It takes a village: community education predicts paediatric lower-respiratory infection risk better than maternal education

Bradford D Gessner,[1] Marc-Andre R Chimonas,[1] Sue C Grady[2]

▸ Supplementary figures 1, 2 are published online only at http://jech.bmj.com/content/vol64/issue2

[1]Alaska Division of Public Health, Anchorage, Alaska, USA
[2]Geography Department, Michigan State University, East Lansing, Michigan, USA

Correspondence to
Dr Bradford D Gessner, POBox 240249, Suite 424, 3601 C Street, Anchorage AK, 99524, USA; brad.gessner@alaska.gov

Accepted 30 April 2009

ABSTRACT

Background Few studies have evaluated the contribution of community and parental education levels in determining paediatric outcomes, including lower-respiratory infection (LRI), the leading global cause of child mortality.

Methods The authors evaluated the association between community and maternal educational attainment and LRI risk among Medicaid-enrolled children age <2 years in Alaska, which has one of the highest LRI incidences ever reported. An individual-level database was created by linking Medicaid data to birth certificate files. A community-level database was created by calculating community LRI incidence rates and linking these values to Department of Labor census variables. Multilevel modelling was used to evaluate the independent effects of maternal and community education levels on LRI risk.

Results Statewide outpatient and inpatient LRI incidences were high at 42 and 6 per 100 child-years. When controlling for potential individual and community level confounding variables, a child's risk of outpatient and inpatient LRI was independently predicted in a dose–response manner by the child's mother's educational attainment and the educational attainment of other adults in the child's community. The latter variable had a stronger association and higher community education levels substantially mitigated the risk of poor maternal education.

Conclusions LRI risk among Alaskan children is affected by the formal education levels of the child's mother and other adults in their community. The mechanisms by which community education might influence LRI risk remain unknown and may include access to medical knowledge or acceptance of scientific versus traditional beliefs.

INTRODUCTION

Pneumonia is the leading cause of paediatric mortality worldwide.[1–3] Indigenous child populations in North America[4–7] and Australia[8] have elevated respiratory disease risks, and Alaska Native children have some of the highest lower-respiratory infection (LRI) rates ever reported.[4 9 10] The reasons for these findings remain elusive. However, many Alaska Native children have risk factors associated previously with LRI including young mothers with low income levels and increased use of tobacco,[11] living in crowded conditions[12] in small rural villages with less access to medical care, and residing in homes often heated with wood or fuel oil[13 14] and that may not have access to piped water and sewage services.[15 16]

Studies also have found a strong association between maternal education and child survival,[17–21] suggesting that maternal education also may influence LRI risk.[22 23] Reported associations between maternal education and childhood outcomes may be modified or confounded by the effect of community education levels. Community education could influence LRI risk independent of maternal education by influencing community standards for hygiene, breastfeeding, use of traditional versus modern medicine and other culture-based factors. Community-level variables have been shown to modify the risk of individual-level socioeconomic variables for some paediatric outcomes[24–26] but not LRI.

MATERIALS AND METHODS

Database construction

The current study examined the population of children age less than 2 years enrolled in Alaska Medicaid during 1998–2003 to evaluate the independent contribution of maternal and community education levels to LRI risk. The Alaska Division of Medical Assistance provided a master file that consisted of data for all persons aged less than 2 years enrolled in Medicaid from 1 October 1998 through 30 June 2003. They also provided an outcomes database that contained provider, inpatient facility and outpatient clinic approved billing claims. Medicaid is a federally created and state-administered health insurance programme designed for low-income citizens. Within Alaska Medicaid resides Denali Kidcare, Alaska's Child Health Insurance Program for pregnant women, children and teens through the age of 18 years. Currently in Alaska, children may qualify if family gross income is at or below 150% of the Federal Poverty Guideline (http://hss.state.ak.us/dhcs/DenaliKidCare/income_guide_dkc.htm, accessed 4 Jan 2009). Approximately 94% of Alaska Native newborns will enroll in Denali Kidcare during their first 2 years of life versus 46% of non-Native newborns.

