Ferraro, Claire F; Trotter, Caroline L; Nascimento, Maria C; Jusot, Jean-François; Omotara, Babatunji A; Hodgson, Abraham; Ali, Oumer; Alavo, Serge; Sow, Samba; Daugla, Doumagoum Moto; +1 more... Stuart, James M; (2014) Household crowding, social mixing patterns and respiratory symptoms in seven countries of the African meningitis belt. PloS one, 9 (7). e101129-. ISSN 1932-6203 DOI: https://doi.org/10.1371/journal.pone.0101129

Downloaded from: http://researchonline.lshtm.ac.uk/id/eprint/1823781/

DOI: https://doi.org/10.1371/journal.pone.0101129

Usage Guidelines:

Please refer to usage guidelines at https://researchonline.lshtm.ac.uk/policies.html or alternatively contact researchonline@lshtm.ac.uk.

Available under license: http://creativecommons.org/licenses/by/2.5/
Household Crowding, Social Mixing Patterns and Respiratory Symptoms in Seven Countries of the African Meningitis Belt

Claire F. Ferraro1, Caroline L. Trotter2*, Maria C. Nascimento1, Jean-François Jusot3, Babatunji A. Omotara4, Abraham Hodgson5,6, Oumer Ali7, Serge Alavo8, Samba Sow9, Doumagoum Moto Daugla10, James M. Stuart1

1 Department of Infectious & Tropical Diseases, London School of Hygiene & Tropical Medicine, London, United Kingdom, 2 Disease Dynamics Unit, Department of Veterinary Medicine, University of Cambridge, Cambridge, United Kingdom, 3 Unité d’Épidémiologie, Centre de Recherches Médicales et Sanitaires (CERMES), Niamey, Niger, 4 Department of Community Medicine, University of Maiduguri, Maiduguri, Nigeria, 5 Navrongo Health Research Centre, Navrongo, Ghana, 6 Research and Development Division, Ghana Health Service, Ghana, 7 Armauer Hansen Research Institute, Addis Ababa, Ethiopia, 8 L’Institut de recherche pour le développement, Dakar, Senegal, 9 Center for Vaccine Development-Mali (CVD-MALI), Bamako, Mali, 10 Centre de Support en Santé Internationale (CSSI), Ndjamena, Chad

Abstract

Objectives: To describe the variation in household crowding and social mixing patterns in the African meningitis belt and to assess any association with self-reported recent respiratory symptoms.

Methods: In 2010, the African Meningococcal Carriage Consortium (MenAfriCar) conducted cross-sectional surveys in urban and rural areas of seven countries. The number of household members, rooms per household, attendance at social gatherings and meeting places were recorded. Associations with self-reported recent respiratory symptoms were analysed by univariate and multivariate regression models.

Results: The geometric mean people per room ranged from 1.9 to 2.8 between Ghana and Ethiopia respectively. Attendance at different types of social gatherings was variable by country, ranging from 0.5 to 1.5 per week. Those who attended 3 or more different types of social gatherings a week (frequent mixers) were more likely to be older, male (OR 1.27, p<0.001) and live in urban areas (OR 1.45, p<0.001). Frequent mixing and young age, but not increased household crowding, were associated with higher odds of self-reported respiratory symptoms (aOR 2.2, p<0.001 and OR 2.8, p<0.001 respectively). A limitation is that we did not measure school and workplace attendance.

Conclusion: There are substantial variations in household crowding and social mixing patterns across the African meningitis belt. This study finds a clear association between age, increased social mixing and respiratory symptoms. It lays the foundation for designing and implementing more detailed studies of social contact patterns in this region.

Introduction

Social mixing and human contact patterns are important determinants of infectious disease transmission. Household contacts are intensive and household crowding is a recognized risk factor for tuberculosis [1,2] and acute rheumatic fever [3] in observational studies. Mass gatherings, such as the Hajj pilgrimage in Saudi Arabia, increase the risk of large-scale transmission and dissemination of infectious diseases, as seen with Neisseria meningitidis group W in 2001 [4]. Information on contact patterns is important for understanding the spread of infection and such information can be used, for example, to more accurately parameterise transmission models of infectious disease [5,6]. However, information on mixing patterns and other social parameters are often lacking. There have been advances in collecting empirical social contact data by self-reported paper and electronic diaries [5,7–9] or recall interviews [10] in Europe, Australia and Vietnam. To our knowledge, only one such similar study has been performed in sub-Saharan Africa [11]. Computational approaches have also been proposed recently to infer contact patterns in a population from sociodemographic data [12–14].

