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Please include the attached study in the official record of the SBCC 2021 Residential Energy Code proceedings The study is *"Cooking Fuels and Prevalence of Asthma: A Global Analysis of Phase Three of the International Study of Asthma and Allergies in Childhood (ISAAC)."* The study analyzed 512,707 primary and secondary school children from 108 centers in 47 countries, and shows there is "no evidence of an association between the use of gas as a cooking fuel and either asthma symptoms or asthma diagnosis."

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Cooking fuels and prevalence of asthma: a global analysis of phase three of the International Study of Asthma and Allergies in Childhood (ISAAC)

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See Online for appendix

Summary

Background Indoor air pollution from a range of household cooking fuels has been implicated in the development and exacerbation of respiratory diseases. In both rich and poor countries, the effects of cooking fuels on asthma and allergies in childhood are unclear. We investigated the association between asthma and the use of a range of cooking fuels around the world.

Methods For phase three of the International Study of Asthma and Allergies in Childhood (ISAAC), written questionnaires were self-completed at school by secondary school students aged 13–14 years, 244 734 (78%) of whom were then shown a video questionnaire on wheezing symptoms. Parents of children aged 6–7 years completed the written questionnaire at home. We investigated the association between types of cooking fuels and symptoms of asthma using logistic regression. Adjustments were made for sex, region of the world, language, gross national income, maternal education, parental smoking, and six other subject-specific covariates. The ISAAC study is now closed, but researchers can continue to use the instruments for further research.

Findings Data were collected between 1999 and 2004. 512 707 primary and secondary school children from 108 centres in 47 countries were included in the analysis. The use of an open fire for cooking was associated with an increased risk of symptoms of asthma and reported asthma in both children aged 6–7 years (odds ratio [OR] for wheeze in the past year, 1·78, 95% CI 1·51–2·10) and those aged 13–14 years (OR 1·20, 95% CI 1·06–1·37). In the final multivariate analyses, ORs for wheeze in the past year and the use of solely an open fire for cooking were 2·17 (95% CI 1·64–2·87) for children aged 6–7 years and 1·35 (1·11–1·64) for children aged 13–14 years. Odds ratios for wheeze in the past year and the use of open fire in combination with other fuels for cooking were 1·51 (1·25–1·81 for children aged 6–7 years and 1·35 (1·15–1·58) for those aged 13–14 years. In both age groups, we detected no evidence of an association between the use of gas as a cooking fuel and either asthma symptoms or asthma diagnosis.

Interpretation The use of open fires for cooking is associated with an increased risk of symptoms of asthma and of asthma diagnosis in children. Because a large percentage of the world population uses open fires for cooking, this method of cooking might be an important modifiable risk factor if the association is proven to be causal.

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Introduction

Despite much research, little is known about the cause of asthma. The international study of asthma and allergies in childhood (ISAAC) has documented a wide variation in asthma prevalence across the world and has also detected evidence of a continuing increase, especially in low-income and middle-income countries.[1,2] The possible role of air pollution in the development of respiratory diseases is a major focus of research. Several studies have investigated the association between indoor air pollution and asthma and chronic obstructive pulmonary disorder (COPD).[3,4] In high-income countries, the use of gas appliances for cooking has been implicated as a cause of respiratory symptoms, particularly in women.[5] The use of gas as cooking fuel has also been implicated as one of the factors that might explain the higher asthma prevalence in Chinese children in Hong Kong compared with children in other Chinese cities.[6] However, results from the European community respiratory health survey of more than 10 000 respondents did not show any relation between the use of gas for cooking and obstructive respiratory symptoms.[7]

Exposures to domestic fire burning of coal and biomass such as wood, animal dung, and crop residues for cooking or heating are widespread, especially in rural areas of poor countries. According to WHO, at least half

the world's population live in households in which solid fuels or biomass are the primary fuel for cooking, heating, or both.[8,9] In resource-poor countries, cooking with biomass is typically done on unvented stoves without any form of ventilation system.[10] In India, biomass burning has been shown to be associated with increased respiratory symptoms in children.[11] A nationwide study in India showed that exposure to the combustion of biomass and solid fuels was associated with an increased risk of asthma in women.[12] A study of 508 adults in the USA also showed a positive association between asthma and exposure to cooking indoors with wood and coal.[13] WHO estimated that indoor air pollution from the burning of biomass causes almost 2 million deaths annually.[8] Because the burning of biomass fuel or the use of gas for cooking are potentially modifiable factors, the study of their relation with asthma and wheezing illnesses in children is important.

