

**THE RELATIONSHIP BETWEEN CHILD PERSONAL CARBON MONOXIDE
(CO) EXPOSURE AND AMOUNT OF TIME SPENT IN CLOSE PROXIMITY
TO INDOOR FIRES IN RURAL NORTH-WEST PROVINCE**

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for the degree of Master of Science in Medicine in Epidemiology and Biostatistics**

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DECLARATION

I, Tshepiso Mafojane, declare that this research report is my own work. It is being submitted for the degree of Master of Science in Medicine in Epidemiology and Biostatistics, in the School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

SIGNED :AT JOHANNESBURG

DATE : July 2008

DEDICATION

To my late mother (my hero)
Mosetsanagape Edith Mafojane
1932 - 1997

ABSTRACT

Background: Indoor air pollution due to the burning of biomass fuels has been associated with acute respiratory infections amongst children less than five years old in developing countries. Very little is known about the relationship between child indoor pollution exposure and time spent near indoor fires.

Aim: To describe the relationship between the amount of time that children spend close to indoor fires and carbon monoxide exposure.

Methods: Cross-sectional study based in rural North-West of South Africa. Secondary analysis of caregivers' estimates of their children's time-activity budgets and children's exposure to carbon monoxide (N=100).

Results: The time spent by children near indoor fires is non-significantly related to their CO exposure (regression coefficient -0.030 to -0.036) after adjusting for explanatory variables.

Conclusion: It is important to be cautious about encouraging caregivers to keep children away from indoor fires at the expense of other established intervention strategies.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Exposure to indoor air pollution (IAP), caused by the indoor burning of biomass and solid fuels, has been linked with Acute Respiratory Infection (ARI) amongst children less than five years old. Almost 90% of rural households in some developing countries rely on biomass fuels (wood, charcoal, crop residues and animal dung) and coal as their primary source of energy (Collins et al. 1990; Ezzati et al. 2000; Smith et al. 2000). The incomplete combustion of biomass fuels release hazardous pollutants like particulate matter and carbon monoxide into the living micro-environment (Smith, 1987). ARI is the most common cause of illness and death in children less than 5 years old (Bruce et al. 2000; Smith et al. 2000).

Smith et al. (2000) pg 518 assert that “ARI accounts for 33% of all deaths from infectious disease in the world and for 27% of the entire burden of infectious diseases. Approximately 80% of the ARI burden occurs in children under five years from less developed countries, accounting for about 7% of the global burden of disease from all causes”. IAP is consequently a major public health hazard (Smith et al. 2000).

Despite the acceleration of electricity provision at the household level post 1994 elections and the onset of democracy and the South Africa’s commitment to meet the Millennium Development Goals (MDG) such as a reduction in child mortality, the proportion of households using electricity has only increased by a margin of 26% in the North-West

Province, South Africa (Statistics South Africa, 2003). Even after electricity provision, households continue to use biomass fuels in addition due to affordability (von Schirnding et al. 1991).

From an environmental health perspective, *behavioural change*, (which has the potential to be feasible at house-hold level) has been identified as a possible preventive strategy to mitigate exposure to indoor smoke (Ballard-Tremmer and Mathee, 2000). Behavioural change has to be evaluated in order to contribute towards efforts to significantly reduce child IAP exposure (albeit as a short term measure) and consequently improve health in poor resource settings (Barnes et al. 2004).

Keeping children away from fires has been suggested as a possible intervention strategy that can be easily adopted by a community (Dasgupta et al. 2006). Yet very little information exists on the relationship between the time spent by children near indoor fires and their IAP exposure. This chapter reviews the literature on the determinants of child IAP exposure and provides the basis for the formulation of the aim and objectives outlined in section 1.6.

1.2 Purpose of the study

To determine the relationship between the amount of time spent near indoor fires and child CO exposure.

1.3 Indoor Air Pollution and child ARI in developing countries

Indoor air pollution (IAP) caused by indoor burning of biomass for example wood, charcoal, crop residues and animal dung, is a causal agent of childhood Acute Respiratory Infection (ARI), the most common cause of illness and the largest contributor to mortality amongst young children in developing countries (Smith et al. 2000). Bruce et al (2000) holds that, although the proportion of energy use derived from biomass fell from 50% in 1900 to around 13% in 2000, there is evidence that their use is now increasing among the poor.

The indoor burning of solid biomass in poorly constructed burning appliances results in emission of substantially high primary pollutants such as CO, nitrogen dioxide (NO₂) and particulate matter (PM) mostly in winter (Linn et al. 2000). Young children are often exposed to high levels of indoor air pollution (especially in poorly ventilated housing) and with an increased risk for child ARI (Bruce et al. 2000). IAP has also been linked with lung cancer, tuberculosis, perinatal outcomes including low birth weight, and eye disease (Smith et al. 2000).

Murray and Lopez (1997) estimate that globally, 4% of disability-adjusted life years lost (DALYs) is attributable to indoor air pollution, exceeded by those of malnutrition (16%), sanitation (9%) and unsafe sex (6%). Ezzati et al. (2002) attribute global mortality in excess of 2 million deaths to IAP and, most of which occur in developing countries. The mortality profile of young children in South Africa mirrors this global trend, with Acute

Lower Respiratory Infections listed as the leading cause of mortality in children less than five years (von Schinding et al. 1991b; Bradshaw et al. 2003).

