such by survey respondents. Survey respondents better reported deaths due to road traffic accidents than deaths from suicides and homicides. Collecting data on deaths from external causes during surveys could significantly improve the monitoring of progress towards the sustainable development goals, but further validation of survey data is needed.

Keywords: data quality, external causes of death, homicide, injury, mortality, road traffic accidents, Senegal, suicide

Introduction

Reducing mortality due to external causes (accidents, homicides, suicides) figures prominently in the 2030 agenda for sustainable development. For example, halving global deaths and injuries from road traffic accidents is one of the targets of the 3rd Sustainable Development Goal (SDG) on ensuring healthy lives and promoting wellbeing. Other SDG targets related to the promotion of mental health will also be monitored through mortality indicators, such as suicide-related mortality rates. There is thus a strong need for accurate statistics on deaths due to external causes to 1) track progress towards the achievement of the SDGs, and 2) evaluate the effectiveness of prevention initiatives and programs (1).

Unfortunately, very few countries have high-quality civil registration and vital statistics systems (CRVS) that permit routinely monitoring mortality from external causes (2-4). In most low and middle-income countries (LMICs), in particular, CRVS data are incomplete and/or include large numbers of deaths attributed to unknown causes and unspecified injuries (5, 6). Other data sources on injuries and accidents in LMICs include police reports and hospital records, but both sources are affected by under-reporting (7-9). For example, large numbers of accident victims in LMICs may never be transported to a hospital for emergency treatment. Health and demographic surveillance systems (HDSS) also provide data on mortality from external causes (10). HDSS are populations where deaths are recorded continuously during frequent household visits and investigated using verbal autopsies (VA), i.e., post-mortem interviews with caregivers of the deceased (11). VA has very high sensitivity/specificity in identifying deaths from external causes (11-14), but HDSS data are rarely representative at the national level. They cover small and highly selected populations, e.g., populations in rural (15-17) or impoverished urban areas (18).

National levels and trends of mortality from external causes are thus currently extrapolated from multiple partial data sources (8, 9, 19). This requires complex statistical models and projections (20, 21). The resulting model-based estimates suggest that injuries and accidents constitute major causes of death in LMICs (21) and exhibit important variations both within and across countries. They also indicate that the number of deaths from external causes is likely to increase significantly in LMICs in coming decades.

But these estimates may be affected by significant bias and uncertainty (22). This may be the case for several reasons. First, deaths attributed to unknown causes by registration data may inaccurately be reclassified as injury-related by statistical models. Second, deaths from external causes are often highly clustered at the local level. Road accidents, for example, are concentrated mainly in large urban areas or along highways. The current models and projections may not correctly account for such heterogeneity at the national level. Finally, in studies of the global burden of disease (GBD, 19, 23), estimates of mortality from external causes are frequently adjusted to ensure that they are compatible with other mortality estimates (e.g., deaths from infectious diseases). Errors in the measurement of other causes of death may confound estimates of the number of deaths due to external causes.

Improving the measurement of road traffic mortality and other accidental deaths in LMICs thus requires collecting accurate and nationally representative data on deaths from external causes. There are ongoing efforts to strengthen CRVS systems (3, 24), but they mainly focus on birth registration and will have limited impact on our ability to measure causes of death in the next 15 years. In this paper, we test whether mortality from external causes may also be accurately measured during household-based surveys such as the Demographic and Health Surveys (DHS) or the Multiple Indicator Cluster Surveys (MICS). Surveys already constitute the primary data source on all-cause (25, 26) and maternal deaths (27-30) for large numbers of LMICs. They measure mortality by asking respondents to report recent deaths among their relatives (31). Questions asking whether the deaths of these relatives were due to injuries or accidents have been asked in several surveys in LMICs, such as DHS in Zimbabwe and Zambia, the WHO's World Health Survey (32), or recent surveys to estimate mortality during conflicts (33-35). But their accuracy has not been evaluated.

We conducted a validation study of survey data on adult mortality (36, 37). We measured the sensitivity/specificity of survey data in recording deaths from external causes at adult ages, and we examined whether survey data can yield unbiased estimates of the proportion of deaths attributable to such causes.

METHODS

Study site

We worked in the Niakhar HDSS (16), which is located 120 km southeast of Dakar, Senegal's capital. The population covered comprises ≈44,000 inhabitants as of 1 January 2013. The main language is Sereer but many people also speak Wolof, the most common language in Senegal. The main religious groups in the area are Muslim (≈80%) and Christian (≈20%). Households in Niakhar live traditionally on one food crop (millet) and one cash crop (groundnuts). They also raise cattle. The three largest villages in the area include health facilities, weekly markets, daily buses to Dakar, and several shops. The educational level is low: 50% of men and 75% of women in the HDSS population have never attended primary school. High levels of mobility, both permanent and temporary, also characterize the area. A large proportion of Niakhar residents move to Dakar, where they seek employment.