Many studies of the association between cooking fuel and asthma have been of low statistical power. Furthermore, estimation of the individual exposure presents a major challenge because the proximity to the sources of exposure, the duration of exposure, and accurate assessment of ventilation are not easily quantifiable in large studies. The existing evidence about the association between household air pollution from biomass burning and asthma is conflicting, with more consistent positive associations in children than in adults.[14–18] We investigated the relation between asthma and the use of a range of cooking fuels in study centres around the world. Using standardised methods, phase one of ISAAC documented large variations in asthma prevalence across the world. Phase two included objective measurements including skin-prick test and bronchial challenge test, providing further support of the importance of environmental factors in the development of asthma. The results reported here are based on a detailed environmental questionnaire administered to children in 47 countries to test different cause hypotheses of asthma as part of the phase three ISAAC study.

Methods

Study design

ISAAC phase three is an expansion using the same study design of the first phase of ISAAC, findings from which showed a wide variation in the prevalence of childhood asthma and related atopic disorders across the world.[1,2,19] The details of the study protocol are available elsewhere.[2,19] Briefly, written questionnaires were self-completed at school by secondary school students aged 13–14 years who were then, in most centres, shown a video questionnaire on wheezing symptoms. 244 734 (78%) adolescents completed a video questionnaire on wheezing symptoms. Parents of children aged 6–7 years completed the written questionnaire at home. School children in these two targeted age groups were randomly selected by individual centres from within a defined geographical area. Studies were done with local ethics approval and the method of consent was determined by local ethics committees.[20] The ISAAC International Data Centre in Auckland, New Zealand, assessed the submitted data for adherence to the standardised ISAAC protocol. In this Article, we focus on "current wheeze" (in response to the question "Have you (has your child) had wheezing or whistling in the chest in the past 12 months?"), "asthma ever" ("Have you (has your child) ever had asthma?"), symptoms of "rhinoconjunctivitis" ("In the past 12 months, have you (has your child) had a problem with sneezing, or a runny, or blocked nose when you (he/she) did not have a cold or the flu?" and "In the past 12 months, has this nose problem been accompanied by itchy-watery eyes?"), and symptoms of "eczema" ("Have you (has your child) had this itchy rash at any time in the past 12 months?" and "Has this itchy rash at any time affected any of the following places: the folds of the elbows, behind the knees, in front of the ankles, under the buttocks, or around the neck, ears or eyes?"). These questions related to eczema were preceded by the question "Have you (has your child) ever had an itchy rash coming and going for at least 6 months?"; if

For the **core and environmental questionnaires** see http://isaac.auckland.ac.nz/

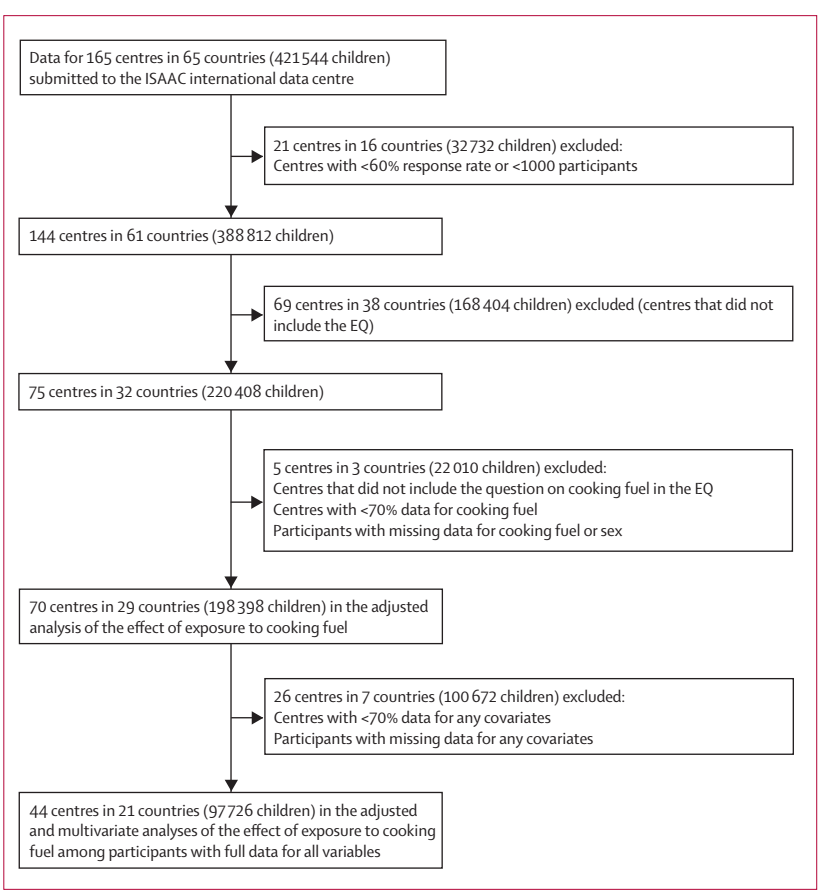

Figure 1: **Trial profile for children aged 6–7 years**
EQ=environmental questionnaire.