In order to contribute towards the design of intervention strategies, it is important to understand the determinants of indoor air pollution exposure. These factors, which may lie in the pathway between children activity patterns and their resultant indoor air pollution exposure are summarised below.

1.4 The determinants of indoor air pollution exposure

A number of factors have been found to determine child IAP exposure. These include fuels burned, burning appliance, housing features, caregiver characteristics and their behaviour.

1.4.1 Fuels

Household energy fuels lie on a spectrum between solid biomass (for example, wood and cow dung – the most polluting), through to liquid kerosene and light petroleum gas (LPG) to electricity (the least polluting) (Bruce et al. 2000). Fuels that are cleaner require advanced stove technologies to burn them for household energy production, which poor households cannot afford (Smith, 1987). Ballard-Tremmer and Mathee (2000) record a significant decrease in indoor pollutant emission levels; a decrease of between 98-100% for the more liquid fuels (eg. LPG), and improved reduction in indoor pollution of 70-90% when using charcoal.

1.4.2 Burning appliances

Bruce et al. (2000) list stove technologies in developing countries as including the Plancha: a wood burning stove with a chimney, open fireplace: three rocks arranged in a circle, U-shaped hole: simple pit dug in the ground or a poor functioning metal stove. These simple household cooking devices are usually not vented to the outside. Ballard-Tremmer and Jawurek (1996) observed that an improvement in stove combustion characteristics (stoves with chimneys, hence with optimized conditions for complete combustion of biomass fuel) as compared to open fire resulted in up to 66% reduction in indoor pollutant emission.

1.4.3 Housing Features

Well-ventilated houses and larger cooking areas were observed to markedly reduce indoor smoke concentration (Albalak et al. 2001). The availability of a separate kitchen in the house exhibited differentials in the spatial distribution of pollutant concentration, with much improved ventilation than in a house without a separate kitchen (Mehta et al. 2004).

1.4.4 User behaviour

Personal indoor air pollution exposure is known to be determined by both the indoor pollutant concentration and the daily time budget spent indoors (Ballard-Tremmer and Mathee (2000). In particular, few activities involve as much person-time as household chores. Women as child minders (children carried on their back) and their responsibility for cooking, are most heavily exposed to indoor air pollution from biomass burning. Ezzati and Kammen (2002) state that, the kitchen-microenvironment contributes

approximately 75% to women indoor smoke exposure, followed by children with 25% of exposure during winter.

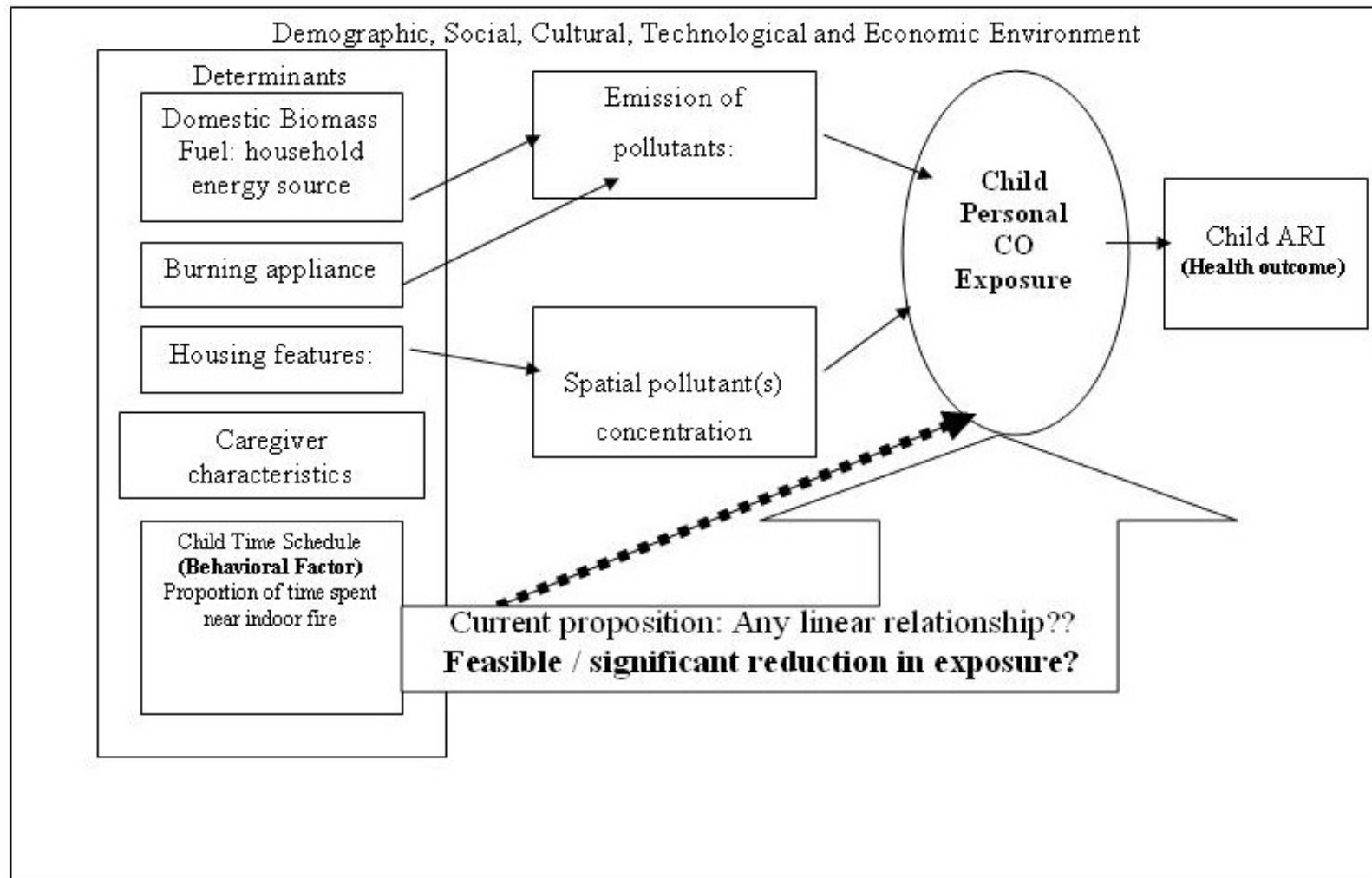
Women and young children are thus consistently closer to the burning source, mostly when fuel is added, the fire is tendered or food is stirred, exposing them to episodes of high indoor pollution levels (Ezzati and Kammen, 2002). The complete activity-schedules of women, and by implication young children, in relation to smoke concentrations, are therefore important determinants of exposure (Armstrong and Campbell, 1991; O'Dempsey et al. 1996)