Reference data set

An initial baseline census was carried out in 1962 in eight villages, followed by another census in 1983, when the study area was expanded to 30 villages. Since these censuses, data on demographic events (births, deaths, marriages and migrations) have been collected from household informants during household visits. Study interviewers use a printed roster of household residents and inquire about the vital status of each household member, as well as possible changes in marital status and births since the previous household visit. They also add new household members to the roster.

Each individual who ever resided in the study area since the start of the HDSS has been assigned a unique ID number. Migrants who move to another household of the HDSS study population are assigned a new residence and continue being part of the longitudinal follow-up under the same ID number. Migrants who move permanently outside of the HDSS area are lost to follow-up: they are not tracked, and their relatives are not asked to report their vital status. As a result, it is not known whether they are still alive at any time after their migration. If a migrant returns to the HDSS area after some time outside, s/he is reassigned his/her previous ID number so as to avoid duplication of individuals in the HDSS dataset. From 1962 to 1987, household visits were conducted yearly. From 1987 to 1997, they were conducted weekly because of requirements of vaccine trials. Between 1997 and 2007, they were conducted every 3 months, and between 2008 and 2013, every 4 months.

Each death is investigated using VA. After review of VA data by physicians, a probable cause of death is assigned to each recorded death using ICD-9 or ICD-10 codes. This permits identifying deaths from external causes. According to the HDSS, over the period 1985-2004, life expectancy at birth for both sexes was 54 years on average in the Niakhar area. The proportion of deaths due to external causes was 1.6%, and the mortality rate from external causes was 30.7 annual deaths per 100,000 inhabitants (45.3 for males and 18.0 for females). The most frequent external causes of death were falls, suicides, road accidents and fire and burning (38).

Design of the validation study of survey data on adult mortality

We conducted a validation study of survey data on adult mortality in the Niakhar HDSS. Our goal was to compare survey reports of adult deaths among the siblings of a respondent, to prospective HDSS records of the survival of these siblings. The Niakhar HDSS allows identifying siblings among the HDSS population because every population member is potentially linked to his/her biological mother through a mother ID number. This number is attributed either at the time of birth (if the mother gave birth in the HDSS area) or the first time an individual enters the HDSS population (i.e., initial census or after in-migration). For some members of the HDSS population however, the mother ID number may be missing because their biological mother was never a member of the HDSS population or because the information reported during household visits was not sufficient to establish a link between mother and child. Similarly, some sibships (i.e., the set of brothers and sisters born to the same biological mother) may be only partially identified if, for example, some of the siblings were born outside of the HDSS area.

We first selected a stratified sample of a) sibships in which one sibling (male or female) died between 15 and 59 years old since the beginning of the HDSS (n = 592), and b) other sibships, in which no adult deaths were recorded by the HDSS (n = 500). We then selected at random up to 2 surviving members of each sibship for a survey interview. Respondents included both men and women aged 15-59 years old. Interviewers had previously conducted one of the Senegal DHS and were unaware of the composition of respondents' sibships. For example, they did not know whether one of the respondent's siblings had died from external causes. In total, 1,189 respondents were interviewed during the validation study.

The survey interviews consisted primarily of the collection of siblings' survival histories (SSH). Respondents were asked to list all their maternal siblings by birth order and report their survival status, their age, and, if deceased, their age at death, and date of death. If the respondent declared that his/her sister had died at ages 12 and above, interviewers also asked if she died while pregnant, during delivery or within 42 days of her last birth. For each brother/sister who had died at ages 12 and above we also included three questions designed to ascertain whether siblings' deaths were due to external causes. First, respondents were asked whether that sibling had died after being injured. If so, they were asked whether the injury was due to an accident, a suicide, a homicide, a war or a natural disaster, following the approach of the WHO's World Health Survey. Finally, they were asked to list the circumstances that led to the injury, including for example, whether the injury was due to a collision with a motor vehicle, to a fall, or whether it involved poisoning or drowning.

