Title: Household environment and behavioral determinants of respiratory tract infection in infants and young children in northern Bangladesh

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Abstract

Objectives: Respiratory tract infections (RTI) are one of the leading causes of under-five mortality in Bangladesh. Solid biomass fuels are the main source of domestic fuel used for cooking across Bangladesh, leading to smoke and pollution exposure in the home. This paper aims to identify risk-factors for RTI among children aged under five years in Bangladesh with a particular focus on the household environment, fuel use and cooking practices.

Method: A cross-sectional household-health survey was carried out in 321 households in northern Bangladesh. The survey included care-giver interviews on cooking practices, child health and household behaviors during cooking. Health status of the youngest child (under 5 years) from each household was recorded through maternal interviews, medical diagnosis, and assessment of biomarkers (c-reactive protein (CRP), hemoglobin) from finger-prick blood samples. Anthropometric status (weight, height) was recorded.

Results: Children who spent ≥30 minutes/day within five feet of the stove during cooking had a significantly increased risk of moderate/severe RTI compared with children spending <30 minutes/day close to the stove (OR=2.15, 95%CI: 1.20-3.86, p=0.01), independent of socio-economic status (SES), biomass fuel type (wood, dung, plant-derived, compressed risk husks), child age, anthropometric status, CRP and hemoglobin.

Conclusions: In environments with a heavy reliance on solid biomass fuels, the amount of time a child spends near the stove during cooking may be an important risk for RTI. These novel findings from Bangladesh warrant further investigation of mother-infant behaviors during cooking in relation to child health, to ascertain whether the association is likely to be causal.

Keywords: Indoor air pollution, child health, acute respiratory tract infections, behavior, cooking practices.

BACKGROUND

Acute respiratory infections are the most significant cause of death among children under the age of five years globally, causing almost 20% of deaths annually (Tomaskovic *et al,* 2004; Rudan *et al,* 2004; Wardlaw *et al,* 2006; CHERG-WHO 2013). As reported in 2012, lower respiratory tract infections are the leading cause of mortality in developing countries (Liu *et al,* 2012). In Bangladesh, respiratory infections are the fourth leading cause of death among children under the age of five years, accounting for 13% of all deaths (Zaman *et al,* 1997; Brooks *et al,* 2010; WHO 2013).

International classification of diseases and related health problems defines acute respiratory infections (or ARIs) as infections of the airways, including upper respiratory tract infections (from nasal cavity to larynx), as well as tracheitis, and bronchial infections, or more commonly termed as lower respiratory tract infections (WHO, 1993).

Solid biomass fuels are used as a source for domestic energy by approximately half of the world's population (Salvi and Barnes, 2009). Fuel classification based on 'cleanliness and efficiency of the fuel', suggests solid biomass fuels as a great source of combustion by-products such as particulate matter, resulting from inefficient and often incomplete burning process (Smith *et al,* 1994; WHO, 2006). The adverse health effects of household fuel pollution exposure most severely impact in developing countries where over 75% of the rural population relies on solid biomass fuels for energy (Reddy *et al,* 1997; Smith and Mehta, 2003). Exposure to household fuel pollution has been linked with more frequent and greater severity of respiratory infections (Smith *et al,* 1994; Ellegård, 1996; Perez-Padilla *et al,* 1999; Zhong *et al,* 1999; Balakhrisna *et al,* 2002; Dasguspta *et al* 2006; Ezzati and Kammen, 2001a; Mishra *et al,* 2005) and chronic systemic inflammation in children. In adult women, household fuel pollution has been associated with chronic obstructive pulmonary disease (COPD) (Smith and Mehta, 2004) and lung cancer (Kleinerman *et al,* 2002; Smith and Mehta, 2004). Household fuel pollution contains solid and gaseous compounds which can damage the respiratory system. Particulate matter with a diameter less than 2.5μmin (PM2.5) can penetrate deeply into the alveoli, and deposits can cause pulmonary irritation as well as direct tissue damage (USEPA, 1997). Inhaled carbon monoxide binds readily to hemoglobin forming carboxyhemoglobin in the blood, which interferes with oxygen transport causing hypoxia and cellular damage, and even death. Young children have under-developed pulmonary function which makes infants potentially more vulnerable to tissue damage from chronic pollution exposure (Chan *et al,* 1989; Palta *et al,* 2007). Low birth weight children are at particular risk of pulmonary damage from household fuel pollution exposure because of their very under-developed immune defenses and immature and narrow airways (Chan *et al,* 1989; Palta *et al,* 2007).