Albalak et al. (2001) noted a significant decrease in indoor air pollution exposure for cooking done outside as opposed to indoor cooking. Raised fire bed has also been seen to encourage venting, resulting in lowered pollutant emission levels (Ballard-Tremmer and Jawurek 1996).

Given a household in a poor rural setting characterised by many of the characteristics of indoor air pollution exposure as described above, the validity of reducing time to exposure as a cost effective intervention measure therefore warrants an investigation.

Figure 1 on page 7 portrays the conceptual framework of the characteristic factors that may pre-dispose young children to indoor air smoke, and their consequent development of ARI.

Figure1. Conceptual framework



1.5 Study justification

Initial studies on the public health benefits from reduction in exposure to indoor smoke were biased towards technical approaches. The emphasis in much of these studies include changes to the source(s) of indoor smoke emission (hereafter referred to as technical interventions), with the view to reduce indoor air pollutant levels; improved cook stove and their efficiency, provision of cleaner energy sources (movement from solid to the more liquid cleaner fuels and electricity) and well ventilated housing (Albalak et al. 2001; Ezzati and Kammen 2002; Ballard-Tremmer and Mathee, 2000).

Given that developing countries are typically fraught with poverty and poor socio-economic contexts, more expensive technical approaches may not be appropriate in such contexts. Barnes (2005) pg.69 argues that technical interventions pose difficulties in terms of application and sustenance “in contexts where the dissemination, uptake and maintenance of technical interventions are likely to be hindered by poverty”.

In 1997, The World Health Organization (WHO), cognisant of affordability and sustainability challenges of technical interventions, encouraged work on simple exposure indicators and an examination of the feasibility of carrying out controlled intervention studies at household level (Ezzati and Kammen, 2002).

Not disregarding the gains realized through technical approaches, pertinent questions that relate to behavioural factors as components of exposure therefore, need to be examined. (Barnes, 2005; Bruce et al. 2000; Smith et al. 2000; Ezzati and Kammen, 2002).

Argawal (1994) also discussed the potential role of behaviour change, showing that intervention strategies that are not robust to behaviour tend to face resistance and may result in failure of well-intended programs. The contribution of time spent by children near indoor fires relative to their personal CO exposure need to be examined, because smoke levels in daily child CO exposure seem to imply that a significant reduction in total exposure can be achieved by keeping children away from indoor fires (Barnes, 2005; Bruce et al. 2000; Smith et al. 2000; Ezzati and Kammen, 2002). Dasgupta et al. 2006, for example, suggested that keeping children away from indoor fires provides a short to medium term solution to a reduction in child indoor air pollution exposure.

However, the actual relationship between time spent by children near indoor fire and their CO exposure has not been explored.

Behavioural change opportunities thus exist; the efficacy of reducing time to exposure as an efficient ARI risk mitigating factor need to be evaluated. Keeping children away from fire as a cost effective, viable intervention strategy has to be explored and possibly implemented at the household level, especially in poor resource settings where the implementation of technical strategies may not be feasible.

In sum, if time spent by children near burning fires shows significant association to their personal CO exposure, and the association holds after adjusting for possible confounding, this will have important implications for the potential health gains that might result from reducing exposure by different amounts (Smith and Sammet, 2000; Barnes, 2005; Bruce et al. 2000; Ezzati and Kammen, 2002) and, as Bruce et al. (2000) pg 1087 puts it, “to quantify the relationships between exposure level and risk ”.

1.6 Aim and objectives

The aim of this study therefore is to explore the relationship between caregiver estimates of the amount of time that children (younger than five years old) spend in the vicinity of indoor fires and child personal CO exposure. To achieve this, the study will have the following objectives:

1. To describe the amount of time that children spend in the vicinity of indoor fires over a 24-hour period.
2. To describe levels of child exposure to CO over a 24 hour period.
3. To describe the relationship between the amount of time that children spend in the vicinity of indoor fires and child personal CO exposure.
4. To describe the multivariate relationship between the amount of time that children spend in the vicinity of indoor fires and child personal CO exposure while adjusting for explanatory variables.