During the validation study, we tested two SSH questionnaires: (1) the standard DHS questionnaire, and (2) a new SSH questionnaire, the siblings' survival calendar (SSC). The SSC incorporates supplementary interviewing techniques to limit omissions of siblings and uses an event history calendar to improve reports of dates and ages (37). Respondents were randomly assigned to either being interviewed with the DHS or the SSC questionnaires. Trial results indicated that the SSC improves the completeness of SSH data, and permits better measuring pregnancy-related deaths, relative to the standard DHS questionnaire (36, 39). In this paper however, we pooled data from the two study groups because there were no detectable differences in the reporting of deaths from external causes between the DHS and SSC questionnaires.

Data analysis

SSH data on deaths from external causes are affected by two types of reporting errors. First, selective omissions happen when the likelihood of reporting a sibling's death depends on his/her cause of death. For example, respondents may be more likely to list their deceased brother during SSH if he died during a car accident, than if he died from HIV/AIDS. Second, misclassifications occur when respondents correctly list the death of one of their adult sibling, but misstate the circumstances of his/her death. For example, they may mistakenly state their sister, who died after falling from a window, did not die from an injury or accident. Selective omissions and misclassifications may bias estimates of the proportion of adult deaths that are attributable to external causes (PEC thereafter). For example, if respondents do not list 10% of their siblings whose death was due to external causes vs. 20%

of their siblings whose death was due to other causes, the PEC will be overestimated. Similarly, all else being equal, the PEC will be overestimated if deaths from other causes (e.g., non-communicable diseases) are attributed to external causes, and it will be under-estimated if the opposite occurs.

We focused on sibships in which a man or a woman died at age 12 years or above in the 15 years prior to the survey. This time frame was selected because it matches the reference period used in several Global Burden of Disease studies. We first described the characteristics of deaths recorded by the HDSS during that time, and we compared the characteristics of deaths from external vs other causes using χ^2 tests. These characteristics included the size of the sibship of the deceased, his/her gender, age at death, and the time elapsed since the death. For deaths from external causes, we described the circumstances of the death according to the HDSS datasets, including whether they were due to falls, road traffic accidents or suicides. We also described how many deaths due to external causes according to the HDSS could not be attributed to a specific circumstance or injury.

Second, we measured the extent of selective omissions in SSH data, i.e., whether the probability of listing a deceased sibling during SSH varied by cause of death (external vs other). Third, we assessed the extent of misclassifications in SSH reports of deaths from external causes. We defined the sensitivity of SSH as the probability of correctly stating the cause of a reported death among respondents in sibships with a death from external causes. We defined the specificity of SSH as the probability of correctly stating the cause of a reported death among respondents in sibships with only deaths from non-external causes.

Fourth, we used estimates of these parameters to assess the likely extent of bias in estimates of the PEC obtained from survey data. To do so, we used the following formula:

$$\widehat{PEC} = \pi \times R_{EC} \times Se + (1 - \pi) \times R_O \times Sp \quad (1)$$

where $\widehat{PEC}$ is the survey estimate of the proportion of deaths due to external causes, π is the true value of this proportion, R_{EC} is the probability that a respondent will list his/her sibling who died from external causes, R_O is a similar probability for siblings who died from other causes, and Se and Sp are the sensitivity and specificity of SSH in recording death from external causes, respectively. We let π vary between 0 and 0.3, where the upper bound corresponds to the maximum of the PEC for adults in Africa according to the Global Burden of Disease study (19, 23).

Finally, to investigate which specific accidents and injuries were more likely to be misreported during SSH, we compared the circumstances of the death recorded by the HDSS between "false negatives" and "true positives". False negatives are instances where a respondent did not classify a death as due to external causes when the HDSS did so, whereas true positives are instances where both the respondent and the HDSS attributed the death to external causes.

RESULTS

Descriptive statistics

Among selected sibships, there were 468 deaths to persons aged 12 years or more during the 15 years before the survey. Twenty-five of these deaths (5.5 %) could be attributed to external causes on the basis of HDSS data (table 1). There were no significant differences in PEC associated with sibship size, age at death, or time since death, according to the HDSS. But the PEC was higher for males than for females (6.7% versus 2.6%, p = 0.079).

[Table 1 about here]

Among deaths due to external causes according to the HDSS, the circumstances of 8 deaths (32.0%, table 2) could not be ascertained on the basis of VA data. Other deaths due to external causes included road traffic accidents (n=5, 20.0%), falls (n=3, 12.0%) and suicides (n=3, 12.0%).

[Table 2 about here]

Validation results

The SSH survey was affected by selective omissions of deaths (table 3). Among respondents whose sibling died of external causes according to HDSS, 34/35 reported a death at ages 12 or more (97.1%). The proportion was lower (498/568, 87.7%) among respondents whose sibling died of non-external causes (p=0.093). Similar results were obtained for the subset of male deaths (p=0.108).