The African Meningococcal Carriage Consortium (www.menafircar.org) is a global research consortium that was established to study how meningococcal meningitis is spread in Africa [15] and to document the impact of a new serogroup A
meningococcal conjugate vaccine [16] on reducing transmission. The consortium includes research institutes from seven countries across the African meningitis belt [17]; Chad, Ethiopia, Ghana, Mali, Niger, Nigeria and Senegal, which have diverse cultural, climatic, socio-demographic and epidemiological profiles. Previous meningococcal carriage studies in Africa have shown wide variation in prevalence ranging from less than 1% to over 30% [18]. Age patterns vary too, with the highest prevalence observed in children aged 1–4 years in Mali and Northern Nigeria, children <10 years of age in Nigeria and teenagers in Northern Ghana and Burkina Faso [18,19]. In the UK, meningococcal carriage in teenagers was particularly associated with social behaviour [20], so this variation in age distribution may represent diverse behavioural and social mixing patterns across the African region [18].

The MenAfriCar studies collected information on household size, composition and crowding in addition to data on attendance at school events and large gatherings such as the Haj pilgrimage via standardized questionnaires. Everyday social activities such as school and workplace attendance were not measured. We set out to describe these household and social mixing patterns in the African meningitis belt and to examine associations between social and demographic factors with recent self-reported respiratory symptoms.

Methods

Study population

Household cross-sectional surveys were conducted in rural and urban areas of seven countries: Chad, Ethiopia, Ghana, Mali, Niger, Nigeria and Senegal, between 1st August and 30th December 2010, mainly during the rainy season. Households were randomly selected from a list derived from a demographic surveillance system (DSS) or, in sites without a DSS from a census performed specifically for the study. Following informed consent, the head of the household was interviewed using a short household questionnaire which recorded details relevant to the entire household such as number of residents, number of rooms, kitchen location and fuel type. Then, each randomly-selected individual resident within that household (up to 5 individuals per household, according to age) was interviewed using an adult (≥15 years) or child (<15 years) questionnaire, which collected individual-level information, including attendance at social gatherings and sleeping arrangements. As the study was motivated by meningococcal carriage and not designed as a social mixing survey, we did not measure attendance at school and workplaces. Full details of the methods used in the MenAfriCar surveys are published elsewhere [15].

Measures of risk factors, outcomes and potential confounders

Information on a range of factors including household size, household arrangements, social gathering attendance, kitchen location, fuel use and self-reported recent respiratory illness were collected in the cross-sectional surveys. Household crowding was summarised using a continuous variable called people-per-room, calculated by number of residents divided by number of rooms. The number of people per bedroom and people per bedmat were also used as additional crowding indicators.

Social mixing patterns were summarised according to the number of different types of social gatherings attended. Attending a market, wedding, funeral, ceremony (e.g. circumcision), social club, bar or other such event in the last week was considered a “social gathering”. The frequency of attendance and length of each social gathering within each of the sub-categories was not recorded. People were categorized by their social mixing patterns into “non-mixers” (individuals who attended no social gatherings in the last week), “occasional mixers” (individuals who attended one or two different types of social gatherings in the last week) and “frequent mixers” (individuals who attended 3–6 different types of social gatherings in the last week). Kitchen location and the types of cooking fuels used were recorded. Fuels were categorised according to biomass content (electricity; oil or gas or paraffin; wood or charcoal; animal dung or millet straws) (Fullerton et al., 2000) to indicate level of air pollution. The main outcome of interest was self-reported respiratory illness. This was defined as at least one symptom (cough, sore-throat, or runny-nose) within the last week.

