**Childhood pneumonia and crowding, bed-sharing and nutrition: a case-control study from The Gambia**

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**Abstract**

Setting

Greater Banjul and Upper River Regions, The Gambia

Objective

To investigate tractable social, environmental and nutritional risk factors for childhood pneumonia.

Design

A case-control study examining the association of crowding, household air pollution (HAP) and nutritional factors with pneumonia was undertaken in children aged 2-59 months. 458 children with severe pneumonia, defined by modified WHO criteria, were compared with 322 children with non-severe pneumonia, and these groups were compared to 801 neighbourhood controls. Controls were matched by age, gender, area, and season.

Results

Strong evidence was found of an association between bed-sharing with someone with a cough and severe pneumonia (adjOR 5.1 (95% CI 3.2-8.2, p<0.001) and non-severe pneumonia (adjOR 7.3 (4.1-13.1), p <0.001)), with 18% of severe cases estimated to be attributable to this risk factor. Malnutrition and pneumonia had clear evidence of association, which was strongest between severe malnutrition and severe pneumonia (adjOR 8.7 (4.2-17.8), p<0.001). No association was found between pneumonia and individual CO exposure as a measure of HAP.

Conclusion

Bed-sharing with someone with a cough is an important risk factor for severe pneumonia, and potentially tractable to intervention, while malnutrition remains an important tractable determinant.

**INTRODUCTION**

Pneumonia is the biggest single cause of death in children globally, accounting for 15% of over 6 million deaths in children under the age of 5 years in 2013 [1](#_ENREF_1). Half of these deaths occur in sub-Saharan Africa, and The Gambia, like other countries in this region, suffers a high toll from pneumonia [2-4](#_ENREF_2). The burden of death from pneumonia needs to be substantially reduced if global child survival targets are to be met [5](#_ENREF_5).

No single intervention, including vaccination against *Haemophilus influenzae* type b (Hib) and *Streptococcus pneumoniae* [6-9](#_ENREF_6), will alone adequately address the complex challenge pneumonia presents. Rather, a multi-pronged approach is needed encompassing vaccination, improved case management, and, importantly, social, environmental and nutritional interventions, which are likely to be as important in contributing to the decline of pneumonia mortality in low and middle-income countries as they were in pre-antibiotic America [10](#_ENREF_10). Such an approach is likely to be cost-effective [11](#_ENREF_11). The objective of this study was to identify the most important of these social, environmental and nutritional factors.

Our primary exposures of interest were bed-sharing with someone with a cough, exposure to household air pollution (HAP), and feeding practices, particularly the early introduction of solids to the infant diet. Crowding is an important risk factor in a range of infectious diseases [12](#_ENREF_12), and while pneumonia has been associated with household crowding [13-19](#_ENREF_13) it is not known if bed-sharing with someone with a cough mediates this association. While HAP, mostly from cooking smoke is, like tobacco smoke [20](#_ENREF_20), believed to be an important risk factor for pneumonia [4](#_ENREF_4) few studies have directly measured exposure at the individual level. Malnutrition is associated with pneumonia but the role of interference with breast-feeding through early introduction of solids is not clear.

**STUDY POPULATION AND METHODS**

***Study setting and population***

The Gambia, in West Africa, is a resource-poor country with a population of 1.8 million. It has a high child mortality (74 children under 5 per 1000 live births), and low HIV prevalence of (< 2%) [21](#_ENREF_21), [22](#_ENREF_22). Childhood pneumonia aetiology has been historically dominated by *Streptococcus pneumoniae* and *Haemophilus influenzae* (vaccination for *Streptococcus pneumoniae* was introduced in 2009 and for *H. influenzae* type b in 1997) along with common respiratory viruses, notably Respiratory Syncytial Virus . Immunisation coverage is high [23](#_ENREF_23" \o "Scott, 2014 #1496) and one-third of men smoke [24](#_ENREF_24). A case-control study of environmental and nutritional risk factors for severe childhood pneumonia was undertaken in two sites, one peri-urban (the Greater Banjul area) and the other rural (the Basse area) (Figure 1).

***Selection of participants***

We conducted a prospective case-control study comparing severe pneumonia cases with both children with non-severe pneumonia and community controls. Cases were children aged 2-59 months with severe pneumonia who presented to the Medical Research Council (MRC) hospital in Fajara, the Edward Francis Small Teaching Hospital (EFSTH) in Banjul, or the major health centres at Fajikunda, Serekunda, Brikama and Basse between June 2007 and September 2010. We defined severe pneumonia using modified World Health Organization (WHO) criteria [25](#_ENREF_25) (cough or difficulty in breathing, plus any of the following: lower chest wall indrawing, nasal flaring, or an oxygen saturation of <90% on pulse oximetry, the last defining very severe pneumonia); non-severe pneumonia was defined as cough or difficulty in breathing plus tachypnoea (defined using WHO age-stratified cut-offs) . We excluded children with a cough of ≥2 weeks duration, or severe anaemia (Hb < 6g/dL) or wheeze on auscultation.