Four additional databases were merged to the Medicaid database. The Alaska Bureau of Vital Statistics provided a birth-certificate file that contained information on maternal education as well as other birth, infant and parental characteristics. The Alaska Department of Labor provided census data for all communities in Alaska, including demographic variables such as average household population and the proportion of adults with particular levels of educational attainment. The Alaska Department of Environmental Conservation provided data on the proportion of households in each Alaska community with piped water or water received from covered haul vehicles. The

Alaska State Medical Association provided information on physician and hospital location by community that was used to create a fourth database. Data files were linked using SPSS version 13.0. Separate databases of individuals (level 1) nested within communities (level 2) were also constructed in SPSS for use in multilevel analysis.

Case definitions

A case of LRI was defined as an approved billing claim for International Classification of Diseases, 9th Revision (ICD-9) codes 466 (acute bronchitis and bronchiolitis), 480–487.1 (pneumonia and flu with pneumonia), 490 (bronchitis not specified as acute or chronic) and 510–511 (empyema and pleurisy). Inpatient LRI was defined as a hospital admission claim for any of the aforementioned codes. Outpatient LRI was defined as a clinic or emergency department visit (without admission) for any of the aforementioned codes.

We used the created data file to follow for the first 2 years of life all children enrolled in Medicaid and born from 1 October 1998 to 30 June 2001. Because, in Alaska, early childhood death is a rare event (infant mortality rate of 5.5–8.3 per 1000 live births during 1998–2001) (http://www.hss.state.ak.us/dph/bvs/death_statistics/Infant_Mortality_Census/frame.html, accessed 4 Jan 2009), it was assumed that all children lived through the age of 2 years. Ideally, all children would have been enrolled continuously in Medicaid throughout their first 2 years of life. Most children, though, move in and out of Medicaid eligibility and enrolment, and so implementing this restriction would have decreased the sample size by over two-thirds. Instead, children were followed through the Medicaid database for all of their recorded days of enrolment through age 2 years. A subanalysis restricting subjects to those continuously enrolled yielded almost identical results, and so this issue was not considered further.

Community level analysis

The community-level analysis evaluated the association between community demographic characteristics and the incidences of inpatient and outpatient LRI calculated as the total events among enrolled children less than age 2 years from each community divided by the total days of enrolment and expressed as events per 100 child-years. Analyses were restricted to communities that had at least 15 children enrolled in Medicaid during the study period to eliminate instances where small numbers of outcomes or risk-factor occurrences could dramatically alter results.

The evaluated independent variables were determined by the available data, primarily those collected during the census. Because no previous work exists on this subject, we did not have an a priori hypothesis as to whether a high proportion of uneducated people or a low proportion of highly educated people would influence paediatric LRI risk more strongly. Consequently, educational variables evaluated included lack of attainment of 7 years of education, lack of attainment of a high school diploma and successful attainment of a college bachelor's degree or equivalent for persons age 25 years or older (we also evaluated these educational outcomes separately for men and women but did not identify substantially different findings). Potential confounding variables included the average household size, proportion of households in the community using firewood for heating, proportion of houses with modern water service (piped, on-site well and septic or use of a closed haul truck), proportion of adults employed, proportion of residents under the federal poverty level, availability of a doctor or hospital in the community or within 50 road miles or location on the road system. As the last three variables did not influence any of the models, they were not considered further.

Separate multivariate linear regression models were constructed for inpatient and outpatient LRI, and for each model the primary exposure variable of interest was community education level. The three education variables of interest could not be included in the same models because of colinearity. Consequently, separate models were created for each and included all potential confounding variables. Assumptions of regression were assessed for each model by plotting a histogram of residuals and a graph of residuals versus predicted values. Departures from assumptions were minor. Analyses were performed using SAS version 8.0: Proc Reg for linear regression models.

Multilevel analysis

We conducted hierarchical generalised linear models (HGLM) to estimate the independent and cross-level effects of mother's education and the cumulative educational attainment of adults in the child's community on LRI risk. At the individual level (level 1) we included the mother's educational level using standard categories (3–4 years college=0 vs some high school, high school or 1–2 years of college) as the primary child risk factor of interest. Based on previous data,[4–10] and the disparity in educational attainment by Alaska Native versus non-Native mothers (27.4% of Alaska Native and 9.5% of non-Native mothers had less than 12 years of education (http://www.hss.state.ak.us/dph/bvs/birth_statistics/Profiles_Census/body.html, accessed 4 Jan 2009)), we included in multilevel multivariate models Alaska Native status using birth certificate assignment of maternal race (Non-Native=0). We also controlled for the number of days of Medicaid enrolment. At the community level (level 2) we included the proportion of adults with <7 years of formal education (<10%=0 vs 11–20% or >20%) as the primary community risk factor of interest (this category was selected, since the community level analysis identified it as most strongly associated with LRI incidence) and the proportion of households with modern water service based on the community analysis and previous data.[12 13]