In resource-poor communities, solid biomass fuels are often the only affordable or available form of fuel. Burning of fuels such as dung, dried plant and vegetable materials leads to household fuel pollution, and the adverse health impact is heightened by the confounding factors of poverty and undernutrition (Balakrishnan *et al*, 2014).

The effectiveness of technological interventions such as stove interventions to reduce household pollution and personal exposure levels has been the subject of considerable research (Anenberg *et al,* 2013). However the problem remains unsolved, due to the complexity of what determines the extent of personal pollution exposure. The degree of personal exposure to pollution is affected by an individual's age, gender and cooking behavior (Ezzati *et al,* 2000: Jiang and Bell, 2008, Gordon *et al,* 2014). Exposure to household pollution during cooking is, in turn, affected by the form of stove used; time spent in the close vicinity of the stove; years spent cooking with solid biomass fuels; household ventilation and the presence of a flue for the emission of fuel smoke (Boadi and Kuitunen, 2005; Tun *et al,* 2005; Dasgupta *et al,* 2006; Diaz *et al,* 2007; Pokhrel *et al,* 2005).

The association between child respiratory health and household environmental and behavioral characteristics has been examined in a number of studies (Tun *et al,* 2005; Barnes, 2014). A recent study from Bangladesh reported on child behaviors, maternal cooking times, together with ARI incidence among children from 0-18 years of age at monthly intervals for 6 months (Azad *et al,* 2014). The study aimed to estimate ARI incidence in children using maternally reported cooking times per day. However the work did not directly examine child behavioral patterns and the closeness of a child to the fire during cooking but simply used overall times engaged in cooking activities by mother as proxy for a child exposure. Tibetan study examined the ARI outcome in children aged under 5 years and reported on cooking practices, and ARI incidence before and after 6-month educational intervention. This study design aimed to evaluate the effectiveness of a behavioral change. Unfortunately, despite a very informative exploration of attitudes and cooking behaviors in communities this study relied on maternally reported ARI incidence in children and also lacked actual indoor air pollution measures (Tun *et al,* 2005). Kilabuko and the team measured indoor pollution levels and health outcomes of children and women in Tanzania. Risk of respiratory tract infection was almost 6 times higher in children than in men and non-cooking women combined (OR: 5.5, 95% CI 3.6 to 8.5) (Kilabuko *et al,* 2007). However, this study relied on self-reported health outcomes of ARI and despite detailed measured pollution data the paper did not address the association between pollution levels and health outcome. A study in Guatemala installed improved cleaner-burning stoves in households in a rural area and reported a 46% decrease in the prevalence of acute lower respiratory tract infections as a result of the intervention (Harris *et al,* 2011). A study in Zimbabwe examined the prevalence of acute respiratory infections among pre-school children in households using electricity compared with household cooking with biomass fuels (Mishra, 2003). However, the data on health outcomes were self-reported with

no pollution measurements. Many health studies have examined the respiratory function of women (as main household cooks) using clinical measures such as lung function tests (such as spirometry or peak air flow tests, e.g. Kurmi *et al,* 2013: Alim *et al,* 2014). An increased risk of physician-diagnosed chronic bronchitis (OR 5.94 (95% CI: 1.02 to 34.45, $p<0.047$) and severe bronchial obstruction diagnosed by peak expiratory flow rate (OR 4.54 (95% CI: 2.10 to 9.82, $p<0.001$) was associated with households using solid biomass compared to households cooking on gas (Alim *et al,* 2014). None of the studies accurately measured the extent of child pollution exposure and associated health outcomes.

Fewer studies have reported associations between the health outcomes of young children and household air pollution levels. Many studies addressing the effect of household fuel pollution on respiratory tract infections use hospital-based data rather than community based studies (Dennis *et al,* 1996; Perez-Padilla *et al,* 2001; Barnett *et al,* 2005; Pokhrel *et al,* 2005; Elledge *et al,* 2012).