We selected two comparison (control) groups. Comparison Group 1 comprised children aged 2-59 months with WHO-defined non-severe pneumonia recruited from the outpatient departments of the health facilities from which the severe pneumonia cases were recruited. We frequency-matched these children to severe cases by municipal area of residence, season, age and gender. Comparison Group 2 comprised children in the community aged 2-59 months without pneumonia, individually matched to cases by neighbourhood, season, age and gender. For each case we selected a Comparison Group 2 community control as follows. From the compound (collection of related dwellings usually demarcated by a fence) of the case, a fieldworker walked at least 50 paces in a direction chosen at random (by spinning a pen [26](#_ENREF_26)). Then, at the nearest compound s/he identified a child by random selection amongst the eligible children. If consent was declined the next randomly selected eligible child was identified, if needed in the next compound. Comparison Group 2 participants were brought to the clinic to be assessed by a study doctor and were later visited at home by a fieldworker in a sequence that mirrored the exposure measurements for cases. Additionally, we selected community controls in exactly the same manner for the children selected with non-severe pneumonia (Control Group 1), allowing examination of risk factors for non-severe pneumonia (Figure 2).

***Measurement of exposure***

We measured exposures by: a questionnaire administered to the primary caregiver (including behaviour and fuel use); observation; examination in the field or clinic; and, for HAP measurement, by carbon monoxide (CO) diffusion tube attached to the child [27](#_ENREF_27). PM is the HAP exposure of interest but PM measurement devices are relatively bulky and not able to be used in small children. Therefore exposure to fine particulate matter (PM2.5)) was modeled using directly measured household-level CO, PM and fuel data coupled with personal CO data. However, validation of the model by direct measurement of PM in a subset of ambulatory children failed through the lack of correlation between directly measured and modeled PM, rendering PM exposure estimates unreliable.[28-30](#_ENREF_28). Crowding-related questions focusing on the month before enrolment established household size, how many people slept in the child’s room, where they slept, and whether the child shared a bed with anyone having a cough. We measured current and past feeding practices by questionnaire and current nutritional status by anthropometry.

***Bias and confounding***

We completed exposure measurements in the home as soon after enrolment as possible. We addressed possible recall bias resulting from the delay in interviewing cases until after discharge by asking questions at the time of admission also. We attempted to minimse information bias from questionnaires by careful training of interviewers, supervision in the field, and by blinding interviewers to participants’ disease status. Interviewees were not aware of the risk factors of most interest.

We considered potential confounders within a hierarchical framework of determinants of pneumonia [31](#_ENREF_31). Age was a likely confounder for all associations of interest. Mothers preferentially keep infants in their own bed, and on their back during cooking, and younger children were less likely to have been weaned. We addressed confounding by age through matching and during analysis, and did the same for gender, geographical area and season, which were also designated *a priori* as potential confounders. We measured a range of other social, demographic, and environmental exposures including variables related to education, hygiene, access to healthcare, and vaccination, and addressed these as possible confounders in the analysis. Similarly, we constructed an index of socio-economic status using principal components analysis (PCA) [32](#_ENREF_32), [33](#_ENREF_33).

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***Analysis, sample size and data management***

We identified risk factors for pneumonia, severe and non-severe, by comparing cases to individually matched community controls, and severe pneumonia cases were also compared to non-severe pneumonia cases to identify specific factors associated with severe disease. For each exposure we constructed a logistic regression model (conditional in the case of the individually matched analyses) that included the exposure of interest, *a priori* confounders (age, gender, geographical area and season) and any other confounders that changed the adjusted odds ratio (adjOR) by 15% or more. P-value were calculated using Wald tests, except for interactions which were tested using the likelihood ratio test (LRT). We calculated the proportion of cases attributable to bed sharing with someone with a cough (i.e. the population attributable fraction) as the product of the proportion of cases exposed to bed sharing with someone with a cough and the attributable fraction (1-1/OR, where OR compares the odds of being a case when in a household where someone had a cough, to the odds of being a case when bed sharing with someone with a cough).

The study size (at least 300 cases of severe pneumonia, 300 cases of non-severe pneumonia and 600 neighbourhood controls) was chosen so that there would be at least 80% power to detect an odds ratio of 2, at the 5% significance level, for exposures with a prevalence of between 10% and 80%. Data were double-entered and verified using an SQL database (Microsoft Corporation). Analyses were performed using Stata versions 11 and 12 (StataCorp).

***Ethics***

We obtained written informed consent for participation in the study from parents or legal guardians of cases and controls. The study was approved by the Gambian Government-Medical Research Council Joint Ethics Committee and the Ethics Committee of the London School of Hygiene & Tropical Medicine (SCC/EC1062).

**RESULTS**

*Study participants*

A total of 458 severe pneumonia cases, 322 non-severe pneumonia cases and 801 community controls were available for analysis (Figure 2). Sixty-seven percent (458/681) of severe pneumonia cases identified initially as eligible were included in the analyses, along with 69% (322/470) of non-severe pneumonia cases and 71% (801/1136) of community controls. Eligible non-participants were similar to participants with respect to age, sex, area of residence and season of enrolment with the exceptions that community control non-participation was more likely in Greater Banjul residents and among those invited to participate in the rainy season, at which time non-severe pneumonia case non-participation was also more likely, probably because of the pressure to sow and reap crops and the adverse road conditions.

Demographic, social, and environmental characteristics of the three study groups were similar (Table 1).