The community in which the child lived was the unique ID used to link these datasets in the HGLM analysis. Since LRI was measured as a dichotomous variable, we estimated Bernoulli-population-average HGLM models. First, we conducted bivariate analyses to estimate the effect of each individual or community level variable on the risk of LRI, averaging over the distribution of level 2 random effects. Second, we conducted multivariate analyses to estimate the independent and cross-level effects of our level 1 and level 2 predictors on the risk of LRI, averaging over the distribution of level 2 random effects. We conducted separate analyses for outpatient and inpatient LRI. Analyses were conducted using Hierarchical Linear Models Software (HLM) version 6.0.

Ethical considerations

The current analysis was conducted on routine public health databases (birth certificates and Medicaid files) as part of the legally mandated work of the Alaska Division of Public Health. Acquisition and analysis of public health surveillance data by legally authorised Public Health representatives have been determined to be exempted from IRB review. Consequently, no prospective IRB approval was sought or obtained.

RESULTS

Descriptive analysis of individuals

From November 1998 to 1 July 2001, there were 17 913 children <2 years of age enrolled in Medicaid. From birth to the second birthday, there were 24 857 years of follow-up. The study cohort experienced 10 401 outpatient LRI episodes (41.8 per 100 child-years) and 1475 inpatient LRI episodes (5.9 per 100 child-years). Of inpatient LRI episodes, 63% (928 of 1475) were reported as due to acute bronchiolitis or respiratory syncytial virus pneumonia, as were 50% (5186 of 10 401) of outpatient LRI episodes. Outpatient and inpatient LRI incidence rates varied substantially by selected risk groups and were higher among Alaska Native children, children whose mothers had less education and children residing in communities with a higher proportion of adults with <7 years of formal education and a lower proportion of households with modern water service (table 1).

Descriptive analysis of communities

There were 117 communities in Alaska with at least 15 children <2 years of age enrolled in Medicaid during the study period. Between communities, the outpatient LRI incidence rate varied from 0 (in two communities) to 157 per 100 child-years of follow-up (mean 58; median 42) while the inpatient incidence rate varied from 0 (in 16 communities distributed over 12 census areas) to 41.2 (mean 10.8; median 6.3). Almost all communities in Western and Northern Alaska—outside four regional hub communities—lack road access to a hospital. However, within these communities, no consistent relationship was found between LRI incidence in the hub community and smaller villages serviced by the hub hospital. For example, within the Bethel census area, the inpatient and outpatient LRI incidences in the hub versus the averages of the surrounding 23 communities were 20 versus 23 and 116 versus 115 per 100 child-years of follow-up.

The percentage of residents with less than <7 years of education varied across communities from 0 to 29% (mean 8.7%; median, 7.0%); the percentage was <10% in 70 communities (60%), 10–20% in 34 (29%) and over 20% in 13 (11%). Communities in which <10% of adults had <7 years of education contained 84% of study subjects, 58% of inpatient LRI episodes and 73% of outpatient LRI episodes. Respective values among communities with 10–20% of adults with <7 years of education were 12%, 27% and 19%, while for communities with over 20% of adults with <7 years of education, the values were 4.6%, 14% and 8.1%.

Table 1 Inpatient and outpatient lower respiratory infection (LRI) incidence rates among Alaskan children less than 2 years of age enrolled in Medicaid during 1998–2003, by categories

Category	Years of enrolment (children enrolled)	Outpatient incidence (events)	Inpatient incidence (events)
Maternal race			
Alaska Native	9188 (6271)	85.5 (5359)	16.5 (1035)
Non-Native	12760 (9291)	45.9 (4263)	4.0 (372)
Maternal education			
Some high school	4890 (3111)	76.4 (2376)	13.4 (417)
High school graduate	11464 (7484)	71.2 (5328)	10.3 (771)
1–2 years postsecondary	3663 (2562)	48.3 (1237)	5.1 (131)
3+ years postsecondary	1794 (1314)	31.6 (415)	2.7 (36)
Percentage of households with modern water service in child's community			
0–24	1235 (760)	172.1 (1308)	37.6 (286)
25–74	794 (505)	100.6 (508)	24.2 (122)
75–100	22074 (16061)	51.8 (8315)	6.5 (1040)
Percentage of persons 25+ years of age with <7 years formal education in child's community			
21–100	822 (211)	167.7 (837)	42.3 (211)
10–20	2296 (402)	136.8 (1957)	28.1 (402)
0–9	21599 (855)	47.8 (7572)	5.4 (855)