This paper aims to examine the association between respiratory tract infections among children with household environment and behaviors influencing exposure to pollution from cooking. In particular, the paper aims to examine the association between the time a child spends in close proximity to the fire during cooking as an exposure risk for respiratory tract infections, in order to identify mother-child behaviors as potential targets for interventions or education.

METHODS

Study setting

A cross-sectional household and health survey was carried out in northern Bangladesh in October 2005. The study was conducted in the district of Rangpur, north-west Bangladesh with the study area covering parts of the district town of Saidpur and some of the outlying villages of Parpatipur. Bangladesh ranks 146th out of 186 countries in the Human Development Index (UNDP, 2013). Considerable advancements in child survival in Bangladesh have been achieved through extensive vaccination and child nutritional schemes and a 72% reduction in under-five mortality has been observed since 1993. However, the under-five mortality rate still remains high at 41 deaths per 1000 children in 2012 (You *et al,* 2014). Respiratory tract infections remain as the leading infectious cause of child mortality. Indoor air pollution is currently a major environmental and health challenge in Bangladesh.

Participants

The study households were selected from five areas in the Rangpur district using Lot Quality Assurance Sampling (LQAS) technique, as according to Valadez *et al* (2002). For the broader environmental and household survey 125 households were identified from each of the five areas and invited to participate (maximum total of n=625). For the child health and respiratory health survey, only households with a child under the age of five years were invited to participate. In case of multiple children aged under five years being present in one family, only the youngest child was included in the survey. Child age was extracted from immunization cards provided by mothers. From the 625 households, a total of 321 children under the age of five agreed to participate and were included in the survey.

Details of the study were explained to the parents and children participating in this study and informed consent was obtained in writing or thumb print from parents of each child. All families were explained that they had the right to withdraw from the study at any point.

Ethical approval for this study was granted by the Bangladesh Medical Research Council (BMRC/ERC/2004-2007/115) and Loughborough University Ethical Advisory Committee (R05/P22).

Household interviews

Trained Bangladeshi female research assistants interviewed the primary care-giver, usually the mother, in each household. Information was collected on socio-economic indicators including a household possession index; parental education and occupation. Data were also collected on variables considered to influence indoor air pollution, including the housing material (for ventilation through walls); stove location; stove type; and cooking and fuel-use practices.

The household questionnaire was based on a format previously used in the Philippines for an indoor air pollution survey project by Winrock International and modified to fit the Bangladeshi settings after pre-testing.

Household socio-economics status (SES) was determined on the basis of item ownership of household items (total of 24 items), housing material and sanitation. The household possession index was then calculated following the principal component analysis applied in the Bangladesh Demographic Health Survey 2004 (Rutstein and Johnson, 2004) and 2007 (Mitra *et al,* 2007). The household possession score is commonly divided into quintiles as an indicator of household SES and has been shown to be more closely associated with child nutritional status than the poverty index in Bangladesh (Mohsena *et al*, 2010) and in Côte d'Ivoire (Rohner *et al,* 2012). Sub group sizes for the original five SES quintiles in the study sample were as follows: 1(n=70), 2 (n=65), 3 (n=62), 4 (n=69), 5 (n=54). In the present paper, SES quintiles were converted into a binary variable in order to overcome the problem of small number of cases of RTI in each quintile. The lowest three quintiles (1 to 3) were grouped into low SES and the highest two quintiles (4 and

5) were combined to form the high SES category. An additional analyses excluding the middle quintile of SES (SES-3) in low (1-2) versus high (4-5) SES analysis produced the same result (results not shown). The former categorization of SES (low (1-3) vs. high (4-5)), using all quintiles was therefore kept in the analyses in order to maximize the sample size

As household pollution is influenced by the level of ventilation through walls, the building materials of walls in each household were included in the analysis. Thatch, wood and bamboo walls were grouped together as having relatively high ventilating nature and corrugated iron, brick or clay walls were combined as low ventilating.