*Association of crowding and bed-sharing with pneumonia*

Adjusted ORs for all exposures of interest in the study were generated including age, gender, season and location in the final regression models, with few additional confounders being identified (see footnotes Tables 3 and 5). Findings related to crowding and bed-sharing are shown in Table 2, web-Table A and Table 3. There was no consistent evidence of associations between the number of people in the compound, household or house and pneumonia (severe or non-severe). There was also little evidence of an association between pneumonia and the number of people sleeping in the same room as the sick child.

Having someone coughing in the house was associated with severe pneumonia (compared to community controls (adjOR 2.5, 95%CI [1.8-3.5], p<0.001) and non-severe pneumonia (adjOR 3.1, [2.0-4.8], p<0.001)). There was strong evidence of associations between bed-sharing with someone with a cough and both severe pneumonia (adjOR 5.1 [3.2-8.2], (p<0.001) and non-severe pneumonia (adjOR 7.3 [4.1-13.1], (p<0.001), in comparison with community controls.

The odds ratio between bed-sharing with someone with a cough (asked after discharge) and severe pneumonia was stronger for cases from Basse (adjOR 10.2 [4.4-24.0], p<0.001) than for cases from Greater Banjul (adOR 3.4 [1.9-6.2], p<0.001) [p-value for the difference =0.03].

There was strong evidence of a dose-response relationship between pneumonia and a child’s exposure to someone with a cough across a gradient of exposure: for severe pneumonia (compared to community controls) the adjOR was 2.3 (1.6-3.4, p<0.001) for someone coughing in the household (but not in the same bed) and 6.2 (3.8-10.1, p<0.001) for someone coughing within the same bed. In households with someone coughing, the adjusted odds ratio for the effect of a coughing bedmate and severe pneumonia was 2.7 (1.6-4.7, p<0.001). Among cases of severe pneumonia in households with someone coughing the prevalence of bed-sharing with someone with a cough was 28%; and, assuming causality, the proportion of all severe cases attributable to this exposure was estimated to be 18%.

*Association of malnutrition with pneumonia*

Findings related to nutrition and cooking smoke-related risk factors are shown in Table 4 and Table 5. No association was found between early introduction of solids or other forms of mixed feeding and severe pneumonia. However, strong evidence was found of an association between malnutrition and both severe and non-severe pneumonia. For severe pneumonia and severe malnutrition (weight-for-height z-score (WHZ) less than -3) the adjOR was 8.7 [4.2-17.8], p<0.001, and for severe pneumonia and less severe malnutrition (WHZ -1 to <-3) the adjOR was 2.3 [1.7-3.1], p<0.001. There was evidence also of an association between severe stunting (height-for-age z-score less than -3) and severe pneumonia (adjOR 2.5 [1.2-5.2], p=0.014).

*Association of cooking smoke exposure with pneumonia*

Firewood was the predominant fuel in 84% of households. Mixed evidence was found concerning back-carrying during cooking. Weak evidence was found for an association between being carried on the mother’s back while cooking and severe pneumonia compared to non-severe pneumonia (adj OR 1.7 (1.0-3.0), p=0.04), but in comparison with controls there was evidence of a lower risk of non-severe pneumonia (adjOR 0.4 [0.2-0.7], p=0.004). No associations were found between pneumonia and measured CO exposure or modelled particular matter exposure (Table 4 and Table 5).

**DISCUSSION**

We found consistent evidence of an association between bed-sharing with someone with a cough and both severe and non-severe pneumonia. The relationship was moderately strong with adjusted odds ratios ranging from 1.7-7.3, showed a dose-response relationship, and was consistently statistically significant. There was no evidence of differential risks for severe and non-severe pneumonia and thus bed-sharing with someone with a cough was not associated with more severe disease amongst those who had pneumonia. No association was seen with mixed feeding (breast milk and other sources) in this highly breast-fed population, but a strong association between malnutrition and pneumonia was observed. The technical limitations still associated with measurement of individual-level HAP exposure, specifically the inability to directly measure PM (the exposure of interest) at individual level in young children and the lack of correlation between CO (measurable at individual level) and PM hampering modelled estimates, make the findings of no association between pneumonia and PM difficult to interpret.

The similar risks between bed-sharing with someone with a cough for non-severe and severe pneumonia may be explained in more than one way. The level of exposure to the infecting organism may not be a dominant factor determining the severity of disease, or it may be due to overlap between the severe and non-severe disease phenotypes. The clinical features of these two groups showed apparent differences in measures such as history of difficulty in breathing (89% v. 49%), and lethargy (17% v. 0%), but it is possible that there was insufficient difference between the phenotypes for a study of this size to demonstrate differences between the groups for this exposure.

The lack of evidence for risk associated with non-exclusive breast-feeding in this almost universally breast-fed population is consistent with previous studies in The Gambia [16](#_ENREF_16), [34](#_ENREF_34) but contrasts with evidence from other settings [35](#_ENREF_35). This may be due to non-breast milk contributing a relatively small part to the nutrition of mixed-fed children in the Gambian setting. The design of the present study, with its risk of recall bias for this exposure, did not allow examination of the high-risk newborn period in which early initiation of breast feeding appears highly protective [36](#_ENREF_36). There was strong evidence for a graded association between malnutrition and both severe and non-severe pneumonia. While malnutrition may be worsened by acute illness the short duration of the illness in cases enrolled in this study (median 3 days) and the lack of evidence of dehydration, which can lead to overestimation of malnutrition [37](#_ENREF_37), suggest that a substantial portion of the observed malnutrition preceded the illness. The association observed between stunting and severe pneumonia also supports the conclusion that preceding nutritional status increased the risk of pneumonia. This is consistent with the broad evidence that malnutrition is a tractable risk factor amenable to practical interventions, and that these must be promoted [38](#_ENREF_38).