[Table 3 about here]

The sensitivity of SSH in recording deaths due to external causes was low (table 4): in sibships with a death attributed to external causes by the HDSS, 20/34 (58.8%) survey respondents correctly classified the reported death as due to external causes. Among the subset of male deaths, the corresponding value was 19/31 (61.3%). The specificity of SSH in recording deaths due to external causes, on the other hand, was high: in sibships with only deaths from causes other than external according to the HDSS, 479/498 respondents correctly classified the reported death (96.2%). Among the subset of male deaths, the corresponding value was 95.8%.

[Table 4 about here]

Based on these estimates, the likely direction and extent of bias in survey estimates of the PEC (equation 1) vary across populations. When the true PEC is below approximately 10%, then survey data overestimate the PEC (figure 1). For example, in populations where the true PEC is 5%, SSH would yield an estimated PEC of 6.8%. On the other hand, in populations where the true PEC is above 10%, then survey data underestimate the PEC. For example, in populations where 20% of deaths are due to external causes, SSH would yield an estimated PEC of 15.7%.

[Figure 1 about here]

In our validation study, 4 out of 6 survey reports in sibships where adult deaths were classified as homicides or suicides by the HDSS were false negatives, i.e., they were reported as due to other, non-external causes by survey respondents (figure 2, panel a). On the other hand, all the survey reports in sibships where adult deaths were classified as road traffic accidents by the HDSS, and 4 out of 5 reports in sibships where adult deaths were due to falls or drownings, were true positives, i.e., they were correctly classified as due to external causes by survey respondents (figure 2, panel b). The difference in the distribution of causes of external deaths between false negatives and true positives was significant at the p=0.069 level.

[Figure 2 about here]

DISCUSSION

Reducing mortality from external causes of death is a key target of the SDGs. But representative and accurate data on such events are rare in LMICs. Survey data could help fill that data gap: nationally representative surveys are frequently conducted in large number of LMICs (40), where the mortality data they generate already constitute the primary source of mortality estimates. We thus tested whether adding questions on injuries and accidents to the mortality questionnaire used in such surveys could accurately identify deaths from external causes. During a validation study in Senegal, we found that survey respondents were more likely to list the deaths of their adult siblings who died from external causes than the deaths of those who died from other causes. We also found that survey data had low sensitivity, but high specificity, in identifying deaths from external causes.

As a result, the accuracy of survey data in estimating mortality from external causes likely varies significantly across populations. In populations where accidents and injuries account for <10% of all deaths, survey data yield estimates of the proportion of deaths due to external causes that are slightly too high. In populations where deaths from external causes are more common, on the other hand, survey data under-estimate this proportion. The accuracy of survey-based estimates may further depend on the types of injuries and accidents that are most prevalent in a population. Survey respondents indeed very accurately reported road traffic accidents, falls and drowning, but often under-reported or misclassified stigmatized causes of death such as suicides and homicides.

Our study had several limitations. First, due to small sample sizes, our measures of data accuracy may be imprecise and we could not measure the correlates of errors in the reporting of deaths from external causes (e.g., educational levels of the respondent). Second, several external causes of death were not represented in our study sample. In particular, war and conflict-related deaths were not included. If such deaths are more (or less) precisely reported during surveys than other accidents and injuries, then the accuracy of survey-based estimates may further vary across populations. Third, the HDSS data does not constitute a gold standard measurement on mortality from external causes. It may misclassify some external causes of deaths as non-external, and vice-versa. Fourth, the wording of some of the questions we used to measure deaths from external causes may have been too narrow. In particular, we asked respondents whether their sibling died following an injury, even though some deaths from external causes may not be accompanied by injury. In such instances, the survey data we collected may mistakenly attribute some deaths from external causes to other causes. Fifth, we only investigated the possibility of measuring deaths from external causes of death among adults and during surveys. However the questions we used in this investigation could also readily be asked about deaths among children, and could be integrated into the mortality questionnaires of censuses. Finally, the Niakhar population in Senegal may not be representative from other LMIC populations where survey data on mortality from external causes may be collected. Since it is a rural population with limited road traffic, its inhabitants may better recall car or bike accidents than inhabitants of urban areas where such events are more common. Because of long-term HDSS activities, Niakhar residents may also be better informed about causes of death than members of other populations.

