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Emily Frost Date

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By

Emily Frost
Master of Public Health

Hubert Department of Global Health

____
Melissa Fox Young, PhD
Committee Chair

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BA, Brandeis University, 2010

Thesis Committee Chair: Melissa Fox Young, PhD

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

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By Emily Frost

[Text of Abstract – no more than 350 words, single spaced]

Objectives Stunting is a major public health problem, affecting 156 million children under five. Respiratory infections are common among children in developing countries, especially those in biomass-fuel using households. Given that repeated infection during childhood has been linked to poor child growth, this study aimed to examine the relationship between exposure to air pollution from biomass fuel smoke and stunting in children under five in the Democratic Republic of Congo.

Methods Data are from the 2013-2014 Demographic Health Survey with a sample of 7,675 children under five with weight and height data available. Air pollution was measured by classifying both the reported cooking fuel used and the place cooking occurred in the household. Confounders controlled for were: maternal education level, child age, type of residence, wealth, maternal height, dietary diversity, parity, sex, maternal age at first birth, and if a household member smokes cigarettes inside.

Results In the adjusted model, exposure to biomass fuels cooked indoors, not in a separate room, was associated an increased risk of child stunting (OR=1.23; 95% CI 1.01, 1.50). Other significant covariates include maternal secondary or higher education (OR=0.72; 95% CI 0.60, 0.88), age of child (OR=1.04; 95% CI 1.03, 1.04), maternal height (OR=0.95; 95% CI 0.94, 0.96), and being in the richest wealth quintile (OR=0.95, 95% CI 0.94, 0.96).

Conclusions Indoor air pollution may be adversely impact child growth in this context. This research supports the need for a multi-sectoral approach that combines environmental, nutritional, and economic strategies to address child stunting.

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Abbreviations

COPD	Chronic Obstructive Pulmonary Disease
DALY	Disability-Adjusted Life Year
DHS	Demographic Health Survey
DRC	Democratic Republic of Congo
HAZ	Height-for-age Z-score
IYCF	Infant and Young Child Feeding
RUTF	Ready-to-Use Therapeutic Food
UNICEF	United Nations Children’s Fund
WHO	World Health Organization

Chapter 1: Introduction

Child health worldwide has dramatically improved in recent decades. The number of annual under-five deaths has decreased from 12.7 million in 1990 to 5.9 million in 2015; the under-five mortality rate has fallen by half [1]. Global prevalence of stunting and wasting have also seen improvements [2].

Despite these large-scale advances, some areas are improving at slower rates than others. Undernutrition in sub-Saharan Africa increased from the 1980s until the late 1990s, only after which rates started to fall [2]. Declines in stunting prevalence have been slowest in west and central Africa, which has seen only a 21% decline since 1990; the number of stunted children in this area has actually increased by five million in this period [1].

Almost half of all under-five deaths globally are attributable to undernutrition [1]. In 2012 the World Health Organization adopted a resolution aiming to reduce maternal and child malnutrition [3]. The first target aims to reduce stunting in children under five by 40%. The UN has adopted similar goals; Target 2.2 of the Sustainable Development Goals aims to end all forms of malnutrition, including stunting and wasting, by 2030 [4].

Stunting is defined as a height to age Z-score below -2 standard deviations from the mean (using the WHO, 2006 child growth reference [5]), and is reflective of chronic malnutrition [6]. Most stunting occurs within the first two years of life [7]. An estimated 156 million, or 23.2%, of children under five worldwide are stunted [8]. Stunting has long term effects on a child's development; it is associated with lower school performance and educational outcomes, a decrease in cognitive development and skills [9-12], behavioral problems, a lower IQ, and reduced motor skills development [12]. Malnourished children suffer from more attention problems, lower social status, and lower standard of living as adults [12]. They also achieve lower schooling levels and educational outcomes [10, 13], which can lead to a decrease in adult income [13]. Each 1% loss in adult height due to stunting is associated with a 1.4% decrease in productivity [14]. Children born to stunted mothers have increased risks of perinatal and child mortality [9], and are more likely to be underweight and stunted themselves [15]. The effects of undernutrition can last for three generations [10].

Given the severe and long-lasting consequences of stunting, its widespread nature, universally acknowledged importance, and direct association with poverty [7], identifying potential determinants of stunting and low-cost interventions is a public health priority. The objective of this paper is to address the gap in literature examining the relationship between exposure to biomass fuel (indoor air pollution) and childhood stunting in the DR Congo, to inform future interventions aiming to reduce childhood stunting.