A number of studies have addressed the issue of crowding as a risk factor for pneumonia. Attendance at a day-care centre has been shown to increase the risk of pneumonia [14](#_ENREF_14). There is evidence from several countries that crowding at the household level is also a risk factor for pneumonia across a spectrum of severity. A case-control study from Brazil showed an association between household overcrowding and death from pneumonia in infants [15](#_ENREF_15). Another case-control study from India showed an association between severe pneumonia and sharing of a bedroom [19](#_ENREF_19) and a cohort study from Kilifi, Kenya showed a modest association between crowding (number and proximity of siblings) and all-cause pneumonia [17](#_ENREF_17). A 1993 Gambian study of risk factors for pneumonia mortality under 2 years of age [13](#_ENREF_13) found no association with the number of co-occupants in the child’s room or in their bed, and another Gambian study found no association between bedroom co-occupancy and pneumococcal disease[16](#_ENREF_16). A protective association between bed co-occupants and pneumonia was observed in the multi-country BOSTID study [18](#_ENREF_18).

The lack of evidence in this study of a consistent association between pneumonia and the numbers of occupants in the compound, household or house, and with the density of occupation within the house can be explained in two ways: either general crowding is not a crucial factor in the development or severity of pneumonia in this context or such crowding is so uniform that a case-control study is unable to identify it as an important contributor to overall pneumonia risk. Bedroom co-occupancy was not identified as a risk factor in this study, and this is consistent with previous Gambian studies [13](#_ENREF_13), [16](#_ENREF_16) but differs from the Indian study [19](#_ENREF_19) and the Kenyan study [17](#_ENREF_17) noted above. The authors are not aware of previous studies specifically examining bed-sharing with someone with a cough.

The association observed in this study between pneumonia and bed-sharing with someone with a cough is strong and consistent, shows a dose-response relationship and is biologically plausible, supporting the conclusion that this association is real. The possibility that this finding is subject to bias, confounding, random error or a combination of these must also be considered. Although care was taken to minimise selection and information bias residual bias is likely. Participation rates of eligible children were around 70%, leaving room for bias despite the apparent similarity of participants and non-participants. Having acknowledged these limitations the observed association appears robust in our study.

Assuming causality, we estimate that 18% of severe pneumonia cases are attributable to bed-sharing with someone with a cough, which indicates the potential public health importance of this risk factor. Consequently, the feasibility of developing an intervention to reduce the exposure of children to a coughing bedmate needs to be considered. A direct health education message to avoid putting a child in the bed of a coughing person is the most obvious route to follow, but there may be other ways of achieving this goal. Designing any intervention of this kind would need a sound background knowledge of the sociological dynamics of the household and community, and poses substantial challenges. Nevertheless such an intervention, once developed, could have a substantial public health impact.

**CONCLUSIONS**

This study suggests that bed-sharing with someone with a cough is an important risk factor for severe pneumonia in young children. Further work to design and test an appropriate intervention is warranted. This study also suggests that malnutrition remains an important tractable determinant for pneumonia.

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Contributions

SH conceived the study, led the design, conduct and analysis of the study, and wrote the first draft and finalised the paper. KM, RA, PS, GG, AP and BG contributed to design and interpretation. CG, PH and ME contributed to design. KD contributed to the design, data acquisition, analysis and interpretation of IAP data. SD and KF contributed to data acquisition. JS and CB contributed to analysis and interpretation. OC, RI, BE, CO, GM, MJ, MN and TC contributed to the design and conduct of the study. All authors contributed to the writing or critical analysis of the paper.

Competing interests

RAA is an employee of GlaxoSmithKline Vaccines in Belgium and received previous grant awards for studies of bacterial diseases whilst working as an employee of the MRC Unit, The Gambia. This does not alter the authors’ adherence to the journal’s policies on sharing data and materials. No other conflicts of interest, real or perceived, are declared.

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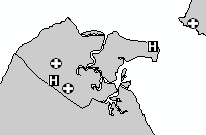
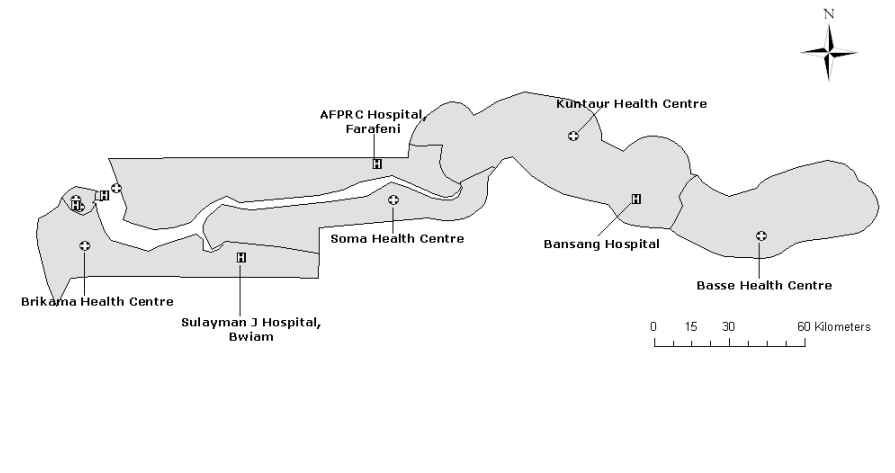
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Figure 1. Map of The Gambia, showing the study sites in the Greater Banjul and Basse areas (cross-hatched), along with hospitals and major health centres