CHAPTER 2: METHODS

2.1 Introduction

Pursuant to the goal of establishing whether keeping children away from indoor fires (as advocated for in the previous chapter) is an effective strategy to minimise child CO exposure, a quantitative method is presented in this chapter to evaluate the efficacy of this strategy with the object of achieving objectives outlined in section 1.6.

2.2 Study Design

This is an analytical, cross-sectional study based on secondary data collected from a rural setting in the North-West Province during the winter of 2003 by the Medical Research Council (MRC) of South Africa to determine the feasibility of behavioural change in reducing child CO exposure.

2.3 Study Population

Indoor Air Pollution, socio-economic and demographic data for the winter 2003 were extracted from the Medical Research Council database covering the Tribal-Delareyville district in the North-West Province, South Africa. The inhabitants are largely black Africans who speak seTswana. The households in this rural district is typical of that in a developing country, characterized by poorly constructed housing, low educational levels, high unemployment rate and low household income. Solid fuel, the primary source of domestic, household energy are burnt in poorly constructed (old), inefficient stoves with poor venting.

This district is amongst the poorest in the North-West province, 65.1% of whose populace are rural inhabitants (Statistics South Africa, 2003). Preliminary survey undertaken then by Barnes (2004) indicated a large reliance on solid fuels as source of household energy.

2.4 Study Sample

A purposive, random sample of 100 families with children between 0-59 months was drawn from the study population. Households were purposively selected based on criteria that they had low household income, relatively poor access to clean energy such as kerosene and electricity, and were largely dependent on biomass that was freely accessible.

2.5 Materials and methods

- 1. Sources of data:** A questionnaire was administered by trained research assistants (after securing consent from households to participate in the study) that included questions on the amount of time that children spend in the vicinity of fires, child age in months, child sex, availability of child minder and other related questions. Child personal CO exposure measurements were collected using the Draeger CO passive diffusion tubes attached to the youngest child for 24 hours. Published evidence show that the Draeger passive diffusion tubes are reasonably reliable (Traynor et al. 1991). Naehler et al (2000) has found that CO is a good proxy for PM_{2.5}, the main criteria pollutant for child ARI. Draeger CO diffusion tubes could thus be used to determine child CO exposure measurements, as CO and

particulate emissions have been found to be well correlated in wood-smoke combustion environments (Naeher et al. 2000). Data were also collected on fuel type, appliance type, housing characteristics, burning location, which are thought to be possible confounders.

2. **Abstraction of data:** Details considered important for cases in this study were demographic data of children, the time they spent in close proximity to indoor fires and their personal CO measure. Factors considered to mediate between proportion of time spent by children near fires and child CO here-in taken as confounders, were also included.

2.6 Quantitative study

2.6.1 Outcome measures

Following the hypothesis that reducing the amount of time spent by children near burning indoor fires might affect their CO exposure, keeping children away from indoor fire is the main outcome measure. Also, given that this study is based at the household level, a number of factors are thought to affect the impact of the proposed intervention measure, and may consequently confound the relationship between child CO exposure and the time they spent near indoor fires. These factors are adjusted for in the quantitative analysis and include child age, child sex, caregiver age, caregiver education, dwelling type and household income. Figure 1 on page 7 portrays the conceptual framework for the quantitative analysis. Outcome measures used in the quantitative analysis are outlined in Table 2 on page 14.

Table 2 Outcome measures used in the quantitative study.

Variables	Justification
Child Age	Young children are consistently near burning fires and, age-specific data showed greater effect in infants than during the second year of life (Armstrong and Campbell, 1991; O’Dempsey et al. 1996).
Child sex	Armstrong and Campbell found that the risk of pneumonia in association with smoke exposure was increased in girls and not with boys (Armstrong et al. 1991).
Fuel type	The composition of smoke was found to be associated with poor energy sources (Albalak et al. 2001).
Stove type	Emission rates for biomass smoke and effective mean exposures were found to be significantly different between those due to cooking stove and open fires (Ezzati et al. 2000).
Household income	The choice of cleaner fuels is related to the affordability of poor, rural household to purchase those fuels (Barnes, 2005).
Support to keep child away from fires	Availability of additional helpers to mind the child assists in keeping them from indoor fires (Barnes 2005).
Caregiver education	Literate and fairly educated child care-givers are thought to be knowledgeable about the health benefits of keeping children away from fires (Kirkwood et al. 1995)
Perceived health benefits	Whether child caregivers believe that it is worthwhile to keep children away from smokey areas, especially during peak levels of biomass burning cycle (Ezzati et al. 2000)
Floor type	Indoor air pollution has been significantly associated with home interior surface type, eg. mud wall and dung floor (Albalak et al. 2001).

2.7 Data Analysis

Data was processed and analyzed using SPSS. Frequencies, percentages and other descriptive statistics, were used to describe the main characteristics of the study population and the distribution of child CO exposure and the distribution of time spent by children near indoor fires. Correlation coefficient(s) were employed to illustrate the relationship between child CO exposure and selected outcome measures; and the relationship between other outcome measures (possible confounders) variables. Regression analysis was also employed to establish the (multivariate) determinants of child CO exposure, notably time spent near burning indoor fires. Variables examined were child CO exposure in association with the time they spent in close proximity to fires, while adjusting for possible confounding variables.