Chapter 2: Literature review

Malnutrition - global context

i. malnutrition overview

Protein-energy malnutrition is often measured using one or a combination of three measures:

- Stunting: a height to age z-score below -2 standard deviations from the mean
- Wasting: a weight to height z-score below -2 standard deviations from mean
- Underweight: a weight for age z-score below -2 standard deviations from the median [6]

Wasting is associated with short term malnutrition and is usually seasonal, whereas stunting is indicative of chronic malnutrition [7].

Childhood nutrition has long term effects on a child's cognitive, motor, and socio-emotional development [12]. In children, stunting is associated with lower school performance and educational outcomes and a decrease in cognitive development and skills [9-12] as well as behavioral problems, a lower IQ, and decreased motor skills [12]. Crucial brain development occurs during infancy; undernutrition at this time damages the brain and impairs the development of these skills [10].

Longitudinal studies report that stunted children have increased levels of depression and anxiety, and lower levels of self-esteem in adolescence [11]. Malnourished children suffer from more attention problems, lower social status, and lower standard of living as adults [12]. They also achieve lower schooling levels and educational outcomes [10, 13], which can lead to a reduction in adult income [13].

In addition, stunting can have intergenerational impacts. Stunted children are more likely to become stunted adults [9]. Stunted mothers have an increased risk of a difficult vaginal birth, since they themselves are smaller, which can lead to maternal mortality or disability [9]. Children born to stunted mothers have increased risks of perinatal and child mortality [9], and are more likely to be underweight and stunted themselves [15].

ii. global burden of malnutrition

Almost half of all under-five deaths globally are attributable to undernutrition [1]; more than one million deaths worldwide are attributable to stunting [11]. Of the 10.5 million deaths each year of children under five, 99% occur in low- and middle- income countries and 40% in sub-Saharan Africa [16]. Half of the deaths of children under the age of five occur within the first month of life [16].

In low- and middle- income countries, disease burden is largely due to risk factors associated with poverty [16]. Undernutrition, which includes both protein-energy malnutrition and micronutrient deficiencies, was the leading cause of global health loss in both 1990 and 2001 [16]. Malnutrition in children is often aggravated by infection, which then exacerbates children's poor nutritional states [17, 18]; see *Malnutrition and infections* below for details.

The combination of poverty, malnutrition, and inadequate stimulation increases a child's risk of morbidity, mortality, and poor growth and development. This leads to poor school performance, lower incomes, and perpetuates social inequalities [19]. According to Hoddinott et al., "Investments in early childhood nutrition can be long-term drivers of economic growth" [20].

iii. stunting
Most stunting occurs within the first two years of life [7] and can begin in utero [9]. In utero stunting can be caused by a number of factors: maternal undernutrition, maternal anemia, maternal tobacco use, and exposure to air pollution [9]. A recent pooled analysis of data from 137 countries determined that the largest risk factors for stunting in developing countries were fetal growth restriction, unimproved sanitation, and childhood diarrhea [21]. Other risk factors for infant stunting include chronic malnutrition [9], frequent infections (especially diarrhea) [7, 9, 11], and inadequate complementary feeding [7, 11].

Stunting has also been found to be related to wealth and maternal age at first birth [22]. Stunted mothers tend to have stunted children, continuing the cycle of malnutrition and poverty [9, 22].

iv. malnutrition and infections
Lack of sanitation often leads to enteric infections, especially in young children with underdeveloped immune systems, causing diarrhea morbidity and mortality [23]. These infections lead to mucosal enteropathy, an inflammation of the small intestine membrane [23], leading to decreased intestinal absorption of nutrients and exacerbating the child's malnutrition [17].

Repeated enteric infections in children leads to impaired intestinal absorption of nutrients, resulting in both increasing incidents of other infections and overall malnutrition [17]; the accumulation of diarrhea episodes in the first year of life has been associated with stunting, independent of socio-economic confounders [18].

<u>Malnutrition - local context</u>

The Democratic Republic of Congo [DRC] is a large country in central Africa with a population of 81,331,050 [24]. Despite being rich in natural resources, the country has struggled due to conflict, resource mismanagement, and lack of development [24].