Our work thus suggests that collecting data on deaths from external causes during surveys could significantly improve the monitoring of several SDG targets in LMICs. But methodological research is also needed in several areas to improve the accuracy of survey data. New questions should be developed that better capture the diversity of accidents and injuries. More confidential interview modes (e.g., voting techniques) should be tested to improve the reporting of stigmatized causes of death such as suicides and homicides. Such improved survey instruments should then be validated in populations with diverse patterns of accidents and injuries, including urban areas and conflict settings. Finally, new statistical models that incorporate prior information on data accuracy should be adopted for the estimation of mortality from external causes.

Acknowledgments

This work was supported by the Eunice Kennedy Shriver National Institute of Child Health and Human Development [R03-HD071117] and the French Agence Nationale de la Recherche [ANR-11-BSH1-0007]. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The authors declare that no competing interests exist.

References

1. Lagarde E. Road traffic injury is an escalating burden in Africa and deserves proportionate research efforts. *PLoS Med* 2007;4(6):e170.
2. Mikkelsen L, Phillips DE, AbouZahr C, et al. A global assessment of civil registration and vital statistics systems: monitoring data quality and progress. *Lancet* 2015;386(10001):1395-406.
3. AbouZahr C, de Savigny D, Mikkelsen L, et al. Towards universal civil registration and vital statistics systems: the time is now. *Lancet* 2015;386(10001):1407-18.
4. Phillips DE, Lozano R, Naghavi M, et al. A composite metric for assessing data on mortality and causes of death: the vital statistics performance index. *Popul Health Metr* 2014;12:14.
5. Polinder S, Haagsma J, Bos N, et al. Burden of road traffic injuries: Disability-adjusted life years in relation to hospitalization and the maximum abbreviated injury scale. *Accid Anal Prev* 2015;80:193-200.
6. Polinder S, Haagsma JA, Lyons RA, et al. Measuring the population burden of fatal and nonfatal injury. *Epidemiol Rev* 2012;34:17-31.
7. Abegaz T, Berhane Y, Worku A, et al. Road traffic deaths and injuries are under-reported in Ethiopia: a capture-recapture method. *PLoS One* 2014;9(7):e103001.
8. Bhalla K, Shahraz S, Bartels D, et al. Methods for developing country level estimates of the incidence of deaths and non-fatal injuries from road traffic crashes. *Int J Inj Contr Saf Promot* 2009;16(4):239-48.
9. Sanghavi P, Bhalla K, Das V. Fire-related deaths in India in 2001: a retrospective analysis of data. *Lancet* 2009;373(9671):1282-8.
10. Pison G. Population observatories as sources of information on mortality in developing countries. *Demographic Research* 2005;13(13):301-34.
11. Chandramohan D, Maude GH, Rodrigues LC, et al. Verbal autopsies for adult deaths: issues in their development and validation. *Int J Epidemiol* 1994;23(2):213-22.
12. Kahn K, Tollman SM, Garenne M, et al. Validation and application of verbal autopsies in a rural area of South Africa. *Trop Med Int Health* 2000;5(11):824-31.
13. Chandramohan D, Maude GH, Rodrigues LC, et al. Verbal autopsies for adult deaths: their development and validation in a multicentre study. *Trop Med Int Health* 1998;3(6):436-46.
14. Streatfieldsw PK, Khan WA, Bhuiya A, et al. Mortality from external causes in Africa and Asia: evidence from INDEPTH Health and Demographic Surveillance System Sites. *Global health action* 2014;7.
15. Pison G, Douillot L, Kante AM, et al. Health & demographic surveillance system profile: Bandafassi Health and Demographic Surveillance System (Bandafassi HDSS), Senegal. *Int J Epidemiol* 2014;43(3):739-48.
16. Delaunay V, Douillot L, Diallo A, et al. Profile: the Niakhar Health and Demographic Surveillance System. *International Journal of Epidemiology* 2013;42(4):1002-11.
17. Oduro AR, Wak G, Azongo D, et al. Profile of the Navrongo Health and Demographic Surveillance System. *Int J Epidemiol* 2012;41(4):968-76.
18. Rossier C, Soura A, Baya B, et al. Profile: the Ouagadougou Health and Demographic Surveillance System. *Int J Epidemiol* 2012;41(3):658-66.
19. Lozano R, Naghavi M, Foreman K, et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012;380(9859):2095-128.
20. Haagsma JA, Graetz N, Bolliger I, et al. The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the Global Burden of Disease study 2013. *Inj Prev* 2016;22(1):3-18.
21. Vos T, Barber RM, Bell B, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–

2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet* 2015;386(9995):743-800.