Ethics

The MenAfriCar surveys were granted ethical approval by the London School of Hygiene & Tropical Medicine in May 2010. Each approval was also sought and gained from appropriate ethical committees of each country (AHRI-ALERT Ethics Review Committee, Ethiopia; Navrongo Health Research Centre Institutional Review Board, Ghana; Ethics Committee of the Faculty of Medicine, University of Bamako, Mali; National Ethics Committee of Niger; Research and Ethics Committee of the University of Malteguri Teaching Hospital, Nigeria; National Ethic Committee for Health Research, Senegal) with the exception of Chad, which did not have a formal ethical committee, where approval was granted by a committee set up to oversee MenAfriCar studies by the Ministry of Health. The study was registered with Clinical-Trials.gov (NCT01119482). Informed consent, as approved by the ethical committees, was obtained from participants as follows. The head of the household or another responsible adult gave verbal informed consent for the household to be included in the study. Each individual selected for inclusion within that household gave written informed consent (signature or thumbprint); for children under the age of 18 a parent or guardian gave written consent and children aged over 12 years were additionally asked to give written assent.

Statistical methods

Logarithmic transformation was used to normalize skewed data (number of residents, rooms, bedrooms per household) and to present summary statistics of continuous variables by country, area, age and sex. Differences between populations in household crowding were evaluated by t-tests and chi-squared tests using data from household questionnaires only. Continuous explanatory variables (e.g. people per room, people per bedroom, people per bedmat) were categorized into four equal quartiles. Only data that were within 2 standard deviations (SD) of the mean for number of people per bedroom (99.0% were within 2SD) and bedmat (99.6% within 2SD) were included because the raw data included nonsensical values. Logistic regression was used to evaluate the characteristics associated with those people who mix more than others and risk factors associated with recent respiratory symptoms. First, univariate logistic regression was performed. Then a multivariable logistic regression model was constructed in a stepwise manner, with age and sex included a priori. Other variables associated with the outcome (p<0.1) in the univariate analysis were included, then any variables in the multivariable model with p<0.1 were excluded. Since the primary sampling unit for the survey was the household, rather than the individual, we adjusted for potential clustering within households by applying the svyset command to household id in Stata (v11.2, STATA Corp, Texas). All statistical analyses were performed in Stata.
Results

Description of Data
MenAfriCar’s first cross sectional study recruited and interviewed 18,047 individuals across seven countries in the African Meningitis Belt. Combined household and individual data was available for 17,805 (95.5%) individuals, (92.7% Mali, 99.6% Niger, 93.8% Ghana, 94.1% Nigeria, 98.4% Chad, 93.5% Ethiopia and 94.0% Senegal) from 6,232 households. There were 8,577 children aged <15 years (48.2%). There were more females than males overall (56.6% female, 43.4% male); the greatest sex difference existed in those aged 15–29 years old (67.3% female, 32.7% male). Household participation was good with 6% or fewer refusals in sites where this data was recorded.

Household Size and Crowding
There was a large variation in household size (Table 1), with 1 to 90 residents reported per household (median 6; IQR 4–10), living in 1 to 62 rooms (median 3; IQR 2–5). (Note that the few extreme values reported were queried and verified with the local study teams). Household crowding, as measured by geometric mean people-per-room, also varied greatly (Table 1). Ghana and Senegal had a significantly lower geometric mean people-per-room compared to other countries, whilst Ethiopia had the most crowded households. There was no difference in crowding between rural and urban areas (geometric mean 2.14 and 2.20 respectively, p = 0.085).

Social Mixing Patterns
The number of non-mixers, occasional mixers and frequent mixers, as previously defined, is shown in Table 2. Ghana had the highest proportion of frequent mixers and the lowest proportion of non-mixers, less than half any other country. Ghana also had the highest average number of types of social gathering per person, with Senegal reporting the lowest.

Age was strongly associated with social mixing patterns (Table 3). When compared to older adults, 15–29 year olds had lower odds of being a frequent mixer (OR 0.63, p < 0.001). When compared to older adults, 15–29 year olds had lower odds of being a frequent mixer (OR 0.63, p < 0.001). The odds of being a frequent mixer were much lower for children aged less than 15 years (OR 0.29 for <1 year olds, OR 0.13 for 1–4 year olds, OR 0.16 for 5–14 year olds, all p < 0.001). In addition, frequent mixers had higher odds of living in urban areas (OR 1.45 p < 0.001) and being male (OR 1.27 p < 0.001).