Cooking and fuel use

Almost all households cooked using biomass fuels namely wood; dried animal dung; coconut husks; dried plant-derived materials; sawdust and *golden*. Only two households used gas and these were excluded from the study sample due to insufficient numbers to analyze this as a separate category of a non-polluting fuel. *Golden* was a local fuel made by compressing rice husk residues to improve the burning capacity. Logs made of compressed rice husks were readily available in the local markets at an affordable price. Households cooked inside the houses either in a separate kitchen building, or a kitchen room or a kitchenette partitioned off by a low wall, or outdoors. For the purpose of statistical analyses four categories of fuels were used: 1) wood; 2) golden; 3) coconut and plant-derived material including thatch and sawdust; 4) dung.

Households used chimneyless stoves made of mud or clay, with one or two holes over which cooking pots were held. Stoves were either portable (could be moved) or fixed to the ground indoors or outdoors.

The presence of a child by the stove during cooking was determined by asking the parent whether a child was present during cooking within 5 feet or more than 5 feet away from the stove.   The amount of time a child spent by the stove was recorded as following categories: Absent (0min), 1<30 min, 30≤60 min, more than 60 minutes.

Child health assessment

Maternally reported child health: As part of the interview household mothers were asked to report on runny nose, sore throat, cough, fever and specific symptoms of respiratory tract infection, asthma, fast breathing and lower chest in-drawing, as well as diarrhea experienced by their child in the previous two weeks.

Respiratory tract infection diagnosis: Local medical physicians working alongside the interviewers examined those children who were reported to have symptoms of illness other than a runny nose or sore throat. The

physicians examined children for symptoms of respiratory tract infection and any other illnesses (e.g. skin and eye infections, pallor, rash, signs of dehydration and malnutrition) and measured the child's breathing rate per minute, checked for chest sounds and wheezing using chest auscultation, measured body temperature (^{0}C) and noted symptoms of chest in-drawing and labored breathing, following World Health Organization recommendations for the diagnosis of respiratory tract infections (WHO, 1991). Acute respiratory infections are commonly classified according to the severity of the symptoms: mild, moderate and severe (WHO, 1984; Pio, 2003):

- Mild: Cough, with sore throat, runny nose and possibly ear discharge for over two weeks in length, no fast breathing or chest in-drawing (as defined by Campbell *et al,* 1989).
- Moderate: Cough and fast breathing* but no chest in-drawing.
- Severe: Cough, fast breathing and chest in-drawing, or stridor at rest.

* Age-specific definitions for fast breathing: under 2 months of age: over 60 breaths per minute (or bpm); 2 to 12 months of age: over 50 bpm; >12 to 59 months of age: over 40 bpm.

Physician-diagnosed reports on respiratory tract health were then categorized into normal (no symptoms of respiratory infections), mild, moderate and severe, following the WHO criteria. For the purpose of statistical analyses a binary variable of RTI status was created: no RTI (healthy or mild symptoms of respiratory infection) versus RTI (combined moderate and severe respiratory tract infection cases).

Anthropometric measures were taken with children wearing light clothing (shorts and vest) and no shoes. Height (mm) was measured using height boards; recumbent length was measured for infants under 2 years of age. Weight was measured to the nearest 100g (Salter, UK). Dates of birth were obtained by immunization cards (if available). If no record of birth date was available mothers were asked to report on the season of birth and the age in years in order to maximize the accuracy of birth date detail. Z-scores of height-for-age, weight-for-age and weight-for-height were calculated using the WHO Anthro software (WHO, 2006; http://www.who.int/childgrowth/en/).

Hemoglobin and c-reactive protein: A finger-prick blood sample was collected from the child's middle finger after cleaning it with an alcohol wipe using an automatic sterile lancet. Hemoglobin concentration was assessed by placing a blood drop into a microcuvette and inserted into a portable hemoglobinometer (HemoCue 201+, UK).

A further blood spot was collected on to Whatman 3 filter paper (Whatman, UK). Two spots of blood were collected for each individual, in order to account for inter-spot variation (Mei *et al,* 2001; McDade *et al,* 2003). Dried blood samples were analyzed for c-reactive protein (CRP) in the UK using the standard ELISA assay (DAKO, UK) and protocol of McDade *et al,* (2004). The cut point for normal and elevated CRP

(normal≤5μg/L, elevated>5μg/L) was applied (Pearson *et al,* 2003). As the study sample consisted of young children from an area of the world where a highly stimulated immune response might be expected the cut-off point was raised from 3μg/L (appropriated by Pearson *et al,* 2003) to 5μg/L.