**The Gambia**

**Essau Health Centre**

**RVT Hospital**

**Serekunda Health Centre**

**Fajikunda Health Centre**

**JFP Hospital**

Figure 2. Profile of entry into the study

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | Severe Pneumonia |  | Non-Severe Pneumonia |  | |
|  |  |
| Examined for eligibility 1834 | Examined for eligibility 765 |
| Non-eligible 1153 |  |  | | | | Non-eligible 295 |
|  | Confirmed eligible 681 |  | Confirmed eligible 470 |  | |
| Excluded 210  (Declined consent 151;  Missed 59) |  |  | | Excluded 141  (Declined consent 98;  Missed 43) |
|  | Enrolled 471 | Enrolled 329 |  | |
| Excluded 13  (Parent withdrawal 11;  Post hoc exclusion for non-eligibility 2) |  |  |  | Excluded 7  (Parent withdrawal 4;  Changed severity status 3) |
|  | Completed follow-up 458 | Completed follow-up 322 |  |
|  | | |
| Available for analysis 458 |  | Available for analysis 322 |
|  | | |
| Matched controls available for analysis 470  (Eligible approached 644; Refused 144; Withdrew 30) |  | Matched controls available for analysis 331  (Eligible approached 492; Refused 132; Withdrew 29) |
|  |  |
| Matched pairs available for analysis 454 | Matched pairs available for analysis 319 |

Table 1. Characteristics of the study participants \*

| **Characteristic** |  | **Severe pneumonia**  (N=458) | **Non-severe pneumonia**  (N=322) | Community controls  *(N=801)* |
| --- | --- | --- | --- | --- |
| Age (months) | Mean (median) | 16.7 (14) | 17.5 (15) | 17.4 (15) |
|  | IQR | 7-24 | 8-23 | (8-24) |
|  |  |  |  |  |
| Gender (%) | Female | 47 | 45 | 46 |
|  |  |  |  |  |
| Ethnicity (%) | Mandinka | 37 | 42 | 38 |
|  | Wollof | 6 | 6 | 5 |
|  | Jola | 6 | 7 | 8 |
|  | Fula | 21 | 16 | 20 |
|  | Serahule | 21 | 19 | 19 |
|  | Serere | 2 | 3 | 2 |
|  | Manjago | 2 | 1 | 1 |
|  | Other | 4 | 6 | 5 |
|  | Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Area of residence (%) | Coast | 50 | 55 | 53 |
|  | Basse | 50 | 45 | 47 |
|  |  |  |  |  |
| Education level of mother/caregiver | Mean duration (years), *median* (IQR)) | 5, *4* (0-15) | 5, *4* (0-15) | 5, *4* (0-15) |
|  | Missing data (%) | 8 | 8 | 7 |
|  |  |  |  |  |
| Education level of father | Mean duration (years), *median* (IQR)) | 8, *8* (4-11) | 8, *9* (5-12) | 8, *9* (5-12) |
|  | Missing data (%) | 59 | 58 | 55 |
|  |  |  |  |  |
| Season of enrolment (%) | Rainy | 54 | 55 | 49 |
|  | Dry | 46 | 45 | 51 |
|  |  |  |  |  |
| Caregiver handwashing episodes (%) | >5 times daily | 27 | 29 | 28 |
| Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Water (%) | Within compound | 34 | 32 | 34 |
|  | Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Bednet in place (%) | Yes | 70 | 71 | 66 |
|  | Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Cooking fuel most used (%) | Firewood | 85 | 84 | 83 |
|  | Other fuel | 12 | 15 | 14 |
|  | Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Nursery school attendance (%) | Yes | 3 | 2 | 4 |
|  | Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Distance to Health Centre (km) | Mean (IQR) | 7 (1-10) | 5 (2-7) | 6 (2-8) |
|  | Missing data (%) | 3 | 1 | 3 |
|  |  |  |  |  |
| Mother/caregiver membership of social groups (%) | Yes | 61 | 64 | 60 |
| Missing data | 3 | 1 | 3 |
|  |  |  |  |  |
| Vaccination (%) | DTP 3 doses (% all participants) | 74 | 80 | 77 |
|  | Missing data | 10 | 9 | 9 |
|  |  |  |  |  |
|  | PCV any doses | 27 | 25 | 26 |
|  | PCV 3 doses | 14 | 14 | 14 |
|  | Missing data | 16 | 21 | 17 |