Community education level and community LRI risk

When controlling for other potentially important variables, outpatient and inpatient LRI incidences were higher within communities with a higher proportion of less educated adults, particularly the proportion with <7 years of formal education (table 2).

The proportion of adults with at least 4 years of college did not predict community LRI incidence. Of the variables included in the model, the proportion of adults with <7 years of education most strongly predicted inpatient and outpatient LRI risk, with each 1% increase in this variable predicting an increase of 2.3 outpatient and 0.73 inpatient LRI events per 100 years of follow-up. The relationship between community education level and community LRI risk is shown graphically in figures 1, 2 (Web only).

Maternal and community education levels and child LRI risk

Based on the above results for the community-level analyses, and previous data,[12 13] the community-level variables entered into all bivariate and multivariate multilevel models included the proportion of adults with less than a 7th-grade education and the proportion of households with modern water service. Interaction terms between individual mother's race, educational levels and community level variables were not significant for any of the multilevel models controlling for length of Medicaid enrolment. For both inpatient and outpatient LRI outcomes, lower maternal education and a higher proportion of adults in a community with less than a 7th-grade education increased the likelihood of inpatient and outpatient LRI in a dose–response manner (table 3). Furthermore, controlling for lower community education levels substantially mitigated the likelihood of poor maternal education. The independent effect of maternal and community education levels can be seen graphically as absolute risk (in this case, the outcome is the proportion of children with at least one LRI episode) (figures 3, 4). We also found that children living in communities with increasing levels of households with modern water service had a reduced likelihood of LRI (table 3) controlling for the other covariates in the model.

DISCUSSION

Summary of results

Maternal education predicted inpatient and outpatient LRI risk independently of such factors as maternal tobacco and alcohol use, race, parental age and gestational age. Maternal education is a well-known risk factor for overall infant and child mortality.[17–21] Few studies have evaluated the impact of maternal education directly on LRI, but others have hypothesised a substantial influence based on the known association between respiratory infection and childhood mortality.[22 23] Given this background, the identified associations between maternal education and paediatric LRI were not unexpected.

More surprising was the influence of community education levels on LRI risk. At the community level, a high proportion of poorly educated adults was more predictive of inpatient and outpatient LRI risk than household crowding, income levels or physician proximity and was independent of the presence of

Table 2 Linear regression analysis of the association between community-level educational attainment and outpatient or inpatient lower respiratory infection (LRI) incidence, for 117 Alaskan communities with at least 15 children less than 2 years of age enrolled in Medicaid during 1998–2003, Alaska, 1998–2003

Educational attainment category	R^2	B (95% CI)	Standardised beta	Standardised betas for covariates
Outpatient LRI as the outcome				
<7 years	0.55	2.3 (1.0 to 3.6)	0.41	W=−0.36; H=0.10; F=0.002, E=0.081
<High school degree	0.52	1.0 (0.13 to 2.0)	0.29	W=−0.36; H=0.21; F=0.024, E=0.11
At least 4 years college	0.49	−0.18 (−1.3 to 0.95)	−0.031	W=−0.36; H=0.43; F=0.048, E=0.12
Inpatient LRI as the outcome				
<7 years	0.56	0.73 (0.40 to 1.1)	0.51	W=−0.29; H=0.046; F=0.011, E=0.026
<High school degree	0.51	0.32 (0.090 to 0.56)	0.35	W=−0.28; H=0.18; F=0.038, E=0.014
At least 4 years college	0.47	0.024 (−0.27 to 0.32)	0.016	W=−0.30; H=0.48; F=0.069, E=0.005

Educational attainment was expressed as the percentage of adults in the community with the designed attainment. LRI incidence was expressed as outcomes per 100 child-years of follow-up. All models included the percentage of households with modern water service (W), average household size (H), percentage of households using firewood for heat (F) and percentage of adults age 16 years or older employed (E). Each row represents a separate regression model so that the table contains six separate models.

modern water and septic services. In the multilevel models, the proportion of poorly educated adults in a child's community had a greater magnitude of effect than maternal education in determining LRI risk at all levels of maternal education. The absolute LRI risk associated with birth to a less educated mother was blunted after controlling for the low educational status of the community. Conversely, the protective effect associated with birth to a well-educated mother was substantially reduced if community educational status was low. This is demonstrated in figures 3, 4 by the increasing proportion of children experiencing an LRI within the same maternal education category as community education worsens.