2.8 Ethics

The proposal for this study, based on data collected by Brendon Barnes in 2003, was submitted to and approved by the Ethics Committee for Research on Human Subjects of the University of the Witwatersrand, Johannesburg, South Africa.

Protocol Number M03-05-43.

CHAPTER 3: RESULTS

The study was carried out to evaluate the possible effectiveness of keeping children away from indoor fires, in a bid to reduce their personal CO exposure. Quantitative analysis was done to identify factors that determine child indoor pollution exposure and their direction.

3.1 Background: Socio-demographic characteristics

A sample of 100 children less than five years old who participated in the study was drawn. The mean number of children in households participating in the study was 1.67 (range: 1 to 5). The mean child age was 19.91 months (range: 0 to 48, Std. Dev. =14.31). Approximately 48% of children were in the 0-18 month age category; 23% of whom were female children (see Table 3.1).

Table 3.1 Age distribution (in months) of study population

	Minimum	Maximum	Mean	Std. Dev.	% of children <18 Months
Overall	0	48	19.91	14.314	48%
Male (n=57)	1	48	21	14.001	25%
Female (n=43)	0	48	18.47	14.759	23%
No. of children <4years old	1	5	1.67	0.85	

3.2 Distributions of *child CO* and *Time* near indoor fire

Child personal CO exposure at most reached 25 ppm/hrs (range: 0.42 - 25); a threshold of 30 p.p.m. (a standard set by WHO (2000) for 1 hour period of exposure)) was not exceeded. This finding is agreeable with work done by Röllin et al. (2004) in a similar setting. Furthermore, there was no significant difference ($P = 0.91$) between mean male and female child personal CO exposures (4.01 p.p.m/hrs v/s 3.94 p.p.m/hrs).

Table 3.2.1 Child personal CO exposure

	Minimum	Maximum	Mean	Std. Deviation	Mean level (p.p.m.)
CO child	10	600	96.21	119.02	4.01
CO female	10	600	94.53	131.29	3.94
CO male	11	600	97.47	110.04	4.06

The mean time spent by children near indoor fire was 2.53 hours and, this average period ranged from 0 to 8 hours. No significant difference exist ($P = 0.22$) between mean time spent before indoor fires for male and that of female children (2.29 v/s 2.84).

Table 3.2.2 Child Time (in minutes) within 1.5m

	Minimum	Maximum	Mean	Std. deviation	Mean time(hr)
Female	0	480	170.26	125.89	2.84
Male	0	470	137.45	125.39	2.29
Child total	0	480	151.67	125.97	2.53

3.3 Potential confounders (extraneous factors)

3.3.1 Household monthly income (Table 3.3.1)

Monthly earnings were, in 78% of the households, less than R1000. This is in tandem with the fact that 40% of households in this community use wood and, 32% use both wood and cow dung; and 72% of homesteads using biomass for energy production

Table 3.3.1

Income (Rand)	Number of Households	Percent	Cumulative Frequency
Less than 500	37	37.0	37.0
500 - <1000	41	41.0	78.0
1000 - <1500	14	14.0	92.0
>1500	8	8.0	100

3.3.2 Care-giver Education (Mother, Table 3.3.2)

Generally, the educational profile of caregivers was low; 27% of caregivers had no formal education, 52% with primary school and the rest with some secondary education.

Table 3.3.2

Education Level	Frequency	Percent	Cumulative Frequency
No Education	27	27.0	27
Primary School	52	52.0	79
Secondary School	21	21.1	100

3.3.3 Perceived health benefits (Table 3.3.3)

An exploration of the association between caregiver belief about the health benefits of keeping the child away relative to indoor fire indicated that 59% of caregivers had a positive perception about the health benefits of keeping children away (Table 3.3.3).

Table 3.3.3

Perceived confidence	No. of respondents	Percent	Cumulative frequency
Not confident	13	13.0	13.0
Somewhat confident	26	26.0	39.0
Very confident	59	59.0	98.0
Not sure	2	2.0	100

3.3.4 Family support to keep child away from fires (Table 3.3.4)

In terms of the reported availability of family support to take care of the child, who would otherwise be carried on mother's back while cooking; 73% of households had another child-minder other than the respondent (Table 3.3.4).

Table 3.3.4

Level of support	No. of respondents	Percent	Cumulative frequency
No support	6	6.0	6.0
Moderate support	18	18.0	24.0
Much support	73	73.0	97.0
Not sure	3	3.0	100

3.3.5 Floor type (Table 3.3.5)

Most dwellings were fairly well constructed, with 31% of houses having floors made of cow dung and, 52% with floor made of concrete (see Table 3.3.5).

Table 3.3.5

Floor material	No. of respondents	Percent	Cumulative frequency
Concrete	52	52.0	52.0
Cow dung	31	31.0	83.0
Bare earth	8	8.0	91.0
Concrete + dung	5	5.0	96.0
Cow dung + bare earth	1	1.0	97.0
Concrete + bare earth	3	3.0	100

3.4 Modelling relationship between *child CO* and *Time* spent near indoor fire.

The linear regression model was used to analyze the relationship between child personal CO exposure and the amount of time they spent near burning indoor fires. The units of analysis are 100 children under age of 5 years in rural North-West province sourced from Medical Research Council, Johannesburg database. Only six other independent variables are considered (Table 2, pg. 14), partly to reduce multi-collinearity in the set of independent variables, but also as motivated for in section 2.6.1.