Table 3 shows that the number of residents per household in Ghana, Mali and Senegal were comparable to other studies, supporting the evidence that on average there are larger households in Mali [21–23]. MenAfriCar surveys defined households as those who “share a cooking pot”, although much debate surrounds the most appropriate definition of households [24]. This is important as

Table 1. Summary of household data and crowding by country.

| Country | Number of individuals recruited to study | Number of households recruited | Geometric mean of residents per household | Geometric mean of people per room (95% CI) |
|---------|----------------------------------------|---------------------------------|----------------------------------------|------------------------------------------|
| Chad    | 2049                                   | 764                             | 5.08                                   | 2.19 (2.09–2.30)                         |
| Ethiopia| 1887                                   | 783                             | 4.55                                   | 2.78 (2.66–2.91)                         |
| Ghana   | 1175                                   | 419                             | 4.92                                   | 1.83 (1.73–1.94)                         |
| Mali    | 4662                                   | 1619                            | 10.86                                  | 2.10 (2.05–2.16)                         |
| Niger   | 4642                                   | 1428                            | 5.49                                   | 2.13 (2.07–2.19)                         |
| Nigeria | 1758                                   | 653                             | 6.22                                   | 2.31 (2.19–2.43)                         |
| Senegal | 1632                                   | 566                             | 9.14                                   | 1.87 (1.80–1.94)                         |
| Total   | 17,805                                 | 6,232                           | 6.68                                   | 2.17 (2.14–2.21)                         |

1The geometric mean of residents per household is based on the number of individuals resident in the study households, and not the individuals recruited to the study shown in the second column above. (A maximum of 5 residents were recruited to the study).
local norms of polygamy and extended family staying within the same compound mean that not all residents of a large household will mix and spread infections to other residents equally. However, in our study, which included seven different countries, it was not feasible to employ a stricter definition of household. We did not find any published data on people per room in our seven countries to facilitate a direct comparison, but a publication from The Gambia (another country in the meningitis belt) found lower levels of crowding [1].

The prevalence of self-reported respiratory symptoms was high, with nearly half of our study population (45.5%) reporting at least one respiratory symptom in the previous week. Although these symptoms are non-specific, self-reported and not validated, we considered that viral respiratory infections were a likely cause. The period of the study was however outside of the main period for influenza transmission [25]. Younger children, aged less than 5 years, were more likely to have symptoms than older children and adults. Despite higher levels of mixing amongst adults, the lower prevalence of symptoms in adults may be due to a shorter duration of symptoms or reduced susceptibility due to immunity.

People living in urban areas were less likely to report symptoms than those living in rural areas. We might have expected more respiratory illness in the urban area since people living there are more likely to mix frequently which is strongly associated with higher prevalence of symptoms. However, other factors which we did not measure, such as household income, may be important. Another study in Indonesia also found that respiratory disease (specifically respiratory syncytial virus lower respiratory tract infections in young children) was more common in rural areas compared to urban areas [26]. Particularly relevant for the MenAfriCar studies are the findings that respiratory tract infections may predispose to meningococcal disease [27,28] and may be associated with meningococcal transmission [29]. Viral respiratory infections are highly transmissible which may explain the association with frequent mixing. Surprisingly our results show no association with household crowding or crowded sleeping arrangements. Crowding has previously been shown to be associated with increased rates [30] and severity of RSV [31] in The Gambia and Indonesia respectively. It is also an important risk factor for infections requiring prolonged or close contact for transmission, including tuberculosis [1,32] and in developed countries, meningococcal disease [2,33,34]. It is possible that our findings have been influenced by our unrestrictive definition of a household (those who share a cooking pot).

Indoor smoke pollution is reported to increase the risk of acute respiratory infections [35,36]. Our results show an increase in

| Table 2. Number (%) of individuals’ social mixing patterns by country. |
|---------------------------------------------------------------|
| **N** | **Non-mixers N (%)** | **Occasional mixers N (%)** | **Frequent mixers N (%)** | **Number of different types of social gatherings per person*** |
|-------|----------------------|-----------------------------|--------------------------|-------------------------------------------------------------|
| Chad  | 2049                 | 805 (39.3)                  | 1128 (55.1)              | 116 (5.7)                                                   |
| Ethiopia | 1887                | 1032 (54.7)                 | 794 (42.1)               | 61 (3.2)                                                    |
| Ghana | 1175                 | 220 (18.7)                  | 758 (64.5)               | 197 (16.8)                                                  |
| Mali  | 4662                 | 2025 (43.4)                 | 2455 (52.7)              | 182 (3.9)                                                   |
| Niger | 4642                 | 2227 (48.0)                 | 1954 (42.1)              | 461 (9.9)                                                   |
| Nigeria | 1758                | 957 (54.4)                  | 707 (40.2)               | 94 (5.4)                                                    |
| Senegal | 1632                 | 948 (58.1)                  | 665 (40.8)               | 19 (1.2)                                                    |
| Total | 17805                | 8214 (46.1)                 | 8461 (47.5)              | 1130 (6.4)                                                  |