Potential mechanisms of action of community education levels

Community-level socio-economic variables have been shown to modify the risk of individual-level socio-economic variables for some paediatric outcomes,[24–26] but we do not know of any similar data for paediatric pneumonia. The current study could not evaluate the mechanisms by which community education might modify the association between maternal education and LRI risk, and several possibilities exist.[27] Poor education may be a proxy for low income. This explanation seems unlikely given that community education was associated with LRI incidence independently of community income and employment levels, and that the analysis was restricted to low-income children. Poor education may reflect less access to healthcare resources. However, physician proximity did not predict community LRI incidence. Moreover, many of the rural communities with the poorest educational attainment have health clinics with trained community health aides supported by physicians based in regional hub cities, a system often not available in other rural communities with higher educational attainment.

Community education levels may reflect access to knowledge in general, such as that regarding the benefits of breastfeeding[10] and hygiene[28 29] as well as early recognition of the need for medical intervention when a child is ill. This mechanism would be amplified by lower education levels in rural, predominantly Alaska Native communities, where children may spend a substantial amount of time with persons outside the nuclear family. Lastly, education may be a proxy for individual and community acceptance of science-based rather than traditional interventions.

Table 3 Hierarchical generalised linear model (Bernoulli—population average model) of the independent contribution of maternal education levels on the likelihood of outpatient and inpatient lower respiratory infection (LRI) among Medicaid-enrolled children <2 years; Alaska, 1998–2003

	Outpatient*: OR (95% CI)		Inpatient†: OR (95% CI)	
Independent variable	Bivariate analysis	Multivariate analysis	Bivariate analysis	Multivariate analysis
Level 1 (individual level)				
Alaska Native person				
No	1.0 (reference)	1.0 (reference)	1.0 (reference)	1.0 (reference)
Yes	1.1 (1.0 to 1.2)	1.1 (1.0 to 1.2)	1.8 (1.6 to 2.1)	1.7 (1.4 to 2.0)
Maternal formal education level				
3+ years postsecondary	1.0 (reference)	1.0 (reference)	1.0 (reference)	1.0 (reference)
1–2 years postsecondary	1.4 (1.2 to 1.7)	1.4 (1.1 to 1.7)	1.6 (1.2 to 2.1)	1.5 (1.0 to 2.3)
High school graduate	1.9 (1.7 to 2.3)	1.7 (1.4 to 2.0)	2.1 (1.6 to 2.7)	1.8 (1.2 to 2.6)
Some high school	2.2 (1.8 to 2.6)	1.8 (1.5 to 2.2)	2.7 (2.0 to 3.5)	2.2 (1.4 to 3.3)
Level 2 (community level)				
Percentage of adults aged 25+ years in child's community with <7 years of formal education				
<10%	1.0 (reference)	1.0 (reference)	1.0 (reference)	1.0 (reference)
10–20%	2.7 (1.9 to 3.7)	1.5 (1.0 to 2.1)	3.5 (2.5 to 4.9)	1.9 (1.4 to 2.8)
>20%	5.9 (3.4 to 9.6)	3.0 (1.8 to 4.9)	5.4 (3.5 to 8.3)	2.9 (1.9 to 4.5)
A 10% increment in the percentage of households with modern water service in the child's community	0.83 (0.79 to 0.88)	0.89 (0.85 to 0.94)	0.86 (0.81 to 0.90)	0.94 (0.90 to 0.99)

Multilevel multivariate models included all listed independent variables and were adjusted for Medicaid enrolment.
*N=10 972 (missing 5359).
†N=10 964 (missing 5373).