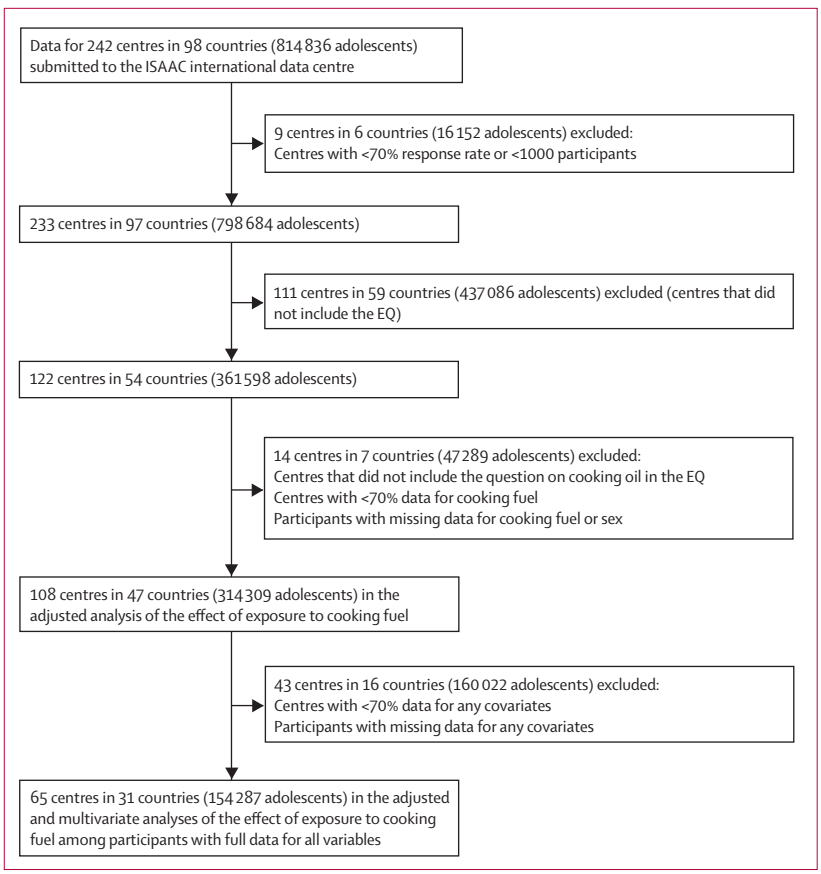

Figure 2: **Trial profile for children aged 13–14 years**
EQ=environmental questionnaire.

the answer to this question was negative, the following questions about eczema were not asked. We analysed "symptoms of severe asthma", defined as children with current wheeze who, according to the written questionnaire, in the past 12 months had four or more attacks of wheeze, or one or more nights of sleep disturbance from wheeze per week, or wheeze that was severe enough to limit the child's speech to only one or two words at a time between breaths. Previous ISAAC analyses showed that a combination of these characteristics of more severe wheezing episodes was more closely associated with asthma mortality and hospital admissions than current wheeze alone.[21] Additionally, children aged 13–14 years were asked to respond to a video questionnaire showing various symptoms of wheeze in children of similar age, and a positive response to the question relating to a scene showing a young person wheezing at rest ("Has your breathing ever been like this in the past 12 months?") was defined as "current wheeze–video".[22]

In ISAAC phase three, an optional environmental questionnaire (dependent on the resources available at each centre) was administered in addition to the core symptom questionnaire to assess several specific cause hypotheses.[19] One of the questions in the environmental questionnaire that we analysed in the present study was "What fuel is usually used for cooking in your house?" The four answers to choose from were "electricity", "gas", "open fires", and "other" (if respondents chose other, they had to specify which fuel they used). Respondents could choose more than one category. For this analysis, we used "electricity" as the reference group, and compared it with the other categories, including "gas", "open fires only", "open fire in combination with other fuel", "multiple non-fire fuel", and "other fuel only". The group of "other fuel" is small but heterogeneous, including the use of microwave, solar power, kerosene, liquid petroleum gas, and methane.