***Number of different types of social gatherings per person: total number of social gatherings in country/study population of that country.

| Table 3. Multivariable analysis comparing frequent mixers to all others by age, sex and area. |
|---------------------------------------------------------------|
| **AGE** | **N** | **Number of (%) frequent mixers** | **Odds Ratio** | **(95% CI)** | **p-value** |
|--------|-------|---------------------------------|----------------|--------------|-------------|
| <1 yr | 869   | 34 (3.9)                        | 0.29           | (0.21 0.41)  | <0.001      |
| 1–4 yr| 3479  | 63 (1.8)                        | 0.13           | (0.10 0.17)  | <0.001      |
| 5–14 yr| 4230  | 94 (2.2)                        | 0.16           | (0.13 0.20)  | <0.001      |
| 15–29 yr| 4304  | 340 (7.9)                       | 0.63           | (0.55 0.72)  | <0.001      |
| >30 yr| 4923  | 599 (12.2)                      | 1              |              |             |
| **SEX** | |                                |                |              |             |
| Female | 10030 | 619 (6.2)                       | 1              |              |             |
| Male   | 7708  | 506 (6.3)                       | 1.27           | (1.11 1.44)  | <0.001      |
| **AREA** | |                                |                |              |             |
| Rural  | 8510  | 442 (5.2)                       | 1              |              |             |
| Urban  | 9295  | 688 (7.4)                       | 1.45           | (1.25 1.68)  | <0.001      |

*Missing data for 67 records.

[doi:10.1371/journal.pone.0101129.t002](doi:10.1371/journal.pone.0101129.t002)
Table 4. Factors associated with reporting respiratory symptoms in the last week.