22. Bhalla K, Harrison JE. GBD-2010 overestimates deaths from road injuries in OECD countries: new methods perform poorly. *Int J Epidemiol* 2015;44(5):1648-56.
23. Wang H, Dwyer-Lindgren L, Lofgren KT, et al. Age-specific and sex-specific mortality in 187 countries, 1970-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012;380(9859):2071-94.
24. AbouZahr C, de Savigny D, Mikkelsen L, et al. Civil registration and vital statistics: progress in the data revolution for counting and accountability. *Lancet* 2015;386(10001):1373-85.
25. Masquelier B, Reniers G, Pison G. Divergences in trends in child and adult mortality in sub-Saharan Africa: survey evidence on the survival of children and siblings. *Population Studies* 2014;68(2):161-77.
26. Wang H, Liddell CA, Coates MM, et al. Global, regional, and national levels of neonatal, infant, and under-5 mortality during 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014;384(9947):957-79.
27. Zureick-Brown S, Newby H, Chou D, et al. Understanding global trends in maternal mortality. *Int Perspect Sex Reprod Health* 2013;39(1):32-41.
28. Wilmoth JR, Mizoguchi N, Oestergaard MZ, et al. A New Method for Deriving Global Estimates of Maternal Mortality. *Stat Politics Policy* 2012;3(2).
29. Alkema L, Chou D, Hogan D, et al. Global, regional, and national levels and trends in maternal mortality between 1990 and 2015, with scenario-based projections to 2030: a systematic analysis by the UN Maternal Mortality Estimation Inter-Agency Group. *Lancet* 2016;387(10017):462-74.
30. Kassebaum NJ, Bertozzi-Villa A, Coggeshall MS, et al. Global, regional, and national levels and causes of maternal mortality during 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014;384(9947):980-1004.
31. Hill K, Choi Y, Timaeus IM. Unconventional approaches to mortality estimation. *Demographic Research* 2005;13:281-99.
32. Obermeyer Z, Murray CJL, Gakidou E. Fifty years of violent war deaths from Vietnam to Bosnia: analysis of data from the world health survey programme. *British Medical Journal* 2008;336(7659):1482a-6.
33. Lafta R, Al-Shatari S, Cherewick M, et al. Injuries, Death, and Disability Associated with 11 Years of Conflict in Baghdad, Iraq: A Randomized Household Cluster Survey. *PLoS One* 2015;10(8):e0131834.
34. Hagopian A, Flaxman AD, Takaro TK, et al. Mortality in Iraq associated with the 2003-2011 war and occupation: findings from a national cluster sample survey by the university collaborative Iraq Mortality Study. *PLoS Med* 2013;10(10):e1001533.
35. Galway L, Bell N, Sae AS, et al. A two-stage cluster sampling method using gridded population data, a GIS, and Google Earth(TM) imagery in a population-based mortality survey in Iraq. *Int J Health Geogr* 2012;11:12.
36. Helleringer S, Pison G, Masquelier B, et al. Improving survey data on pregnancy-related deaths in low-and middle-income countries: a validation study in Senegal. *Tropical Medicine & International Health* 2015;20(11):1415-23.
37. Helleringer S, Pison G, Masquelier B, et al. Improving the Quality of Adult Mortality Data Collected in Demographic Surveys: Validation Study of a New Siblings' Survival Questionnaire in Niakhar, Senegal. *PLoS Med* 2014;11(5):e1001652.
38. Guyavarch E, Pison G, Duthé G, et al. Mortality due to External Causes in Three Rural Areas of Senegal [La mortalité violente dans trois régions rurales du Sénégal]. *European Journal of Population* 2010;26(4):483-505.
39. Helleringer S, Pison G, Masquelier B, et al. Improving the quality of adult mortality data collected in demographic surveys: validation study of a new siblings' survival questionnaire in Niakhar, Senegal. *PLoS Med* 2014;11(5):e1001652.

40. Corsi DJ, Neuman M, Finlay JE, et al. Demographic and health surveys: a profile. *Int J Epidemiol* 2012;41(6):1602-13.

	External causes (N=25)	Other causes (N=443)	P-value
Sibship size			0.656
1-4 maternal siblings	6 (4.4)	130 (95.6)	
5+ maternal siblings	19 (5.7)	313 (94.3)	
Gender			0.079
Male	21 (6.7)	291 (93.3)	
Female	4 (2.6)	152 (97.4)	
Age at death			0.529
<25 years old	10 (5.9)	159 (94.1)	
25-34 years old	8 (6.5)	115 (93.5)	
35-44 years old	5 (5.8)	82 (94.3)	
≥ 35 years old	2 (2.3)	87 (98.8)	
Time since death			0.730
≤ 5 years	11 (6.1)	169 (93.9)	
6-10 years	7 (4.2)	160 (95.8)	
11-15 years	7 (5.8)	114 (94.2)	

Table 1: Characteristics of deaths recorded by the Niakhar HDSS during the 15 years prior to the survey, and included in the validation study

Notes: figures in parentheses are row percentages. P-values are based on a two-sided Fisher exact test.