Statistical analysis

We calculated odds ratios (ORs) using generalised linear mixed models for a binomial distribution and logit link and with the centres modelled as a random effect. In the initial analyses of associations between outcomes and use of different types of cooking fuel, all children from centres with submission of cooking fuel data were included with adjustment for sex, region of the world, language, and gross national income. Regions of the world were Africa, Asia-Pacific, Eastern Mediterranean, Latin America, North America, northern and eastern Europe, Oceania, the Indian subcontinent, and western Europe. The written questionnaire was translated from English, according to the standardised ISAAC phase three protocol, into local languages: including Arabic, Chinese, English, Hindi, Indonesian, Portuguese, and Spanish.[24] Centres were allocated to four categories of socioeconomic status based on their country's gross national income per person: low, lower-middle, upper-middle, and high, as categorised by World Bank gross national income data.[25] To define affluent and non-affluent status, we combined the lower three categories as the non-affluent countries and the top category as the affluent countries. In the final models, we did multivariate analyses, adjusting for other covariates in the environmental questionnaire, including maternal education, maternal and paternal smoking, television watching, exercise, siblings (older and younger), consumption of fast food, frequency of truck traffic, and paracetamol use. We included these factors because they were known to be associated with respiratory symptoms or have been shown by our previous studies to be associated with wheeze and asthma.[26,27] We tested the effect modification by sex and by affluence by comparing the log-transformed ORs for boys and girls, and for affluent and non-affluent study centres. The log-odds-ratio for interaction was derived as the difference between the stratum-specific log-odds-ratios, and its variance was estimated as the sum of the variances of each of the stratum-specific log-odds-ratios. For the children aged

13–14 years, data for 242 centres in 98 countries with 814 836 participants were submitted to the ISAAC International Data Centre for data analyses. For children aged 6–7 years, data for 165 centres in 65 countries with 421 544 participants were submitted. Adherence to the ISAAC protocol was assessed, and centres with serious deviations from protocol (<70% response rate for the adolescents and <60% for the children, and centres with <1000 participants for both age groups) were excluded from the worldwide data analyses.[19,23] For inclusion in the final analysis, centres needed 70% or more of participants with data for the use of cooking fuels and all covariates. SAS version 9.1 was used for all analyses.

Role of the funding source

The study sponsors had no role in the study design, data collection, analysis, data interpretation, writing of the report, or the decision to submit the paper for publication. The authors had the responsibility to write and submit the paper for publication, with the involvement of the ISAAC Phase Three Study Group. The corresponding author had full access to all the data and the final responsibility to submit for publication.

Results

Data were collected between 1999 and 2004. In the initial statistical models, there were 198 398 children aged 6–7 years from 70 centres in 29 countries (figure 1) and 314 309 children aged 13–14 years from 108 centres in 47 countries (figure 2). Tables 1 and 2 show the distribution of the use of different types of fuel for cooking by region for the two age groups (see appendix for the prevalence rates of the various health outcomes in relation to the use of different types of cooking fuel in the two age groups). In the final multivariate analysis, only those children with complete covariate data were included (figures 1 and 2). As shown in tables 1 and 2, the highest percentages for the use of any open fire or open fire only were from Africa, the Indian subcontinent, and the Asia-Pacific region. For the initial and final multivariate analyses in both age groups, we detected statistically significant and consistent associations between the use of an open fire for cooking and current symptoms of wheeze and asthma (tables 3 and 4). In the multivariate analyses for children aged 13–14 years, the "use of open fire only" for cooking was associated with current wheeze as assessed by both the written and video questionnaires (table 4). In children aged 6–7 years, "use of open fire only" for cooking was associated with current wheeze, severe asthma symptoms, and ever reported asthma (table 3). Furthermore, in children aged 13–14 years, the use of open fire only for cooking was associated with ever reported eczema and current symptoms of eczema, and the use of open fire in combination with other fuels for cooking was also associated with ever reported eczema and current symptoms of eczema (table 4). In those aged 6–7 years, the association between the symptom of wheeze or severe asthma with the use of open fires only seemed stronger compared with use of open fire in combination with other fuel (table 3).

Tables 5 and 6 show the association between current wheeze and the use of different types of cooking fuel stratified by sex and country affluence. We did not detect any significant interaction between sex and the use of different fuels in their associations with current wheeze. When stratified by country affluence, the associations with current wheeze were statistically significant for the two age groups for any open fires and open fire only in non-affluent countries only, but tests for interaction between country affluence and use of different fuels in their associations with current wheeze were not significant (appendix).

In both age groups, symptoms of wheeze and ever reported asthma were not associated with the use of gas as a cooking fuel (table 7). Furthermore, none of the associations of these outcomes with gas cooking was statistically significant when stratified according to sex or country affluence in either age group (tables 5 and 6).