Statistical analysis

Statistical analyses were performed using Statistical Package for Social Sciences version 21. Univariate analyses were carried out using independent sample *t*-tests and Pearson's Chi-square tests. The sample sizes for the univariate analyses were as follows: SES (n=321); cooking location (n=321); fuel type (n=318); housing wall material (n=321); stove type (n=317); child age (n=319); Sex (n=321); smoking household member (n=321); anthropometric z-scores; number of children in household below the age of 5 years (n=321); child present during cooking (n=321); and time child spends by the stove/day (n=297).

Binary logistic regression was performed using covariates with a significance value of p<0.05 from the univariate analyses, in order to identify the determinants of respiratory tract infection. Child age, anthropometric status and sex were controlled for as covariates in order to account for known influences on susceptibility to RTI (Nair *et al,* 2013; Hasan *et al,* 2014). For the purpose of logistic regression time child spends by the stove was grouped into <30min and ≥30min. 30min was considered as the natural cut-off point for the binary variable, based on the univariate analysis. The final sample size for the regression analysis was n=265. The validity of the model applied was tested using likelihood tests (281.9, Cox & Snell R^2= 0.087, Nagelkerke R^2=0.127). The Hosmer and Lemeshow test was insignificant (X^2=3.061, p=0.930).

RESULTS

The ethnic origin of the sample was mixed: Bangla (two-thirds) and Urdu-speaking Biharis (one-third). The study sample primarily relied on solid biomass fuels which were collected from surrounding areas or bought for domestic cooking and heating. Most households used simple traditional stoves made of clay, with a slight tendency towards the use of the fixed model by households of higher SES. Maternal smoking was very uncommon in this population (0.3% of mothers). Smoking by other household members was uncommon inside the house as men, who were the main smokers, and spent long hours working away from home.

The overall prevalence of moderate/severe respiratory tract infection in the sample was 23.7%. Table 1 shows the univariate associations between children with respiratory tract infection (moderate/severe) or

those without RTI and household SES (high versus low), household cooking practices (cooking location , fuel type, household wall material, stove type), child age, sex, smoking household member, anthropometric z-scores, number of children under the age of 5 years present in a household, c-reactive protein and hemoglobin concentration, the presence of the child by the stove during cooking and the time a child spends by the stove/day, estimated by the cook (mother).

Table 1 shows that children with RTI were significantly younger than those without RTI group (23.1 months vs. 27.8 months, t=2.299, p<0.05); had significantly lower hemoglobin concentration (t= 2.581. p<0.01); were also more likely to be from families with one child than families with more than one child (X^2=8.329); and were significantly more prevalent in households with low SES vs. high SES (27.8% versus 17.1%, X^2=4.811. p<0.05). Those children who spent more than 30≤60 minutes or over an hour (>60min) per day within 5 feet away from the stove were more likely to have been diagnosed with moderate or severe RTI (33.8%, 30.3% respectively) by the examining doctor compared to those spending less than 30 minutes by the stove (X^2=8.498, p<0.05). Children who were reported by the mother as being present by the stove during cooking (irrespective of time duration), were not significantly more likely to have RTI (X^2=3.069. p=0.08)

There was no difference in stove type, choice of fuel type, household wall material or cooking location between children with RTI and without RTI. Similarly, child sex, anthropometric status (weight-for-height z-score), smoking of a household member and c-reactive protein levels did not differ between the two groups.

Logistic regression: Variables that were associated with the presence of RTI in the univariate analysis were entered into the binary logistic regression analysis whilst controlling for child age (months), anthropometric status and sex. Table 2 presents the results of the logistic regression analysis showing that children who spent ≥30 minutes in the proximity of the stove had an odds ratio of 2.15 (95% CI: 1.1 to 3.9, p=0.01) for moderate or severe respiratory tract infections compared to children who spent less than 30 minutes a day near the stove. When time spent near the stove was included in the logistic regression model, child age was no longer significantly associated with the presence of RTI. No other variables were significantly associated with the presence of RTI.