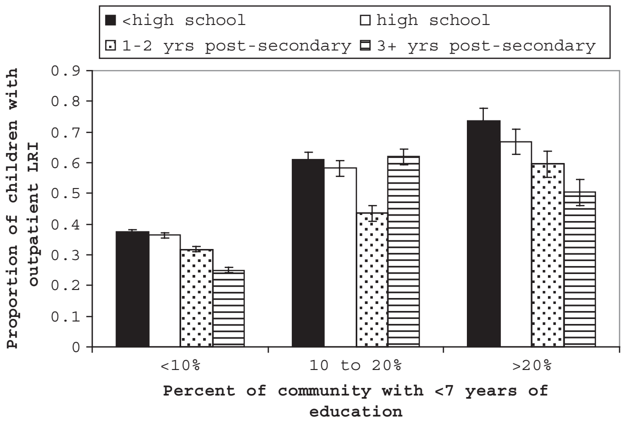

Figure 3 Cumulative proportion of Medicaid-enrolled children age <2 years with at least one outpatient lower respiratory infection (LRI) by maternal education and stratified by the proportion of the child's community with less than 7 years of education; Alaska, 1999-2003. Adjusted for the number of days of enrolment in Medicaid, Alaska Native race and the proportion of the child's community with modern water service. N=12 312.

Study limitations

We used an administrative database, which did not allow verification of the diagnosis of LRI. Our case definition included only instances where a trained provider billed for LRI, but even trained providers may identify LRI when only upper-respiratory infection exists. Consequently, our results may apply more to respiratory-tract infection overall than LRI. Some potentially important risk factors were not available for analysis including breastfeeding history[10] and malnutrition. Breastfeeding initiation and continuation at 4 weeks postpartum vary little by region, Alaska Native status and Medicaid enrolment, making this risk factor unlikely to explain the observed findings.[30] No evidence exists to suggest that protein-calorie malnutrition is a substantial problem for Alaskan children. Nevertheless, micronutrient deficiency, for example vitamin D deficiency, may play a role in respiratory illness in Alaska[31–33] and thus may have confounded the observed associations. Lastly, our study evaluated children enrolled in Medicaid, preventing extrapolation of results to children from more affluent families. Nevertheless, most Alaskan children during the study period enrolled in Medicaid during their first 2 years of life.

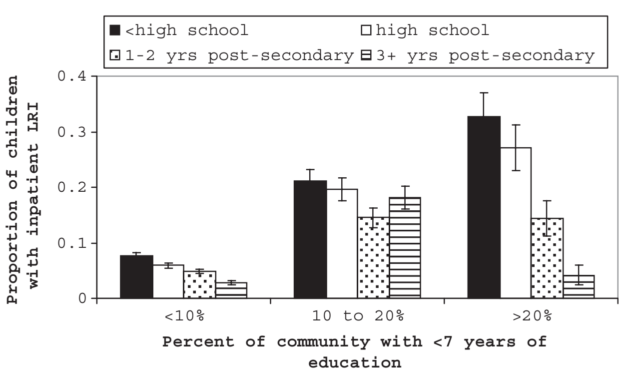

Figure 4 Cumulative proportion of Medicaid-enrolled children age <2 years with at least one inpatient lower respiratory infection (LRI) by maternal education and stratified by the proportion of the child's community with less than 7 years of education; Alaska, 1999-2003. Adjusted for the number of days of Medicaid enrolment, Alaska Native race, and the proportion of the child's community with modern water service. N=12 322.

Policy implications

Although the mechanisms for the association between maternal community education and LRI remain unknown, it is likely that causal pathways are complex and reflect the contribution of formal and informal education, culture, belief systems and migration between urban and rural communities. Consequently, disease burden may not decrease simply by promoting higher education. However, the strong association and dose–response effect suggest that improving education may reduce LRI outcomes regardless of the baseline education level. Our results may be of particular importance to developing countries, where most of the world's pneumonia burden occurs. While most children with LRI outcomes in our study did not have mothers with less than 12 years of education or reside in a community with a high proportion of poorly educated adults, this is not true in many areas of the world, particularly Africa.[34] Consequently, the attributable risk associated with education may be much higher elsewhere than in Alaska.

Concluding remarks

Pneumonia is the leading cause of childhood death worldwide.[3] Rural Alaska differs substantially from rural communities in many other places in that the climate is cold, paediatric human immunodeficiency virus infection prevalence is low, and protein-calorie deficiency is rare. Nevertheless, rural Alaska is similar to rural communities elsewhere with respect to relatively poor education, frequent lack of basic water and sanitation infrastructure, household crowding and an increased importance of traditional belief systems and extended family relationships. Thus, results from the current study may have some relevance for other settings, although this hypothesis requires further testing. If our results are confirmed by others, it might increase education financing as a method of improving child survival.