	N	Multiple non-fire fuels (%)	Other fuel only (%)	Any open fire (%)	Open fire only (%)	Gas only (%)	Electricity only (%)
Africa	2308	0%	42%	21%	0%	23%	14%
Asia-Pacific	27 022	11%	1%	1%	2%	78%	7%
Eastern Mediterranean	14 977	3%	<0·5%	1%	<0·5%	94%	1%
Indian subcontinent	42 521	4%	9%	3%	4%	79%	1%
Latin America	46 586	3%	<0·5%	1%	1%	91%	5%
North America	3948	1%	0%	<0·5%	0%	67%	32%
Northern and eastern Europe	15 139	5%	<0·5%	1%	3%	65%	26%
Oceania	10 810	7%	<0·5%	<0·5%	1%	9%	82%
Western Europe	35 087	4%	1%	<0·5%	1%	61%	33%
All centres	198 398	5%	3%	1%	2%	74%	15%

Table 1: **Global use of different types of fuels for cooking (children aged 6–7 years)**

	N	Multiple non-fire fuels (%)	Other fuel only (%)	Any open fire (%)	Fire only (%)	Gas only (%)	Electricity only (%)
Africa	27 563	6%	3%	11%	18%	43%	18%
Asia-Pacific	49 820	8%	4%	3%	3%	71%	12%
Eastern Mediterranean	15 523	4%	1%	2%	<0·5%	91%	3%
Indian subcontinent	41 703	3%	8%	6%	3%	78%	1%
Latin America	79 606	5%	<0·5%	3%	2%	81%	9%
North America	5290	1%	1%	1%	0%	54%	43%
Northern and eastern Europe	26 922	7%	<0·5%	2%	3%	53%	35%
Oceania	19 282	10%	1%	6%	12%	19%	53%
Western Europe	48 600	6%	1%	<0·5%	1%	57%	35%
All centres	314 309	6%	2%	4%	4%	66%	18%

Table 2: **Global use of different types of fuels for cooking (children aged 13–14 years)**

	Adjusted model		Multivariate analysis	
	Any use of open fire	Use of open fire only	Any use of open fire	Use of open fire only
Current wheeze	1·78 (1·51–2·10)	1·79 (1·52–2·10)	1·51 (1·25–1·81)	2·17 (1·64–2·87)
Current symptoms of severe asthma	1·83 (1·42–2·35)	1·80 (1·40–2·32)	1·33 (1·02–1·73)	1·79 (1·18–2·70)
Asthma ever	1·37 (1·10–1·71)	1·26 (1·06–1·49)	1·32 (1·08–1·61)	1·45 (1·03–2·03)
Current symptoms of rhinoconjunctivitis	1·24 (0·97–1·59)	1·06 (0·86–1·30)	1·02 (0·80–1·30)	1·12 (0·74–1·69)
Hay fever ever	1·16 (0·90–1·49)	1·09 (0·91–1·31)	1·06 (0·84–1·33)	1·20 (0·79–1·82)
Current symptoms of eczema	0·93 (0·73–1·21)	1·14 (0·96–1·35)	1·10 (0·91–1·33)	1·08 (0·75–1·55)
Eczema ever	0·80 (0·64–1·00)	0·97 (0·82–1·15)	0·90 (0·74–1·09)	0·64 (0·45–0·93)

Data are odds ratio (95% CI). The reference category for these estimates is electricity only used for cooking.

Table 3: **Association between any use of open fire and open fire only for cooking and current symptoms of asthma, rhinoconjunctivitis, and eczema (children aged 6–7 years)**

	Adjusted model		Multivariate analysis	
	Any use of open fire	Use of open fire only	Any use of open fire	Use of open fire only
Current wheeze	1·20 (1·06–1·37)	1·19 (1·05–1·35)	1·35 (1·15–1·58)	1·35 (1·11–1·64)
Current wheeze (video)	1·42 (1·18–1·71)	1·37 (1·14–1·64)	1·74 (1·41–2·13)	1·87 (1·46–2·40)
Current symptoms of severe asthma	1·31 (1·12–1·52)	1·29 (1·10–1·50)	1·19 (0·98–1·46)	1·20 (0·93–1·55)
Asthma ever	1·24 (1·10–1·40)	1·23 (1·09–1·39)	1·48 (1·28–1·72)	1·70 (1·43–2·03)
Current symptoms of rhinoconjunctivitis	1·09 (0·96–1·24)	1·07 (0·95–1·21)	1·08 (0·91–1·28)	1·02 (0·83–1·26)
Hay fever ever	1·10 (0·96–1·26)	1·09 (0·95–1·25)	1·15 (0·95–1·40)	1·08 (0·85–1·38)
Current symptoms of eczema	1·35 (1·17–1·56)	1·29 (1·13–1·49)	1·37 (1·13–1·66)	1·33 (1·07–1·66)
Eczema ever	1·23 (1·07–1·42)	1·22 (1·06–1·40)	1·35 (1·12–1·62)	1·42 (1·14–1·76)

Data are odds ratio (95% CI). The reference category for these estimates is electricity only used for cooking.