Table 3.4.1 Correlation matrix

	Time(1.5m)	Child sex	Income	Education	Child age	Benefits	Support	Floor	Child CO
Time	1								
Child sex	0.13	1							
Income	-0.156	0.026	1						
Education	-0.177	-0.051	-0.155	1					
Child age	0.021	-0.095	-0.118	-0.094	1				
Benefits	-0.089	-0.121	0.013	0.049	0.177	1			
Support	-0.225*	-0.153	0.048	-0.091	0.052	-0.001	1		
Floor	-0.366**	-0.033	0.187	0.170	-0.008	0.165	0.024	1	
Child CO	-0.003	-0.012	-0.007	-0.066	0.034	-0.082	-0.083	0.00	1

*Correlation is significant at the 5% level

** Correlation is significant at the 1% level

3.4.2 Regression analysis

Table 3.4.2 Uni-variate analysis (Child CO v/s Time 1.5m away)

Variable	Beta coefficient	Standardize	t-value	Significance
		d Coefficients Beta		
Constant	103.76		6.296	0.000
Time 1.5m away from fire		-0.030	-0.276	0.783

$R^2 = 0.001$; Dependent Variable: Child CO.

Table 3.4.3 Multivariate analysis (Child CO v/s selected Independent Variables)

Variable	Beta Coefficient	Standardize	Significance	Correlations (Partial)
		d Coefficients Beta		
Constant	243.58		0.064	
Child sex		-0.049	0.665	-0.046
House income		-0.034	0.812	-0.032
Caregiver education		-0.067	0.601	-0.064
Child age		-0.001	0.952	-0.001
Perceived health benefits		-0.111	0.343	-0.108
Support to keep child away		-0.115	0.321	-0.110
Floor type		0.036	0.664	0.033
Time 1.5m away from fire		-0.036	0.884	-0.033

Adjusted $R^2 = 0.026$; Dependent Variable: Child CO.

3.5 Analysis Results

The correlation of the dependent variable with each of the independent variables (Table 3.4.1) suggest that the hypothesized relationships – between child CO exposure and time spent near indoor fire, care-giver characteristics, housing features, child characteristics - are borne out, though weak and statistically insignificant. Variables child sex, care-giver education (education), perceived benefits to keep children away from fires (benefits), family support to keep children away (support) and floor type (floor) are represented by indicator variables, coded as 0 or 1. Child sex is coded 0 for female and 1 for male child; education coded 1 for non-formal and 0 for formal; benefits coded 1 for poor perception and 0 for good perception; support coded 1 for non-family support and 0 for family support, and floor coded 1 for poor condition and 0 for good condition.

The (linear) relationship to all independent variables is as generally postulated (Tables 3.4.2 and Table 3.4.3): keeping children away has some benefit, though statistically insignificant; girl children are more prone to CO exposure compared to male counterparts; improved levels of house income, care-giver education, child age, perceived benefits and family support to improve child location relative to indoor fire and reduction in time near fire are protective against child CO exposure, while poor floor conditions enhance child CO exposure.

Inclusion of all independent variables in the regression gives a multiple correlation coefficient (R) of 0.16, so that the “degree of explanation” of child CO exposure can be regarded as 2.6 percent (coefficient of determination = R^2).

CHAPTER 4: DISCUSSION

4.1 Introduction

Indoor locations have been shown to predispose children to diverse, respirable particulate matter and gaseous substances (produced by combustion) that pose adverse health effects through exposure to these environmental air contaminants. Indoor air pollution in particular, precipitated by biomass smoke (emitted from incomplete combustion of biomass fuel, the primary source of household energy in developing countries) contains CO, the principal indoor air pollutant that has been shown to lie in the causal pathway for ARI. In South Africa, ARI is listed as one of the principal causes of pre-mature deaths amongst children less than five years old (Bradshaw et al. 2003; von Schinding et al. 1991).

The central focus of this *strategy* research has been to explore whether keeping children away from fires (behavioural modification) has any significant relationship with reducing child CO exposure. To accomplish this objective, the scope of the investigation was narrowed to household-level variables; child personal CO exposure and the time they spend near burning indoor fires being the primary variables in the analysis.

This chapter discusses the findings of this study with reference to the study objectives as outlined in section 1.6, and the literature review used to formulate them. Data analysis shows that the majority of dwellings (cumulative percent of 77) had a strong reliance on biomass fuels. Röllin et al. (2004) in a similar study found that houses that used biomass

exclusively for household energy production had some of the highest indoor air pollutant concentration as opposed to those using cleaner fuels. Children in this study spent fairly high periods of time near indoor fires (see Table 3.2.2) and were exposed to high levels of indoor air smoke during winter (Table 3.2.1).