|                              | N  | N ≥1 symptom (%) | Unadjusted OR (95% CI) | p-value | Adjusted OR (95% CI) | p-value |
|------------------------------|----|------------------|------------------------|---------|----------------------|---------|
| **SOCIAL GATHERINGS**       |    |                  |                        |         |                      |         |
| Non-mixers                   | 8214 | 3561 (43.4)      | 1                      |         | 1                    |         |
| Occasional mixers            | 8461 | 3913 (46.3)      | 1.12 (1.05, 1.20)      | <0.001  | 1.37 (1.27, 1.47)    | <0.001  |
| Frequent mixers              | 1130 | 601 (53.1)       | 1.48 (1.30, 1.69)      | <0.001  | 2.25 (1.95, 2.61)    | <0.001  |
| **NUMBER of PEOPLE PER ROOM**|    |                  |                        |         |                      |         |
| 0.125–1.6                    | 4598 | 2116 (46.0%)     | 1                      | n/a     |                      |         |
| 1.6–2.33                     | 4727 | 2101 (44.4%)     | 0.94 (0.85, 1.03)      | 0.203   |                      |         |
| 2.33–3.14                    | 3969 | 1735 (43.7%)     | 0.91 (0.82, 1.01)      | 0.078   |                      |         |
| 3.14–17                      | 4386 | 2081 (47.5%)     | 1.05 (0.95, 1.17)      | 0.276   |                      |         |
| **NUMBER of PEOPLE PER BEDROOM (cleaned <2sd)** |    |                  |                        |         |                      |         |
| 1–2                          | 8461 | 3819 (45.1)      | 1                      | n/a     |                      |         |
| 3                            | 3567 | 1712 (48.0)      | 1.12 (1.02, 1.22)      | 0.010   |                      |         |
| 4                            | 2537 | 1142 (45.0)      | 0.99 (0.90, 1.10)      | 0.924   |                      |         |
| >4                           | 3010 | 1322 (43.9)      | 0.95 (0.86, 1.05)      | 0.330   |                      |         |
| **NUMBER of PEOPLE PER BEDMAT (cleaned <2sd)** |    |                  |                        |         |                      |         |
| 1                            | 3811 | 1518 (41.5)      | 1                      | n/a     |                      |         |
| 2                            | 8025 | 3588 (44.3)      | 1.12 (1.03, 1.22)      | 0.006   |                      |         |
| 3                            | 4375 | 2155 (49.5)      | 1.37 (1.24, 1.50)      | <0.001  |                      |         |
| >3                           | 1594 | 781 (49.0)       | 1.35 (1.19, 1.54)      | <0.001  |                      |         |
| **KITCHEN LOCATION**         |    |                  |                        |         |                      |         |
| Inside house                 | 4892 | 1994 (40.7)      | 1                      |         |                      |         |
| Open air                     | 6729 | 3075 (45.7)      | 1.22 (1.11, 1.34)      | <0.001  | 1.11 (0.99, 1.23)    | 0.056   |
| Separate hut                 | 5682 | 2824 (49.7)      | 1.44 (1.31, 1.58)      | <0.001  | 1.05 (0.94, 1.18)    | 0.343   |
| **FUEL USE**                 |    |                  |                        |         |                      |         |
| Electricity, Oil, Gas, Paraffin | 267 | 133 (50.0)      | 1                      | n/a     |                      |         |
| Wood, Charcoal               | 15559 | 7077 (45.5)    | 0.84 (0.65, 1.07)      | 0.169   |                      |         |
| Animal Dung, Millet Straws   | 1747 | 786 (45.0)       | 0.82 (0.62, 1.07)      | 0.158   |                      |         |
| **AREA**                     |    |                  |                        |         |                      |         |
| Rural                        | 8510 | 4254 (50.0)      | 1                      |         |                      |         |
| Urban                        | 9295 | 3821 (41.1)      | 0.70 (0.65, 0.75)      | <0.001  | 0.71 (0.66, 0.77)    | <0.001  |
| **AGE**                      |    |                  |                        |         |                      |         |
| <1yr                         | 869 | 557 (64.1)       | 2.72 (2.35, 3.15)      | <0.001  | 3.17 (2.71, 3.70)    | <0.001  |
| 0–4yr                        | 3479 | 2083 (59.9)      | 2.28 (2.09, 2.48)      | <0.001  | 2.79 (2.54, 3.07)    | <0.001  |
| 5–14yr                       | 4230 | 1816 (42.9)      | 1.14 (1.06, 1.24)      | <0.001  | 1.30 (1.20, 1.42)    | <0.001  |
| 15–29yr                      | 4304 | 1671 (38.8)      | 0.97 (0.89, 1.05)      | 0.434   | 0.97 (0.90, 1.06)    | 0.555   |
| >30yr                        | 4923 | 1948 (45.3)      | 1                      |         |                      |         |
| **SEX**                      |    |                  |                        |         |                      |         |
| Female                       | 10030 | 4505 (44.9)    | 1                      |         |                      |         |
| Male                         | 7708 | 3534 (45.8)      | 1.04 (0.98, 1.10)      | 0.206   | 0.95 (0.89, 1.01)    | 0.116   |
| **SMOKING**                  |    |                  |                        |         |                      |         |
| No                           | 8564 | 3355 (39.2)      | 1                      | n/a     |                      |         |
| Yes                          | 564 | 238 (42.2)       | 1.13 (0.95, 1.35)      | 0.16    |                      |         |
| **COUNTRY**                  |    |                  |                        |         |                      |         |
| Chad                         | 2049 | 1078 (52.6)      | 1                      |         |                      |         |
| Ethiopia                     | 1887 | 910 (48.2)       | 0.84 (0.72, 0.97)      | 0.02    | 0.89 (0.75, 1.04)    | 0.162   |
| Ghana                        | 1175 | 622 (52.9)       | 1.01 (0.85, 1.20)      | 0.883   | 0.95 (0.79, 1.15)    | 0.590   |
| Mali                         | 4662 | 2443 (52.4)      | 0.99 (0.87, 1.12)      | 0.894   | 0.99 (0.87, 1.14)    | 0.916   |
respiratory symptoms reported by people with kitchens outside or in a separate hut in a univariate analysis, but in the multivariate analysis we found no association between location of the kitchen and symptoms. We found no association between fuel and symptoms; this may be because the vast majority of study participants (88.5%) used wood or charcoal whereas the cleaner fuels (electricity, oil, paraffin, gas) were only used by 267 (1.5%). Cleaner cooking fuels have been found to reduce the risk of respiratory illness [36].