Table 4: **Association between any use of open fire and open fire only for cooking and current symptoms of asthma, rhinoconjunctivitis, and eczema (children aged 13–14 years)**

Discussion

The findings from this large multicentre survey show that the use of open fires for cooking is associated with symptoms of asthma and ever reported asthma in school children of two age groups: 6–7 years and 13–14 years. The associations were consistent between sexes. Furthermore, the associations were similar using three different validated methods to assess the symptoms of current wheeze or ever reported asthma (self-completed written questionnaire and video questionnaires for children aged 13–14 years and parent-completed questionnaires for children aged 6–7 years).[22,23] When stratified according to country affluence, we found that current wheeze was associated with open-fire cooking in non-affluent countries only.

The potentially detrimental effects of indoor air pollution on the development of respiratory diseases have attracted much attention from the research community. Household air pollution from burning of solid fuels has been shown to be a leading risk factor for global disease burden.[28] The association between acute lower respiratory tract infections and exposure to household burning of biomass has been investigated in several studies and the association has been consistent (panel).[29–31] However, restricted data are available for the relation between burning of biomass and asthma. In epidemiological studies, accurate assessment of exposure can be difficult because the intensity of exposure depends on a range of factors such as proximity to the source of pollution, the duration of exposure, and the ventilation system available in the household. The concentrations of pollution from cooking by open fire with indoor burning of biomass are commonly in the order of hundreds and might be up to several thousand μm/m³ of particulates smaller than 10 μm in diameter (PM_{10}).[32,33] Furthermore, households using biomass fuel in low-income and middle-income countries do not usually have effective ventilation systems to reduce the indoor levels of pollutants. In high-income countries, the effects of gas stoves and other combustion appliances on respiratory symptoms and lung function have been studied extensively. The use of domestic gas appliances has been associated with respiratory symptoms and a diminished respiratory function in children.[34–36] However, the evidence was conflicting as to whether the use of gas cooking is associated with asthma.

About half the world population is exposed to household air pollution from the burning of coal or biomass in open fires, the use of these forms of energy sources have received much attention. The use of biomass fuel has been estimated to be more important than smoking of tobacco as a risk factor for COPD globally.[4] In a meta-analysis done by Kurmi and colleagues, strong associations between the use of solid fuel and COPD (OR 2·80 [95% CI 1·18–4·00]) and chronic bronchitis (2·35 [1·92–2·80)] were seen.[37] Exposure to wood smoke was associated with the greatest risk of development of COPD and chronic bronchitis. In high-income countries, most research studies have focused on the possible effects of the use of gas as cooking fuel. Available data are inconsistent, with some studies showing a positive association between gas cooking and asthma and others showing no association. A multicentre study of children from three Chinese cities showed that exposure to gas cooking was one of the risk factors explaining the higher prevalence of childhood asthma in Hong Kong when compared with children from mainland China.[6] However, the PIAMA birth cohort study did not find any association between gas cooking and any of the respiratory outcomes assessed, including asthma.[38] Furthermore, the results from the European Community Respiratory Health Survey of more than 10 000 adults from 11 countries did not show any association between the use of gas for cooking and obstructive respiratory symptoms.[7] Some of these inconsistencies can be explained by errors in exposure

	Countries (n)	Centres (n)	Children (n)	Multiple non-fire fuels	Other fuel only	Any use of open fire	Open fire only	Gas only
Girls	21	44	48 743	1·31 (1·12–1·54)	0·86 (0·43–1·72)	1·56 (1·19–2·05)	1·93 (1·23–3·02)	0·92 (0·82–1·03)
Boys	21	44	48 983	1·09 (0·94–1·27)	1·10 (0·64–1·90)	1·45 (1·13–1·87)	2·35 (1·64–3·37)	0·99 (0·89–1·09)
Affluent countries	6	19	42 047	1·22 (1·07–1·40)	0·84 (0·45–1·57)	1·27 (0·90–1·79)	1·55 (0·78–3·11)	1·01 (0·92–1·10)
Non-affluent countries	15	25	55 679	1·10 (0·90–1·34)	1·12 (0·61–2·04)	1·49 (1·18–1·88)	2·11 (1·53–2·90)	0·88 (0·76–1·01)

Data are odds ratio (95% CI), unless otherwise stated. The reference category for these estimates is electricity only used for cooking.