Since the aim of this study was to determine the relationship between child CO exposure and the amount of time spent near indoor fire, regression analysis was used to adjust for potential confounders, which included household income, child sex, child age, floor type, caregiver education, family support to keep child off indoor fires and perceived (belief) benefits of keeping child off indoor fire; these extraneous factors may complicate the establishment of the existence of a relationship between child CO and the time they spend near fires. It was found that regression coefficients for all the explanatory factors (Table 2, pg 14) are intuitively correct, and in agreement with the published literature. The fact that none of the extraneous factors (controls) were non-significantly associated with child CO exposure may be a result of them being poor proxies for child CO exposure. The chapter ends with a critique of the study design and its findings.

The controls that were selected for this research report, though arbitrary, reflect setting of a typically poor, rural community. By adjusting for confounders, this research report attempts to adjust for the effect of an extraneous factor (confounder) which may mediate between the interaction of time spent by children near fire and their resultant CO exposure. In order to see how various confounders affect the relationship between child

CO exposure and the amount of time they spent near indoor fire, stepwise regression analysis was used, and improvement in the coefficient of determination was observed.

Confounders were confirmed to affect this relationship, with the coefficient of determination improving from $R^2 = 0.001$ to $R^2 = 0.026$. Therefore these factors can be thought to modify the relationship between child CO exposure and the time they spend near indoor fires.

4.2 Determinants of child CO exposure

In order to examine the determinants of child CO, correlation coefficient between the dependent variable and a set of independent variables were calculated, and regression analysis was employed to establish the existence of a linear relationship between child CO exposure and explanatory factors. The results are presented in Table 3.4.1 through to Table 3.4.2. and Table 3.4.3 respectively.

It should be noted that the (size of) correlation coefficients between a specific pair of explanatory variables may be spurious due to multi-collinearity, making it almost impossible to assess the individual effect of independent variables on the dependent variable using regression analysis. All the variables are correlated and specifically in Table 3.4.1 Time is significantly correlated with Support ($r = -0.225$) and also with the Floor ($r = -0.366$); Older age was protective of child CO exposure ($r = 0.021$); child CO

exposure decreases with improved household income, which supports the argument that affluent families can afford cleaner fuels (Barnes 2005).

Educated mothers are most likely to be conversant with the benefits of keeping children away ($r = -0.177$) and, family support availability promotes the chances of keeping children away ($r = -0.225$).

4.3 The association between child CO exposure and selected outcome measures

This study sought to determine (primarily) the relationship between amount of time spent by children near indoor fires and their CO exposure, and whether keeping children away from fires as a proposed intervention measure can be attributed to selected explanatory factors (discussed in sections 3.3.1 to 3.3.5). Keeping children away from fires is taken as the dependent variable.

4.3.1 Household income

Monthly earnings were, in 78% of the households, less than R1000. This is in tandem with the fact that 40% of households use wood and, 32% use both wood and cow dung. The theory that affluent households have an advantage with regard to fuel choice is valid as postulated in literature (Barnes 2005) and, the study yielded a positive result, albeit weak and statistically insignificant between child CO exposure and household income; that is, improved household income offers a preventive measure to child CO exposure ($\beta = -0.034$).

4.3.2 Child characteristics

The average age of the child in this study is 19.91 months and, female children are comparatively younger than their male counterparts (see Table 3.1) and these female children spend relatively longer periods of time near fires (see Table 3.2.2), though there is a strange observation in their decreased level of CO exposure compared to male children (94.53 and 97.47 respectively). The raised level of time spent by female children near fires is in agreement with literature, that they ‘share’ execution of household chores of cooking with the mother (Armstrong et al 1991), and it could also be due to their young age, thus being carried possibly at mothers back during cooking (O’Dempsey et al. 1996). The regression coefficients for child sex ($\beta = -0.049$) and child age ($\beta = -0.001$) suggest that elderly children would not be susceptible to high levels of CO exposure, but also that female children are more prone to raised levels of CO exposure; male children would be -0.049 less likely to be subjected to CO exposure (see Table 3.4.3).

4.3.3 Caregiver characteristics

Child caregivers in this study display the potential not only to comprehend the health benefits of keeping children away from indoor fires (see Table 3.3.2 and Table 3.3.3), but also to sustain such ‘modified’ behaviour if the necessary education and family support (Table 3.3.4) arrangements are in place. Much of these caregivers exhibit these necessary attributes even under these dire socio-economic circumstances (Kirkwood et al. 1995; Ezzati et al. 2000 ; Barnes 2005) and thus present with the opportunity perhaps to launch massive educational campaigns about the health benefits of ‘keeping susceptible children away from indoor fires’.

4.3.4 Dwelling type

Most of the dwellings were poorly constructed, either of mud or corrugated iron. The mean number of rooms per house was 4.1 and, approximately 24% with two rooms or less. 86% of homesteads have at most two windows and, 13% have barely a window. 31% of houses have floors made of cow dung and close to 36% of the houses have wall made of mud. These household have fairly high occupancy rates; 20% of households have three people who share a bed with a child, 12,8% of households with six people who share a bed with a child. Albalak et al. 2005 contend that properly built households reduce not only the composition of indoor smoke, but also its concentration per unit volume in the household. Housing characteristics like number of windows, occupancy rate, number of rooms could find their expression through floor type as a housing feature. The correlation between child CO exposure and floor type could thus be a valid proxy about housing features and, it supports the assumption (together with the regression coefficient, $\beta = 0.036$) that poor housing construction enhances child CO exposure.