DISCUSSION

This study reports a novel finding that the length of time a child spends in close proximity to a stove during cooking is significantly associated with the risk of acute respiratory infection. Despite the extensive

literature on health impact of indoor air pollution and wide range of intervention studies that have been carried out most work until now has focused on reducing pollution levels, improving cooking efficiency and ventilation, keeping children away from the fire, community work on raising awareness on adverse health impact of household fuel pollution exposure (Barnes *et al,* 2004; Dasgupta *et al,* 2006; Barnes *et al,* 2014). Studies have reported on child health outcomes but to our knowledge, no studies so far have linked the RTI to actual time period a child is physically exposed to fuel pollution.

This study was conducted in a population with a heavy reliance on solid biomass fuels for cooking (98%). The use of a traditional stove design without any flue, coupled with the almost universal use of biomass fuels, contribute to the risk of respiratory morbidity. Passive tobacco smoke exposure was minimal in this population and therefore unlikely to contribute to the incidence of respiratory infection among children. The prevalence of acute respiratory tract infections among the children in the study was over 23%, with 72.5% of all RTI cases diagnosed within lower socio-economic status households. The prevalence of RTI in this study is consistent with the national prevalence of RTI of 20.8% reported by the Bangladesh Demographic Health Survey in 2004, contemporary to our study (BDHS, 2004).

The results of this study identified larger family size, younger child age, lower socio-economic status, lower hemoglobin level and greater time (≥30 minutes) spent by the stove, as being associated with RTI in univariate analyses. Interestingly the logistic regression analysis revealed that the behavioral factor - time spent by the stove - was the only significant risk factor for respiratory tract infection after controlling for other variables. A child who spent 30 minutes or more per day in the proximity of the stove had double the risk of respiratory tract infection (OR: 2.1, 95% CI: 1.1 to 3.9, p=0.01), independent of age, sex, number of young children in a family and anthropometric status. Our study did not find a sex difference in the prevalence of respiratory tract infections suggested by some studies (Nair *et al,* 2013: Hasan *et al,* 2014). However, Devakumar *et al* (2014) also reported no gender association between personal pollution exposure and respiratory health outcome in children. In the latter study, the lack of gender effect was explained by the fact that all infants and young children were supervised by adults, independent of gender, resulting in the uniform exposure to fuel pollution and related health outcome (Devakumar *et al,* 2014).

The results of the univariate analysis showed a lower hemoglobin concentration among children with respiratory tract infection but this effect was not significant in the logistic regression analysis. Low hemoglobin concentration is likely to increase general susceptibility to infections, and low hemoglobin has been reported as a risk factor for respiratory tract infections in developing countries (Hussani *et al* 2014). However, evidence from tobacco studies suggests that (in extreme cases) smoke exposure can lead to higher hemoglobin levels through systemic adaptation to hypoxia.

Our results suggest that the time spent by the stove may be a simple but potential important indicator of exposure to household fuel pollution. The presence of a child by the fire alone does not reliably explain the health outcome and a short exposure (<30min) did not appear to impact the prevalence of RTI in our sample. Children spending 30 minutes or more by the stove had double the risk of respiratory tract infections compared to those spending less than 30 minutes by the stove. This would indicate that a reduction of time spent in the vicinity of the stove may help to prevent respiratory infections in this sample.

A study in Kenya has however reported on a negative concave function of an exposure-response relationship between personal exposure and respiratory health outcome (Ezzati and Kammen, 2001b) where the prevalence of respiratory tract infections did not increase with particulate matter levels higher than 2000μg/m^3. It may be that remaining very close to the fire frequently for a long time can lead to chronic exposure in which the severity of exposure no longer has effect on the severity of symptoms of acute respiratory tract infections. This should be noted when designing interventions in areas communities where household fuel pollution is a community-wide health danger.