Circumstances of death	
Fall	3 (12.0)
Road traffic accidents	5 (20.0)
Other accidents	4 (16.0)
Drowning	1 (4.0)
Homicide	1 (4.0)
Suicide	3 (12.0)
Unknown	8 (32.0)

Table 2: Circumstances of deaths due to external causes included in the validation study according to HDSS data

	Sibships with adult death from external causes		Sibships with adult deaths from other causes		p-value
	Reported/ expected	% (95% CI)	Reported/ expected	% (95% CI)	
All deaths	34/35	97.1 (82.2, 99.6)	498/568	87.7 (84.7, 90.1)	0.093
Male deaths	31/32	96.9 (80.8, 99.6)	334/383	87.2 (83.5, 90.2)	0.108

Table 3: Selective omissions of adult deaths during siblings' survival histories, by sibship composition.

Notes: 'Reported' refers to the number of respondents who reported an adult death among their siblings over the past 15 years; 'Expected' refers to the number of respondents who were members of sibships in which there was at least one death due to injuries or one death due to other causes, in the past 15 years; P-values test the null hypothesis of no difference in proportion of respondents reporting an adult death over the past 15 years between sibships with an injury death and sibships with only non-injury deaths. This P-value is based on a χ^2 *test. Standard errors are adjusted for the clustering of respondents within sibships.*

	Sensitivity		Specificity		p-value
	Correct/ reported	% (95% CI)	Correct/ reported	% (95% CI)	
All deaths	20/34	58.8 (41.9, 73.9)	479/498	96.2 (94.1, 97.6)	<0.001
Male deaths	19/31	61.3 (43.4, 76.6)	320/334	95.8 (93.0, 97.5)	<0.001

Table 4: Sensitivity/specificity of reports of adult deaths collected during SSH survey.

Notes: "sensitivity" refers to the proportion of deaths classified as due to injuries by the HDSS dataset, that were also classified as due to injuries during the SSH survey. Specificity refers to the proportion of deaths classified as due to other causes of death (i.e., non-injuries) by the HDSS dataset, that were also classified as such during the SSH survey. P-values test the null hypothesis of no between sensitivity and specificity. This P-value is based on a χ^2 *test. Standard errors are adjusted for the clustering of respondents within sibships.*