These results, though statistically insignificant, support the idea that keeping children away from indoor fires affect child CO exposure, with the resultant decrease in the prospects of them developing ARI.

This research report confirms a negative relationship between child CO exposure and amount of time they spend near fires, though insignificant ($\beta = -0.030$). Also, after adjusting for possible confounding, level of child CO exposure drops by 0.036 for every

unit increase in the child's distance (1 meter) away from indoor fire (see Tables 3.4.2 and 3.4.3).

4.4 Strengths and weaknesses

The study design, with reliance on data for only (part of) a single year, is inherently limited to the extent that it could not capture, with reasonable certainty, the daily changes in time spent by children near fires. Empirical relationships have been found to be fairly stable over time if based on longitudinal data (Naeher et al. 2001). More crucial perhaps, is the possibility that children may differ in the duration and time spent near burning fires relative to high (peak) pollution levels for a particular part of the day (Naeher et al. 2000). Rollin et al. (2004) has also observed that real-time “measurable levels of CO are synchronous with the time of cooking”.

Naeher et al. (2000) has shown that there are significant variations in the production ratios of particulates and CO at different times during the wood burn cycle. The ideal situation would be for child minders to keep child-activity *diaries* (Ezzati et al. 2002). Information collected retrospectively with regard to child time-activity budgets is quite a demanding exercise and, respondents in surveys often scrawl illegible responses. Impact of strict participation (in adopting behaviour that has the potential to significantly reduce child CO exposure) has a profound effect on affecting the outcome of child CO exposure (Bruce et al. 2000).

Mis-classification of exposure through recall bias thus, which is typical of retrospective cross-sectional studies, presents the possibility that limited information is available to quantify the relationship between child CO exposure and proportion of their daily routine time spent near indoor fire.

Poor and statistically insignificant parameter estimates based on such limited evidence leads to less robust quantification of the relationship between child CO exposure and amount of time they spend near burning indoor fires.

Secondly, in examining the possibility of a linear relationship, cross-sectional data were thought to embody the implicit assumption that model parameters are constant across households and over time. Systematic differences among child CO exposures, the differing household characteristics and related time-activity patterns of children are not trivial. In fact, cross-sectional data (which lack the dimension of time and the continuous monitoring of child CO exposure in this instance) were being used in this study to estimate a model whose parameters may in fact vary over time and across households. Child caregivers differ in their response to willingly cooperate with (all the) components of the study, because they face different restrictions on their behaviour (Barnes 2005). Agarwal (1983) found that a household's compliance in the uptake of intervention strategies depends fundamentally on "it's distinctive, sustainable participative advantage which derives from the possession and use of peculiar, non-transferable, household-specific resources". For example, high income households have more discretion in their

choice of fuel type/spending and, educated child minders would be somewhat more confident about the health benefits of keeping the child away from indoor burning fire.

That is, the resultant outcome of the relationship between keeping children away from indoor fires and key child outcome of a measured reduction in child CO exposure, are all dependent on household-specific characteristics. Furthermore, only one micro-environment (household) and snapshot of child time schedules lead to a loss of resolution in the correlation between child CO exposure and the time they spent near indoor fires.

There is therefore a need for a systematic, standardized approach to *monitor levels* and *trends* of (CO) exposure (Bruce et al. 2000) to markedly strengthen the evidence of a possible relationship between child CO exposure and the time they spend near indoor fires. Such randomized controlled intervention studies would obviate uncertainty in study results.

This study has established that keeping children away from fires, as a single enabling factor is not a sufficient behavioural practice to reduce child CO exposure; other contextual enabling factors, such as mother's education and household income, are probably more important in determining outcome in child CO exposure. Also, given that many of the explanatory variables in the model are linearly combined (multi-collinearity), the distinct and differential effect of each factor (behavioral intervention strategy) is masked by other factors.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

This study sought to verify the possible effectiveness of keeping children away from indoor fires to reduce child CO exposure. Reduction in the amount of time spent by children near burning indoor fires has been determined as beneficial, although it has not been found to be statistically significant as a (*sole*) enabling/mitigating factor. Keeping children away from (for extended periods of time) indoor fires cannot thus be promoted at the expense of the more established intervention strategies.

This study has most probably accentuated two subtle issues worth lots of thought: it has magnified to some extent the limitations in the use of cross-sectional data to estimate a linear relationship between two variables that are time dependent.; secondly it has emphasized the need to appreciate the importance of an across-household variation for intervention strategy research, and by default perhaps argued for an adoption of improved methods that would explicitly incorporate variation in model parameters across households and (or) over time.

Longitudinal studies based at household level (prospective cohort study, for example) would permit the more robust investigation of the empirical relationship between the two variables of interest, as well as allowing one to account for the possible omission of important explanatory variables.

The results from this study have some contribution (though limited) towards policy formulation and (intervention) programme implications, including campaigns to educate communities about the risks of child exposure to indoor smoke and, where the use of cleaner fuels is prohibitive due to poverty, a move to encourage behaviour modification in keeping children away from indoor fires. To ensure effectiveness of this approach, factors that promote the adoption of this behavioural approach strategy should be strengthened and, local needs and community participation should be given a priority.

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APPENDIX A

APPROVAL OF TITLE

APPENDIX B

ETHICAL APPROVAL CERTIFICATE