This study found no association between respiratory tract infections and the type of fuel used by the household; this may because the all households included in the analysis used some form of solid biomass fuel all of which generate smoke pollution. Similarly, the location of cooking (indoors or outdoors) was not associated with respiratory tract infection in children. Although surprising this may be because children spent time near the stove even when the cooking was performed outside, and because outdoor stoves tended to be placed in a courtyard next to the house, often near doorways. Similar findings have been reported by Devakumar *et al* (2014).

Further research is needed on the best indicators of child exposure to household fuel smoke (Clark *et al,* 2013). The precise effects of household fuel pollution can be difficult to pinpoint as smoke readily spread from one household to another in areas with high density housing and intense overcrowding within households. In the study area, in common with much of Bangladesh, houses were typically small with only one or two rooms per household (Dasgupta *et al,* 2006: Devakumar *et al,* 2014). Few studies have examined the effect of ventilation within households on health outcomes effectively (Mahalanabis *et al,* 2002). Studies have indicated that particulate matter *levels* measured in household kitchen could not reliably be used as a proxy for personal exposure, especially in the case of children (Baumgartner *et al* 2011; Balakrishnan *et al*, 2014; Azad *et al,* 2014). A detailed investigation of the time-activity of household members with personal pollution exposure measures would improve the estimate of morbidity due to household fuel pollution exposure (Gordon *et al,* 2014). The interaction between poverty and household fuel pollution exposure may also give rise to more severe respiratory health outcomes (Balakrishnan *et al*, 2014). Better understanding of the relationship between an exposure and health effect of an intervention

aimed to reduce household fuel pollution, and the role of behavioral determinants, is crucial in order to effectively reduce the health impact of household fuel pollution (Clark *et al,* 2013).

The best way to tackle air pollution is likely to be through an effective community campaign and awareness-raising involving all levels of decision-making in order to improve the health of the poor and marginalized populations. Inter-disciplinary effort including a wide range of specialties to design a simple, sustainable, but effective way to reduce is needed to tackle household fuel pollution exposure in communities with a high reliance on solid biomass fuels.

This study has some limitations due to the cross-sectional nature of the study design relying on a single time point of assessment. The association between RTI and spending ≥30 minutes by the stove during cooking requires further investigation for possible cause and effect. Parents were asked about the habitual behavior of their child, rather than behaviors on one particular day, and this should reduce the possibility that children stayed by the fire for longer when they were unwell. In addition, respiratory infections were diagnosed by clinicians via chest auscultation and physical examination but were not confirmed by laboratory testing, and therefore the causative agents for respiratory infections are not known. Measures of lung function, such as spirometry, were not feasible for children under the age of five and therefore were applied in this survey. The study would also have benefited from the quantitative assessment of household fuel pollution indicators such as carbon monoxide and particulate matter. However, these measures would not necessarily equate with individual levels of exposure to fuel pollution among children

A strength of this study is the detailed examination of household and behavioral factors in relation to respiratory health in young children, with a particular emphasis on maternal-child behavior, as well as cooking practices and fuel use. Many prior studies in developing countries have used data on respiratory infections from hospital or clinic samples. Such studies lack the contextual details of household, demographic, socio-economic and behavioral variables associated with household fuel pollution exposures and risk of ARI (Dennis *et al,* 1996; Perez-Padilla *et al,* 2001; Barnett *et al,* 2005; Pokhrel *et al,* 2005; Elledge *et al,* 2012). Those studies which reported on respiratory health outcomes in relation to household fuel exposure often rely on self-reported RTI (e.g. Kilabuko et al, 2007; Mishra, 2003), despite effective reporting on potential determinants of personal exposure (e.g. Boadi and Kuitunen, 2005; Dasgupta *et al,* 2006; Diaz *et al,* 2007; Pokhrel *et al,* 2005). Further studies of maternal-child behaviors and household determinants of household fuel pollution exposure together with a reliable assessment of child health are needed to ascertain whether the association between time spent near the stove and increased risk of respiratory infection is likely to be causal.