What is already known on this subject

- Lower-respiratory illness (LRI) is the leading cause of childhood pneumonia in the world.
- Within developed countries, indigenous populations have greatly elevated LRI risks for unknown reasons.
- While maternal education is one of the most important risk factors for child mortality, little data exist linking this variable to LRI risk and no study has evaluated the association between community education levels and LRI.

What this paper adds

- Among low-income Alaskan children aged less than 2 years, when controlling for Alaska Native status and other relevant variables, both low maternal education level and the proportion of adults in the child's community with less than 7 years of formal education were strong predictors of LRI.
- The latter variable was more strongly associated with LRI risk, and higher community education levels substantially mitigated the risk of poor maternal education.

Acknowledgements The authors acknowledge the Alaska Bureau of Vital Statistics for provision of vital records data and assistance with data linkage.

Funding Supported in part by project H18 MC-00004-11 from the Maternal and Child Health Bureau (Title V, Social Security Act), Health Resources and Services Administration, Department of Health and Human Services.

Competing interests None.

Contributors BDG conceived the analysis, performed most of the analyses, wrote the initial manuscript draft, and is the guarantor of the study. M-ARC assisted with analysis and interpretation. SCG performed multilevel modelling and assisted with data interpretation.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

1. **Rudan I,** El Arifeen S, Black RE, *et al*. Childhood pneumonia and diarrhea: setting our priorities right. *Lancet Infect Dis* 2007;**7**:56—61.
2. **Rudan I,** Tomaskovic L, Boschi-Pinto C, *et al*. Global estimate of the incidence of clinical pneumonia among children under five years of age. *Bull World Health Organ* 2004;**82**:895—903.
3. **Rudan I,** Boschi-Pinto C, Biloglav Z, *et al*. Epidemiology and etiology of childhood pneumonia. *Bull World Health Organ* 2008;**86**:408—16.
4. **Holman RC,** Curns AT, Cheek JE, *et al*. Respiratory syncytial virus hospitalizations among American Indian and Alaska Native infants and the general United States infant population. *Pediatrics* 2004;**114**:437—44.
5. **Peck AJ,** Holman RC, Curns AT, *et al*. Lower respiratory tract infections among American Indian and Alaska Native children and the general population of US children. *Pediatr Infect Dis J* 2005;**24**:342—51.
6. **Lowther SA,** Shay DK, Holman RC, *et al*. Bronchiolitis-associated hospitalizations among American Indian and Alaska Native children. *Pediatr Infect Dis J* 2000;**19**:11—17.
7. **Banerji A,** Bell A, Mills EL, *et al*. Lower respiratory tract infections in Inuit infants on Baffin Island. *CMAJ* 2001;**164**:1847—50.
8. **Chang AB,** Grimwood K, Mulholland EK, *et al*. Bronchiectasis in indigenous children in remote Australian communities. *Med J Aust* 2002;**177**:200—4.
9. **Karron RA,** Singleton RJ, Bulkow L, *et al*. Severe respiratory syncytial virus disease in Alaska native children. *J Infect Dis* 1999;**180**:41—9.
10. **Bulkow LR,** Singleton RJ, Karron RA, *et al*. Risk factors for severe respiratory syncytial virus infection among Alaska native children. *Pediatrics* 2002;**109**:210—16.
11. **Bradley JP,** Bacharier LB, Bonfiglio J, *et al*. Severity of respiratory syncytial virus bronchiolitis is affected by cigarette smoke exposure and atopy. *Pediatrics* 2005;**115**:e7—14.
12. **Cardoso MR,** Cousens SN, de Goes Sigueira LF. Crowding: risk factor or protective factor for lower respiratory disease in young children. *BMC Public Health* 2004;**4**:19.
13. **Morris K,** Morgenlander M, Coulehan JL, *et al*. Wood-burning stoves and lower respiratory tract infection in American Indian children. *Am J Dis Child* 1990;**144**:105—8.