\* Data were complete unless otherwise stated

Table 2. Frequency and prevalence of crowding-related exposures by severity category

| **Risk factor** | **Categories/parameter** | **Severe pneumonia, N (%)** | **Non-severe pneumonia, N (%)** | Community controls, N (%) |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| Number of occupants in compound | Median *(IQR)* | 27 *(17-44)* | 24 *(15-43)* | 25 *(15-42)* |
| Missing data | 14 (3) | 7 (2) | 23 (3) |
|  |  |  |  |  |
| Number of members of household | Median *(IQR)* | 17 *(9-31)* | 15 *(9-28)* | 15 *(9-27)* |
| Missing data | 12 (3) | 3 (1) | 20 (2) |
|  |  |  |  |  |
| Number of occupants in house | Median *(IQR)* | 6 *(4-10)* | 6 *(4-9)* | 6 *(4-10)* |
| Missing data | 12 (3) | 3 (1) | 20 (2) |
|  |  |  |  |  |
| Number of occupants sleeping in same room | Mean *(SD)* | 3.7 *(1.3)* | 3.5 *(1.2)* | 3.7 *(1.3)* |
| Missing data | 12 (3) | 3 (1) | 20 (2) |
|  |  |  |  |  |
| Number of rooms in house | Mean *(SD)* | 3.8 *(3.1)* | 3.5 *(2.6)* | 3.6 *(2.8)* |
| Missing data | 12 (3) | 3 (1) | 21 (3) |
|  |  |  |  |  |
| Crowding index (No. occupants/No. rooms) |  | 2.9 (2.2) | 2.7 (1.6) | 2.8 (1.9) |
| Missing data | 12 (3) | 3 (1) | 21 (3) |
|  |  |  |  |  |
| Person with cough in house N(%) | Yes | 147 (32) | 99 (31) | 119 (15) |
|  | No | 305 (67) | 215 (67) | 667 (83) |
|  | Missing data | 6 (1) | 8 (2) | 15 (2) |
|  |  |  |  |  |
| Bedsharing (any) | Yes | 444 (97) | 319 (99) | 777 (97) |
|  | No | 2 (0) | 0 (0) | 4 (1) |
|  | Missing data | 12 (3) | 3 (1) | 20 (3) |
|  |  |  |  |  |
| Bedsharing with someone with cough (asked post-discharge) | Yes | 125 (27) | 100 (31) | 54 (7) |
| No | 320 (70) | 219 (68) | 725 (91) |
| Missing data | 13 (3) | 3 (1) | 22 (3) |
|  |  |  |  |  |
| Bedsharing with someone with cough (asked at enrolment) | Yes | 73 (16) | 59 (18) | 52 (6) |
| No\* | 385 (84) | 263 (82) | 749 (94) |
|  |  |  |  |  |
| Bedsharing with someone who coughed before index case (asked post-discharge) | Yes | 95 (21) | 81 (25) | 54 (7) |
| No | 350 (76) | 238 (74) | 725 (91) |
| Missing data | 13 (3) | 3 (1) | 22 (3) |
|  |  |  |  |  |
| Bedsharing with someone who coughed before index case (asked at enrolment) | Yes | 51 (11) | 43 (13) | 52 (6) |
| No \* | 407 (89) | 279 (87) | 749 (94) |
|  |  |  |  |  |

\* Includes missing data: the exact number with data missing is unclear due to the coding of this question on the form and in the database, but examination of forms and the sequence of questions indicates that the proportion of missing data mirrors that for household cough (1-2%)

Table 3. Adjusted ORs\* for the association between key crowding-related exposures and severe pneumonia and non-severe pneumonia§