Table 5: **Association between cooking fuels and current wheeze by sex or country affluence (children aged 6–7 years)**

	Countries (n)	Centres (n)	Children (n)	Multiple non-fire fuels	Other fuel only	Any use of open fire	Open fire only	Gas only
Girls	31	65	78 550	1·25 (1·06–1·48)	0·72 (0·49–1·06)	1·31 (1·05–1·64)	1·36 (1·04–1·78)	0·98 (0·89–1·09)
Boys	31	65	75 737	1·06 (0·89–1·27)	0·98 (0·70–1·38)	1·39 (1·11–1·74)	1·36 (1·03–1·78)	1·00 (0·90–1·12)
Affluent countries	5	17	43 344	1·08 (0·90–1·31)	1·04 (0·70–1·56)	0·98 (0·61–1·56)	0·75 (0·32–1·75)	1·00 (0·90–1·11)
Non-affluent countries	26	48	110 943	1·18 (1·01–1·39)	0·74 (0·53–1·04)	1·38 (1·16–1·65)	1·39 (1·13–1·71)	0·98 (0·88–1·09)

Data are odds ratio (95% CI), unless otherwise stated. The reference category for these estimates is electricity only used for cooking.

Table 6: **Association between cooking fuels and current wheeze by sex and country affluence (children aged 13–14 years)**

assessment or differences in the toxicity of the pollutant mixtures. The type and efficiency of the ventilation systems could also have affected the relation between gas cooking and respiratory symptoms.

In poor countries, the use of open fire associated with use of biomass burning for cooking is far more common than the use of gas or electricity. Indoor air pollution from biomass burning has been associated with a variety of respiratory illnesses such as respiratory tract infection, asthma, and bronchitis.[39] In a study from Kentucky, USA, adults reported to have used coal or wood indoors for cooking for more than 6 months had an increased risk of asthma (OR 2·3 [1·1–5·0]).[13] A study of 1058 children aged 4–6 years from Guatemala showed that exposure to open fires for cooking was associated with symptom of wheeze (OR 3·4 [1·3–8·5]).[18] A study of 755 children from rural villages in India reported that the use of biomass burning was associated with doctor-diagnosed asthma (OR 4·27 [3·00–4·90]).[40] In addition to many studies showing the association of indoor air pollution and respiratory symptoms, findings from several studies have suggested an association between traffic-related air pollution and symptoms of eczema.[26,41] Our results also showed that there was a consistent association between use of open fire for cooking and reported eczema diagnosis and symptoms of eczema in the older age group, but there was a weak protective effect of the use of open fire only on eczema diagnosis in the younger age group (table 3, multivariate analysis). Two studies have shown a positive association between eczema and the levels of indoor air pollutants such as PM_{10}, nitrogen dioxide, and carbon monoxide.[42,43] The normal skin barrier is impaired in patients with eczema. This defect of skin barrier function might enhance the penetration of environmental pollutants or allergens into the skin, resulting in inflammatory responses and persistent symptoms of eczema. Chronic exposure to pollutants could also disrupt the normal skin barrier resulting in increased sensitivity to chemicals or allergens. Further studies are needed to clarify these associations between environmental pollution and eczema, and to expose the possible underlying mechanisms.

	Adjusted model		Multivariate analysis	
	6–7 years	13–14 years	6–7 years	13–14 years
Current wheeze	0·98 (0·92–1·04)	0·99 (0·94–1·04)	0·96 (0·89–1·03)	0·99 (0·92–1·07)
Current symptoms of severe asthma	1·01 (0·92–1·10)	0·97 (0·91–1·03)	0·97 (0·87–1·09)	0·97 (0·89–1·07)
Asthma ever	0·95 (0·89–1·01)	0·98 (0·93–1·02)	0·94 (0·88–1·02)	0·99 (0·93–1·05)
Current symptoms of rhinoconjunctivitis	1·04 (0·97–1·01)	0·96 (0·91–1·01)	1·00 (0·92–1·09)	0·99 (0·92–1·06)
Hay fever ever	1·02 (0·95– 1·09)	0·96 (0·91–1·01)	1·00 (0·92–1·09)	0·99 (0·92–1·07)
Current symptoms of eczema	0·97 (0·91–1·03)	1·00 (0·94–1·06)	0·94 (0·87–1·02)	1·00 (0·92–1·09)
Eczema ever	0·91 (0·86–0·96)	0·99 (0·93–1·04)	0·93 (0·88–0·99)	1·01 (0·93–1·09)

Data are odds ratio (95% CI), unless otherwise stated. The reference category for these estimates is electricity only used for cooking.