14. **Robin LF,** Less PS, Winget M, *et al*. Wood-burning stoves and lower respiratory illnesses in Navajo children. *Pediatr Infect Dis J* 1996;**15**:859—65.
15. **Gessner BD.** Lack of piped water and sewage services is associated with pediatric lower respiratory tract infection in Alaska. *J Pediatr* 2008;**152**:666—70.
16. **Hennessy TW,** Ritter T, Holman RC, *et al*. The relationship between in-home water service and the risk of respiratory tract, skin, and gastrointestinal tract infections among rural Alaska natives. *Am J Public Health* 2008;**98**:2072—8.
17. **Cleland JG,** Van Ginneken JK. Maternal education and child survival in developing countries: the search for pathways of influence. *Soc Sci Med* 1988;**27**:1357—68.
18. **Cochrane SH,** Leslie J, O'Hara DJ. Parental education and child health: intracountry evidence. *Health Policy Educ* 1982;**2**:213—50.
19. **Bicego GT,** Boerma JT. Maternal education and child survival: a comparative study of survey data from 17 countries. *Soc Sci Med* 1993;**36**:1207—27.
20. **Stoltenberg C,** Magnus P, Lie RT, *et al*. Influence of consanguinity and maternal education on risk of stillbirth and infant death in Norway, 1967—1993. *Am J Epidemiol* 1998;**148**:452—9.
21. **Pena R,** Wall S, Persson LA. The effect of poverty, social inequity, and maternal education on infant mortality in Nicaragua, 1988—1993. *Am J Pub Health* 2000;**90**:64—9.
22. **Van Ginneken JK,** Lob-Levyt J, Gove S. Potential interventions for preventing pneumonia among young children in developing countries: promoting maternal education. *Trop Med Int Health* 1996;**1**:283—94.
23. **Kirkwood BR,** Gove S, Rogers S, *et al*. Potential interventions for the prevention of childhood pneumonia in developing countries: a systematic review. *Bull World Health Organ* 1995;**73**:793—8.
24. **Juhn YJ,** Sauver JS, Katusic S, *et al*. The influence of neighborhood environment on the incidence of childhood asthma: a multilevel approach. *Soc Sci Med* 2005;**60**:2453—64.
25. **McGrath JJ,** Matthews KA, Brady SS. Individual versus neighborhood socioeconomic status and race as predictors of adolescent ambulatory blood pressure and heart rate. *Soc Sci Med* 2006;**63**:1442—53.
26. **Grady SC.** Racial disparities in low birthweight and the contribution of residential segregation: a multilevel analysis. *Soc Sci Med* 2006;**63**:3013—29.
27. **Dackam Ngatchou R,** Van Der Pol H. Level of maternal education and mortality: a critical evaluation. *Ann IFORD* 1988;**12**:25—47.
28. **Luby SP,** Agboatwalla M, Feikin DR, *et al*. Effect of handwashing on child health: a randomized controlled trial. *Lancet* 2005;**366**:225—33.
29. **Rabie T,** Curtis V. Handwashing and risk of respiratory infections: a quantitative systematic review. *Trop Med Int Health* 2006;**11**:258—67.
30. **Perham-Hester KA,** Wiens HN, Schoellhorn J. *Alaska Maternal and Child Health Data Book 2004*: PRAMS Edition. Anchorage: Maternal and Child Health Epidemiology Unit, Section of Women's, Children's and Family Health, Division of Public Health, Department of Health and Social Services, http://www.epi.hss.state.ak.us/mchepi/pubs/databook/2004/MCHDataBook04_ch0.pdf (accessed 4 Jan 2009).
31. **Gessner BD,** Plotnik J, Muth PT. 25-hydroxyvitamin D levels among healthy children in Alaska. *J Pediatr* 2003;**143**:434—7.
32. **Wayse V,** Yousafzai A, Mogale K, *et al*. Association of sub-clinical vitamin D deficiency with severe acute lower respiratory infection in children under 5 y. *Eur J Clin Nutr* 2004;**58**:563—7.
33. **Laaksi E,** Ruohola JP, Tuohimaa P, *et al*. An association of serum vitamin D concentrations <40 nmol/L with acute respiratory tract infection in young Finnish men. *Am J Clin Nutr* 2007;**86**:714—17.
34. **United Nations Children's Fund.** *The State of the World's Children 2008: Child Survival*. New York: United Nations Children's Fund, 2008. http://www.unicef.org/sowc08/ (accessed 5 Nov 2008).