| **Risk factor** |  | **Severe v. non-severe pneumonia** | | **Severe pneumonia v. community control** | | Non-severe pneumonia v. community control | |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | OR (95% CI) | P-value | OR (95% CI) | P-value | OR (95% CI) | *P-value* |
|  |  |  |  |  |  |  |  |
| **Number of occupants in compound** (quintiles) | 5th (48-350) | 1.4 (0.9-2.3) | 0.18✝ | 1.0 (0.6-1.6) | 0.25✝ | 1.4 (0.7-2.7) | 0.11✝ |
| 4th (31-47) | 1.2 (0.7-1.9) |  | 1.4 (0.9-2.4) |  | 1.2 (0.7-2.1) |  |
| 3rd (21-30) | 1.7 (1.1-2.7) |  | 1.3 (0.8-2.1) |  | 0.7 (0.4-1.2) |  |
| 2nd (14-20) | 1.5 (0.9-2.4) |  | 1.4 (0.9-2.2) |  | 1.0 (0.6-1.7) |  |
|  | 1st (4-13) | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Number of members of household** (quintiles) | 5th (33-273) | 1.1 (0.6-1.8) | 0.90✝ | 0.9 (0.5-1.6) | 0.85✝ | 1.2 (0.6-2.2) | 0.74✝ |
| 4th (19-32) | 1.0 (0.6-1.7) |  | 1.0 (0.6-1.6) |  | 0.8 (0.5-1.5) |  |
| 3rd (12-18) | 1.1 (0.7-1.8) |  | 0.8 (0.5-1.2) |  | 0.9 (0.5-1.5) |  |
| 2nd (8-11) | 0.9 (0.5-1.4) |  | 0.9 (0.6-1.5) |  | 0.9 (0.5-1.5) |  |
|  | 1st (2-7) | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Number of occupants in house** | 10+ | 1.2 (0.8-1.7) | 0.38 | 0.9 (0.7-1.3) | 0.64 | 0.8 (0.5-1.2) | 0.32 |
| <10 | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Number of people sleeping in same room as participant** | 4+ | 1.3 (1.0-1.8) | 0.10 | 1.0 (0.7-1.3) | 0.76 | 0.7 (0.5-1.0) | 0.08 |
| 0-3 | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Number of rooms in house** | 4+ | 1.0 (0.7-1.5) | 0.91✝ | 1.2 (0.8-1.7) | 0.73✝ | 1.2 (0.7-1.9) | 0.79✝ |
| 2-3 | 0.9 (0.6-1.4) |  | 1.1 (0.7-1.6) |  | 1.1 (0.6-1.9) |  |
|  | 1 | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| **Crowding index** (No. occupants / No. rooms) (quintiles) | 5th (4.0-27.0)) | 0.9 (0.5-1.5) | 0.27✝ | 1.0 (0.6-1.6) | 0.91✝ | 1.3 (0.7-2.5) | 0.15✝ |
| 4th (2.8-3.9) | 1.0 (0.6-1.6) |  | 1.1 (0.7-1.8) |  | 1.1 (0.6-1.9) |  |
| 3rd (2.0-2.7) | 0.6 (0.4-1.0) |  | 1.0 (0.6-1.6) |  | 1.7 (1.0-3.0) |  |
|  | 2nd (1.5-1.9) | 0.8 (0.5-1.4) |  | 1.2 (0.7-1.9) |  | 1.6 (0.9-3.1) |  |
|  | 1st (0.2-1.4) | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Cough in house** | Yes | 1.0 (0.8-1.4) | 0.84 | 2.5 (1.8-3.5) | <0.001 | 3.1 (2.0-4.8) | <0.001 |
|  | No | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Bed-sharing\*\*** | Yes | - |  | 1.4 (0.2-8.7) | 0.69 | - (0 - .) | 0.99 |
| No | - |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Bed-sharing with someone with cough** (asked post-discharge) | Yes | 0.8 (0.6-1.2) | 0.30 | 5.1 (3.2-8.2) | <0.001 | 7.3 (4.1-13.1) | <0.001 |
| No | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **Bed-sharing with someone with cough** (asked at enrolment) | Yes | 0.8 (0.6-1.2) | 0.40 | 2.4 (1.5-3.7) | <0.001 | 3.6 (2.0-6.3) | <0.001 |
| No | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| **Bed-sharing with someone with cough,**  *where cough preceded child’s in pneumonia cases* (asked post-discharge) | Yes | 0.8 (0.5-1.1) | 0.14 | 3.4 (2.2-5.4) | <0.001 | 5.1 (2.9-8.9) | <0.001 |
| No | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| **Bed-sharing with someone with cough**, *where cough preceded child’s in pneumonia cases* (asked at enrolment) | Yes | 0.8 (0.5-1.2) | 0.29 | 1.7 (1.1-2.7) | 0.03 | 2.5 (1.4-4.5) | 0.002 |
| No | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |

\* All analyses adjusted for age, gender, season and geographical location, with no additional confounders being identified for inclusion in the models

\*\* The prevalence of bed-sharing in non-severe pneumonia cases was 100% so not all parameters could be generated in comparisons including non-severe pneumonia cases

✝ P-value for trend

§ All final regression models included >97% of observations

Table 4 Frequency and prevalence of nutrition and household air pollution-related exposure variables by participant category (severe pneumonia (N=458), non-severe pneumonia (N=322), community controls (N=801)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Exposure** | **Categories** | **Severe pneumonia, N (%)** | **Non-severe pneumonia, N (%)** | Community controls, N (%) |
|  |  |  |  |  |
| **Age introduction of solids, N (%)** | <3m | 21 (5) | 24 (7) | 48 (6) |
|  | 3-5m | 144 (31) | 107 (33) | 250 (31) |
|  | 6-11m | 207 (45) | 150 (47) | 354 (44) |
|  | 12+m | 24 (5) | 17 (5) | 46 (6) |
|  | Missing data | 62 (14) | 24 (7) | 103 (13) |
|  |  |  |  |  |
| **Age introduction of non-breast milk feeding (age non-exclusive BF)** | <1m | 174 (38) | 106 (33) | 302 (38) |
|  | 1-2m | 64 (14) | 43 (13) | 101 (13) |
|  | 3-5m | 123 (27) | 102 (32) | 225 (28) |
|  | 6+m | 77 (17) | 61 (19) | 139 (17) |
|  | Missing data | 20 (4) | 10 (3) | 34 (4) |
|  |  |  |  |  |
| **Child’s weight for height z-score** | < -3 | 54 (12) | 17 (5) | 17 (2) |
|  | -3 to <-1 | 247 (54) | 178 (55) | 312 (39) |
|  | -1 and above | 151 (33) | 123 (38) | 460 (57) |
|  | Missing data | 6 (1) | 4 (1) | 12 (2) |
|  |  |  |  |  |
| **Child’s height for age z-score** | < -3 | 28 (6) | 14 (4) | 19 (2) |
|  | -3 to <-1 | 145 (32) | 111 (34) | 302 (38) |
|  | -1 and above | 279 (61) | 193 (60) | 468 (58) |
|  | Missing data | 6 (1) | 4 (1) | 12 (2) |
|  |  |  |  |  |
| **Participant carried on mother’s back while cooking** | Most of time | 199 (43) | 123 (38) | 347 (43) |
| Some of time | 213 (47) | 161 (50) | 395 (49) |
| Never | 34 (7) | 35 (11) | 39 (5) |
|  | Missing data | 12 (3) | 3 (1) | 20 (3) |
|  |  |  |  |  |
| **CO exposure (ppm)** |  |  |  |  |
| 1st CO tube (direct) | Mean (SD) | 0.9 (1.1) | 1.0 (1.2) | 1.0 (1.3) |
|  | Missing data | 132 (29) | 58 (18) | 217 (27) |
|  |  |  |  |  |
| **PM exposure (µg/m3)** |  |  |  |  |
| Estimated exposure season of enrolment | Mean (SD) | 144 (35) | 143 (38) | 143 (38) |
|  | Missing data | 12 (3) | 3 (1) | 20 (2) |
|  |  |  |  |  |