Table 7: **Association between use of gas only for cooking and current symptoms of asthma, rhinoconjunctivitis, and eczema, by age group**

The large sample size, the use of standardised methods of assessment, and validated instruments are the strengths of this study. Findings from four validation studies have substantiated the assocation between current wheeze and asthma-related bronchial hyper-responsiveness or confirmation of asthma by physician assessment.[44–47] Our results are consistent with those of other studies in finding that the use of an open fire for cooking was associated with wheeze symptom and reported asthma in both age groups.

Panel: **Research in context**

Systematic review

We searched PubMed for reports published before March 18, 2013, with the following combinations of the search terms "cooking fuel" and "asthma", and "biomass fuels" and "asthma". We identified 40 and 29 reports, respectively. Most of these reports were review articles or studies of the possible effects of gas cooking in rich countries. There were only seven studies investigating the effects of biomass burning and asthma. Among them, only two studies investigated the association in children and both studies were from poor countries. The results of these studies were inconsistent as to whether exposure to biomass burning was associated with asthma or not.

Interpretation

We report a positive association between cooking with open fires and the symptoms and diagnosis of asthma in childhood in both affluent and non-affluent countries. No association was seen with the use of gas. Because cooking with open fires with biomass or coal is very common, especially in non-affluent countries, more detailed studies are urgently needed to establish whether the relation is causal and to assess intervention strategies.

Although not statistically significantly different, the younger age-group seemed to have higher ORs for current wheeze for the exclusive use of open fires as compared with the use of an open fire in combination with other fuels. When stratified according to country affluence, associations tended to be seen only in non-affluent countries. Many factors might affect the health effects of air pollution generated from open fire cooking. These would include the frequency of use of open fire cooking, the type of housing, and the availability and efficiency of kitchen ventilation systems. Most households using open fires for cooking in less affluent countries are usually not equipped with an efficient ventilation system.[10] By comparison with the situation in less affluent countries, kitchen ventilation is likely to be better in homes in affluent countries and this factor could partly explain the discrepancy in the effect of the use of open fire for cooking between affluent and non-affluent countries. A randomised controlled study of 552 women from rural Mexico showed that the use of an improved biomass stove with lower levels of pollution was associated with a reduction of respiratory symptoms and of lung function decline.[48] A major limitation of our study is that we do not have information related to the frequency of open fire cooking and information about kitchen ventilation that would allow us to test these hypotheses. Our environmental questionnaire did not enquire about information related to exposure during pregnancy such that we could not test if exposure factors during pregnancy were associated with various health outcomes in question. The absence of information about the use of asthma drugs is another limitation. Our results would have been strengthened if we could show the association of asthma drug use and exposure to open fire cooking. Furthermore, family history of allergies is a potential confounder but adjustment for parental allergies in our regression models did not change our results.

There are several factors that could affect the validity of our results. In particular, selection bias and recall bias could have led to a spurious positive association between the exposure of open fire cooking and asthma symptoms. We think this is unlikely to explain the present findings because there is coherence between the initial analyses using all available children and the final analyses in selected children adjusted for important covariates, and the results are consistent across the two age groups using three different methods to identify asthma. By contrast with parents of the younger children, children aged 13–14 years are unlikely to be aware of the potential relation between the exposure and asthma symptoms making recall bias less likely. With regards to possible misclassification of exposure, this problem would bias our results towards the null hypothesis. The negative findings from children exposed to open fire cooking in affluent countries might be explained by the lack of statistical power owing to the small sample size. Determination of whether current asthma symptoms were related to the acute exposure or long term exposure could be of interest, but our risk factor questionnaire did not obtain information about the types of cooking fuel used in early life or when the mother was pregnant with the child. The use of multiple non-fire fuels was associated with wheeze in girls in both age groups, and in the younger children in affluent countries (tables 5 and 6). This category of fuel refers to the use of different combinations including gas, electricity, microwave, and even solar energy. Because many of these fuels are thought to be clean sources of energy, the reason for this association is not clear. However, families who can afford the use of multiple types of fuels might have a higher socioeconomic status and if these were more likely to report symptoms or a diagnosis of asthma, a possibility of residual confounding by socioeconomic status could exists that would not be accounted for by the inclusion maternal education in our statistical model.

If the association between open fire cooking and asthma is causal, this factor might be a major modifiable risk factor of asthma in children worldwide. However, more detailed investigations are needed to confirm and quantify this association, understand the underlying mechanisms, and assess intervention strategies. Our results provide further evidence that public policies and measures to reduce indoor air pollution from burning of biomass will translate into significant health benefits especially in developing countries.

Contributors

All authors participated in the development, design, data collection, analysis, and interpretation of this work. GWKW wrote the first draft and all authors contributed to the writing of subsequent drafts of the paper.

Conflicts of interest

We declare that we have no conflicts of interest.

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