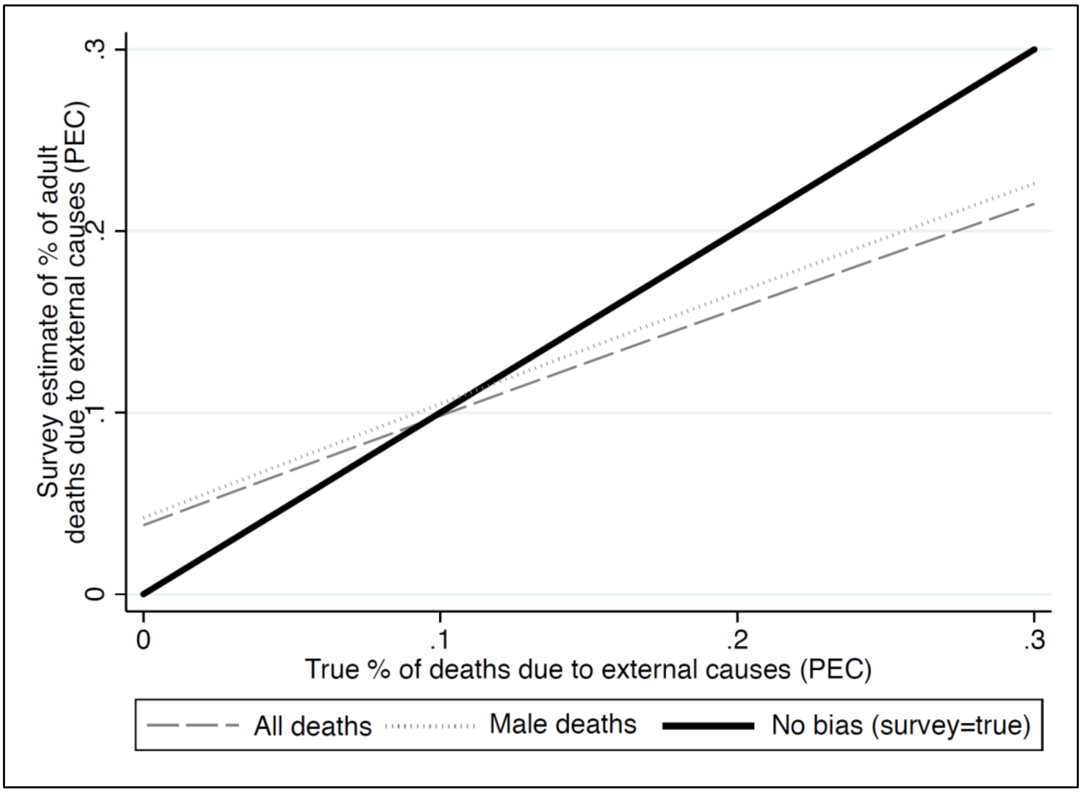

Figure 1: Bias in SSH estimates of the proportion of deaths due to injuries

Notes: the dotted line represents the 45 degrees line, where the reported proportion of injury-related deaths is equal to the hypothesized true proportion of injury-related deaths in the population. The distance between the dotted lines and the predicted reported proportions measures the extent of bias in SSH estimates.

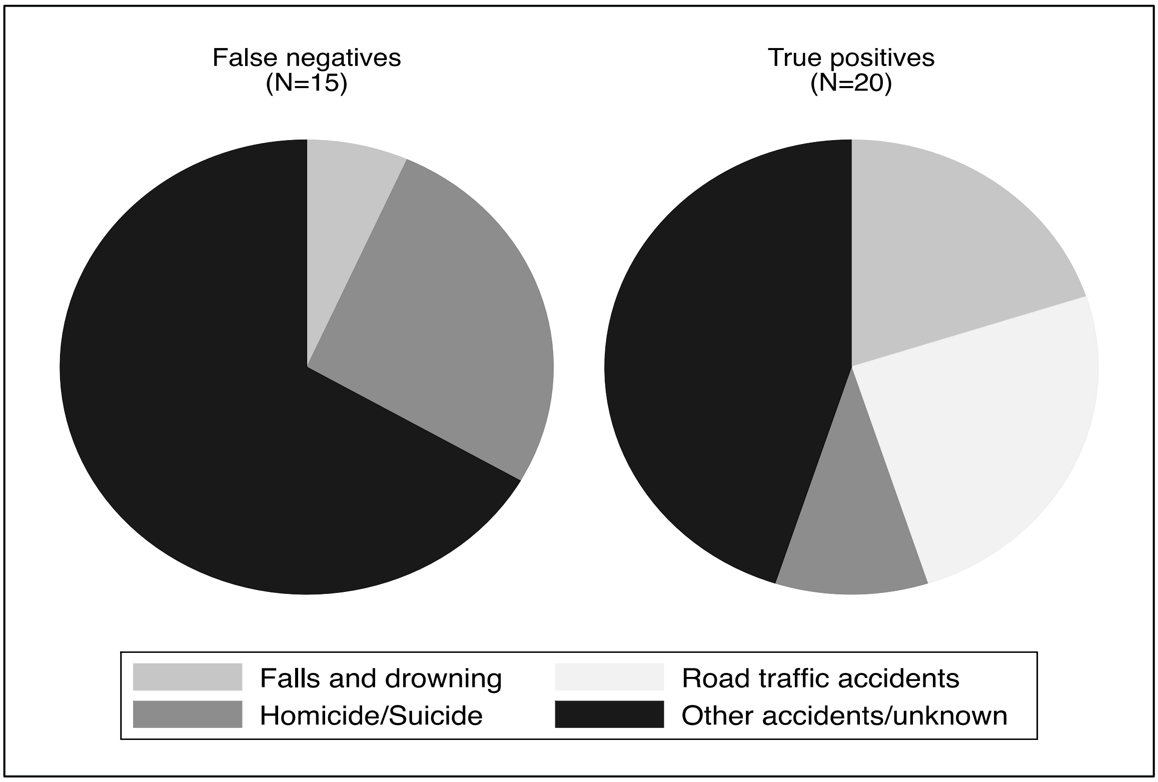

Figure 2: Causes of deaths among deaths from external causes by reporting status during SSH

Notes: false negatives are deaths that were classified as injury-related by the HDSS, but were not classified as such during SSH. True positives are deaths that were classified as injury-related both by the HDSS and the SSH. The difference in distribution of causes of death between false negatives and true positives was significant at p<0.1 level according to an exact χ^2 *test (2-sided).*