Table 5. Adjusted ORs\* for the association between key nutritional and household air pollution exposures of interest and severe pneumonia and non-severe pneumonia

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Risk factor** |  | **Severe v. non-severe pneumonia** | | **Severe pneumonia v. community control** | | Non-severe pneumonia v. community control | |
|  |  | OR (95% CI) | P-value | OR (95% CI) | P-value | OR (95% CI) | P-value |
|  |  |  |  |  |  |  |  |
| Age introduction solids (months) | <3 | 1 | 0.41✝ | 1 | 0.83✝ | 1 | 0.90✝ |
| 3-5 | 1.7 (0.9-3.2) |  | 1.2 (0.6-2.5) |  | 0.7 (0.3-1.7) |  |
| 6-11 | 1.7 (0.9-3.2) |  | 1.3 (0.6-2.6) |  | 0.8 (0.3-1.9) |  |
|  | 12+ | 1.8 (0.7-4.3) |  | 1.0 (0.4-2.5) |  | 0.8 (0.3-2.4) |  |
|  |  |  |  |  |  |  |  |
| Child’s weight for height z-score | < -3 | 2.6 (1.4-4.7) | 0.008✝ | 8.7 (4.2-17.8) | <0.001✝ | 3.7 (1.5-9.5) | <0.001 |
| -3 to <-1 | 1.1 (0.8-1.6) |  | 2.3 (1.7-3.1) |  | 2.5 (1.7-3.6) |  |
| -1 and above | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| Child’s height for age z-score | < -3 | 1.4 (0.7-2.8) | 0.54✝ | 2.5 (1.2-5.2) | 0.009✝ | 1.9 (0.7-5.2) | 0.18✝ |
| -3 to <-1 | 0.9 (0.7-1.3) |  | 0.8 (0.6-1.1) |  | 0.8 (0.6-1.2) |  |
| -1 and above | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| **Carried on mother’s back while cooking** | All/most of time | 1.7 (1.0-3.0) | 0.04 | 0.7 (0.4-1.2) | 0.17 | 0.4 (0.2-0.7) | 0.004 |
|  | Sometimes | 1.4 (0.8-2.3) | 0.23 | 0.6 (0.3-1.0) | 0.06 | 0.5 (0.3-0.9) | 0.03 |
|  | Never | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **CO exposure (ppm)** | 5th (1.49-10.35) | 0.7 (0.4-1.3) | 0.63✝ | 0.8 (0.4-1.5) | 0.80✝ | 1.1 (0.5-2.3) | 0.99✝ |
| 1st CO tube (direct), (quintiles) | 4th (0.75-1.48) | 0.8 (0.5-1.3) |  | 1.0 (0.6-1.8) |  | 0.9 (0.5-1.9) |  |
|  | 3rd (0.46-0.74) | 0.8 (0.5-1.4) |  | 1.0 (0.5-1.7) |  | 1.0 (0.5-1.9) |  |
|  | 2nd (0.20-0.45) | 0.7 (0.4-1.1) |  | 0.8 (0.4-1.4) |  | 1.0 (0.5-1.9) |  |
|  | 1st (0-0.19) | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |
| **PM exposure (µg/m3)** | 5th(166-371) | 0.9 (0.6-1.5) | 0.70✝ | 1.0 (0.6-1.6) | 0.48✝ | 0.9 (0.5-2.3) | 0.74✝ |
| Estimated exposure season of enrolment (quintiles) | 4th(150-165) | 1.2 (0.7-2.0) |  | 1.2 (0.7-2.0) |  | 1.3 (0.7-2.3) |  |
|  | 3rd(140-149) | 1.0 (0.6-1.6) |  | 0.8 (0.5-1.4) |  | 1.0 (0.6-1.9) |  |
|  | 2nd (115-139) | 0.9 (0.5-1.4) |  | 0.9 (0.6-1.5) |  | 0.9 (0.5-1.6) |  |
|  | 1st (54-114) | 1 |  | 1 |  | 1 |  |
|  |  |  |  |  |  |  |  |

\* All analyses adjusted for age, gender, season and geographical location. In addition analyses of estimated CO exposure were adjusted for distance to the nearest health centre in models for severe pneumonia versus non-severe pneumonia.

✝ P-value for trend

§ All final regression models included >98% of observations with the exceptions of ‘Age of introduction of solids’ (89%) and ‘CO exposure’ (76%)