Other studies have highlighted the importance of population movements and mixing on disease transmission; coinciding with agricultural seasons [37], differences between men and women in Islamic society [38] and DNA fingerprint studies of TB transmission outside the household [39,40]. This study quantifies social mixing patterns simply as attendance at different types of "social events or meeting places". We did not measure more commonplace activities such as attending school or regular workplace, nor did we measure frequency, duration, repetition and clustering of contacts, e.g. by age or sex [41,42]. These factors are likely to be important, so this is a key limitation of our study. The questions on social gatherings may have been more likely to be relevant to adults, so the amount of social contact in children in particular could have been underestimated. Nevertheless, our demonstration of considerable heterogeneity across this region suggests there is a need for more detailed studies of social contacts in meningitis belt countries. Future research could focus on collecting data on duration, type and location of contacts using diary based methods [9] or recall at interview [10]. A detailed study of social contacts in a South African township showed that numbers of close contacts were 40% higher than in corresponding populations in industrialized countries [11]. This also illustrates the importance of generating geographically-specific measures of contact. The detailed social mixing pattern studies referenced above and others based on dynamics within households [43,44] have contributed to our theoretical understanding of network analysis but the evidence from observational studies linking this with the impact on disease transmission is lacking. Our study demonstrates the heterogeneity in crowding and social mixing across the African meningitis belt and finds that social mixing, but not household crowding, is associated with respiratory symptoms. This lays a foundation for further research into the impact of social mixing patterns on the spread of airborne infections through populations of sub-Saharan Africa.

Acknowledgments

We thank the many individuals who contributed to the design and implementation of the first MenAfriCar cross-sectional surveys and all of the study participants. We thank Dr Chris Metcalfe, School of Social and Community Medicine, University of Bristol for offering statistical advice. The work of the MenAfriCar Consortium is supported by grants from the Bill & Melinda Gates Foundation and from the Wellcome Trust.

Author Contributions

Conceived and designed the experiments: JMS MCN CLT DMD OA AH. Analyzed the data: CFF CLT. Wrote the paper: CFF CLT JMS.

Funding: The work of the MenAfriCar Consortium is supported by grants from the Bill & Melinda Gates Foundation and from the Wellcome Trust.

Table 4. Cont.

| N     | N ≥1 symptom (%) | Unadjusted OR (95% CI) | p-value | Adjusted OR (95% CI)* | p-value |
|-------|------------------|------------------------|---------|-----------------------|---------|
| Niger | 4642             | 1658 (35.7)            | 0.50 (0.44, 0.57) | <0.001               | 0.52 (0.45, 0.60) | <0.001 |
| Nigeria | 1758             | 737 (41.9)             | 0.65 (0.56, 0.77) | <0.001               | 0.67 (0.57, 0.80) | <0.001 |
| Senegal | 1632             | 627 (38.4)             | 0.55 (0.47, 0.65) | <0.001               | 0.60 (0.49, 0.72) | <0.001 |

*Only adults were questioned about their smoking habits.