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Table 1: Univariate analysis of factors associated with respiratory tract infection among children under the age of five years in the study sample

Variable	Sub-category	non-RTI (n=245)		RTI (n=76)		Total row n	Statistical test
		%	n	%	n		
Socio-economic status quintile (n=321)	Low SES (1-3)	72.2	143	27.8	55	198	X^2=4.811, p<0.05
	High SES (4-5)	82.9	102	17.1	21	123	
Location of cooking stove (n=321)	Indoors	75.0	126	25.0	42	168	X^2=0.342, p=NS
	Outdoors	77.8	119	22.2	34	153	
Fuel type (n=318)	Wood	79.7	110	20.3	28	138	X^2=4.898, p=NS*.
	Compacted rice husks (*Golden*)	81.0	51	19.0	12	63	
	Coconut husk, thatch and plant-derived material	68.5	50	31.5	23	73	
	Dung	70.5	31	29.5	13	44	
Housing wall material (n=321)	Thatch, wood, bamboo	72.5	121	27.5	46	167	X^2= 2.883, p=NS
	Corrugated iron, iron , brick, clay	80.5	124	19.5	30	154	
Stove type	Portable	74.8	110	25.2	37	147	X^2=0.643, p=NS
	Fixed	77.1	131	22.9	39	170	
Child age (months) (n=319)	Mean ± SD	27.8 ±15.6	245	23.1±14.3	76	321	t=2.299, p<0.05
Sex (n=321)	Male	79.3	134	20.7	35	169	X^2=1.737, p=NS
	Female	73.0	111	27.0	41	152	
Smoking household member (n=321)	No	79.2	137	20.8	36	173	X^2=1.706, p=NS
	Yes	73.0	108	27.0	40	148	
Anthropometric status	Mean weight-for-age z-score (n=302)	-1.964 ± 1.090	226	-1.932 ± 1.400	76	302	t= -0.205, p=NS
	Mean height-for age z-score (n=298)	-1.996 ± 1.307	224	-1.996 ± 1.307	74	298	t= 0.336, p=NS
	Mean Weight-for-height z-score (n=290)	-1.180 ± 1.060	217	-1.198 ± 1.131	73	290	t= 0.121, p=NS

No of children in household below the age of 5 years (n=321)	1	80.3	192	19.7	47	239	X^2=8.329, p<0.01
	>1	64.6	53	35.4	29	82	
C-reactive protein (n=282)	Normal (≤5ug/L)	75.0	177	25.0	59	236	X^2=0.283, p=NS
	Elevated (>5ug/L)	67.4	31	32.6	15	46	
Hemoglobin concentration (n=286)	Mean (g/L)	104.9 ± 12.8	212	100.0 ± 16.7	74	286	t= 2.581, p<0.01
Child present during cooking (n=321)	No	86.0	43	14.0	7	50	X^2=3.069, p=0.08
	Yes	74.5	202	25.5	69	271	
Time child spends by the stove/day (n=297)	0 min (child absent)	86.0	43	14.0	7	50	X^2=8.498, p=0.05
	1<30 min	79.5	101	20.5	26	127	
	30≤60 min	66.3	53	33.8	27	80	
	>60 min	70.0	28	30.0	12	72	

*Two households using gas cooking fuel excluded.

Table 2: Binary logistic regression analysis of determinants of respiratory tract infection among Bangladeshi children under the age of 5 years of age (n=265).

Variable	Ref	Category	n	p-value	OR (95% CI)
Child age (months)			265	0.464	0.992 (0.970 to 1.014)
Mean weight-for-height z-score			265	0.390	1.107 (0.878 to 1.395)
Sex	Ref	Male	134		
		Female	131	0.329	1.337 (0.746 to 2.397)
SES (High vs. Low)	Ref	Low (1-3)	167		
		High (4-5)	98	0.105	0.592 (0.314 to 1.117)
Number of children in household below the age of 5 yrs	Ref	1	195		
		More	70	0.088	1.767 (0.918 to 3.402)
Hemoglobin concentration (g/L)			265	0.077	0.980 (0.959 to 1.002)
Time child spends by the stove/day (min)	Ref	< 30 min	155		
		≥ 30 min	110	0.010	2.151 (1.199 to 3.861)
Validity of the model was tested using the following tests_ -2 log likelihood tests (281.9), Cox & Snell R^2 (0.087), Nagelkerke R^2 (0.127). Hosmer and Lemeshow test was insignificant (X^2=3.061, p=NS); Omnibus test of significance (p=0.02).					