doi:10.1371/journal.pone.0101129.t004

References

1. Hill PC, Jackson-Sillah D, Donkor SA, Otu J, Adegbola RA, et al. (2006) Risk factors for pulmonary tuberculosis: a clinic-based case control study in The Gambia. BMC Public Health 6, 156.
2. Baker M, McNicholas A, Garrett N, Jones N, Stewart J, et al. (2000). Household crowding a major risk factor for epidemic meningococcal disease in Auckland children. Pediatr Infect Dis J 19, 985-90.
3. Jasine R, Baker M, Venugopal K. (2000) Epidemiology of acute rheumatic fever in New Zealand 1996-2005. J Paediatr Child Health 44, 564–71.
4. Abubakar I, Gauvreau K, Blumberg L, Johnson D, et al. (2012). "Social event" and meningococcal disease. Lancet Infect Dis 12, 66–74.
5. Wallinga J, Teunis P, Kretzschmar M (2006) Using data on social contacts to estimate age-specific transmission parameters for respiratory-spread infectious agents. Am J Epidemiol 164, 936–44.
6. Ogungini B, Hansen N, Greywaerts N, Aerts M, van Damme P, et al. (2009) Using empirical social contact data to model person to person infectious disease transmission: An illustration for varicella. Math Biosci 218, 80–87.
7. Edmunds WJ, Kelaris G, Wallinga J, Mossong J, et al. (2006) Mixing patterns and the spread of close-contact infectious diseases. Emerg Themes Epidemiol 3, 10.
8. McCaig FM, Forbes K, Nathan PM, Pattison PE, Robins KL, et al. (2010) Comparison of three methods for ascertaining of contact information relevant to respiratory pathogen transmission in encounter networks. BMC Infect Dis 10, 166.
9. Mossong J, Hens N, Jit M, Beutels P, Auranen K, et al. (2008) Social contacts and mixing patterns relevant to the spread of infectious diseases. PLoS Med 5, e74.
10. Horby P, Pham QT, Hens N, Nguyen TT, Le QM, et al. (2011) Social contact patterns in Vietnam and implications for the control of infectious diseases. PLoS One 6, e16965.
11. Johnstone-Robertson SP, Mark D, Morroco C, Middelkoop K, Chiswell M, et al. (2011) Social mixing patterns within a South African township community: implications for respiratory disease transmission and control. Am J Epidemiol 174(11):1246–55.
12. Ioaz F, Triniano F, Chinazzi M, Billari FC, Zagheni E, et al. (2010). Little Italy: an agent-based approach to the estimation of contact patterns- fitting predicted matrices to serological data. PLoS Comput Biol 6(12):e1001021.
13. Fumanelli L, Ajelli M, Manfredi P, Vespignani A, Merler S (2012) Inferring the structure of social contacts from demographic data in the analysis of infectious diseases spread. PLoS Comput Biol 8:e1002673.
14. Xia S, Liu J, Cheung W (2013) Identifying the relative priorities of social mixing. PLoS Comput Biol 8:e1002711.
15. MenAfriCar Consortium (2013) Meningococcal carriage in the African meningitis belt. Trop Med Int Health 18(9):968–78.
16. LeForce FM, Okubo-Bele JM (2011) Eliminating epidemic Group A meningococcal meningitis in Africa through a new vaccine. Health Aff (Millwood) 30, 1949–57.
17. Molesworth AM, Thomson MC, Connor SJ, Cresswell MP, Morse AP, et al. (2009) Where is the Meningitis Belt? Defining an area at risk of epidemic meningitis in Africa. Trans R Soc Trop Med Hyg 93:242–9.
18. Trotter CL, Greenwood BM (2007) Meningococcal carriage in the African meningitis belt. Lancet Infect Dis 7, 597-603.
19. Kristiansen PA, Diamande F, Wei SC, Ouedraogo R, Sangaré L, et al. (2011) Baseline meningococcal carriage in Burkina Faso before the introduction of a meningococcal serogroup A conjugate vaccine. Clin Vaccine Immunol 18, 435–43.

20. Maclean N, Kafatos G, Neal K, Andrews N, Cameron JC, et al. (2006) Social behavior and meningococcal carriage in British teenagers. Emerg Infect Dis 12, 950–7.

21. Bongaarts J (2001) Household Size and Composition in the Developing World. US Population Council. Available: http://www.popcouncil.us/pdfs/wp/144.pdf

22. Bediako G (2008) Ghana Living Standards Survey. Ghana Statistical Service. Available: http://www.statsghana.gov.gh/docfiles/glss5_report.pdf. Accessed 2012 July 16.

23. Randall S, Coast E, Leone T (2011) Cultural constructions of the concept of household in sample surveys. Popul Stud (Camb) 65, 217–29.

24. Classen CN, Warren R, Richardson M, Hauman JH, Gie RP, et al. (1999) Impact of social interactions in the community on the transmission of tuberculosis in a high incidence area. Thorax 54, 136–40.

25. Smieszek T (2009) A mechanistic model of infection: why duration and intensity of contacts should be included in models of disease spread. Theor Biol Med Model 6, 25.

26. Smieszek T, Fiebig L, Scholz RW (2009) Models of epidemics: when contact repetition and clustering should be included. Theor Biol Med Model 6, 11.

27. Becker NG, Dietz K (1995) The effect of household distribution on transmission and control of highly infectious diseases. Math Biosci 127, 207–19.

28. Cross PC, Johnson PL, Lloyd-Smith JO, Getz WM (2007) Utility of R0 as a predictor of disease invasion in structured populations. J R Soc Interface 4, 315–24.