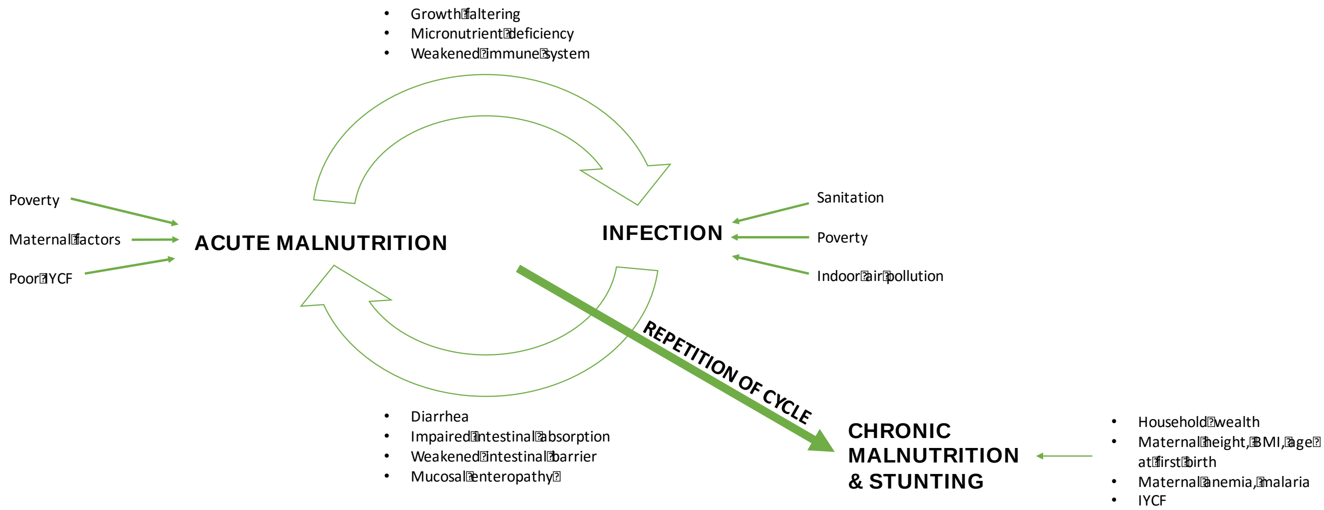
Malnutrition and child mortality rates in DRC are some of the highest in the world. For every 1,000 live births, 58 die within the first year and 98 within the first five years, giving DRC the ninth highest under-five mortality rate in the world [25]. Approximately 305,000 children under the age of five die per year in DRC [26]. Among children under five, 43% are stunted, 8% are wasted, and 23% are underweight [25]. Chronic malnutrition among children is prevalent country-wide [27].

Children in the DRC are particularly at risk for infection and growth failure during the first 1000 days [27, 28]. The relationships between child diarrhea, fever and acute respiratory infection in the previous two week and a child's age has a positive association until around 10-15 months, when the effect decreases in strength [28]. The introduction of complementary food and a child's increased exploration around 20 months usually coincides with increased risk for infection due to increased exposure to pathogens [5, 29].

This high risk of growth failure and infection may be due to mothers giving children liquids other than breastmilk, possibly contaminated water, due to either cultural beliefs or difficulty breastfeeding [28]. Other potential factors include unsanitary conditions due to poverty or the child's consumption of low quality food [27, 28].

Children in African countries with worsening socio-economic situations, such as DRC, are at an increased risk for missing routine health checks, also affecting their nutritional statuses [30]. The interaction between poor nutrition and infection across the first 1000 days places these children at risk for not reaching their full developmental potential and lifelong health (Figure 1).

Figure 1: Conceptual framework



The malnutrition / infection cycle has been well-documented [31-34] and is illustrated in Figure 1. Young children are especially susceptible to infection due to their underdeveloped immune systems [29]. Infection leads to diarrhea, dehydration, impaired intestinal absorption, weakened intestinal barrier, and mucosal enteropathy [22, 23]. These factors inhibit a child's ability to absorb nutrients, leading to acute, or short-term, malnutrition [17, 31]. This acute malnutrition can be caused independently or exacerbated by outside factors, such as poor infant and young child feeding practices [IYCF] or food shortages [32]. Acute malnutrition in children further weakens the immune system and results in growth faltering and micronutrient deficiencies [31, 33]. These factors combine to make children more susceptible to infection [31, 34], beginning the cycle again. Repeated diarrhea infections during childhood are associated with stunting [32, 35]. This paper posits that, as the malnutrition / infection cycle repeats over the first two years of life, chronic malnutrition, or stunting, manifests; and that repeated infection specifically caused by exposure to indoor air pollution via biomass cooking fuel, may facilitate this cycle.

Air pollution background & effects of exposure

Types of cooking fuel are categorized either as “clean fuels” - electricity, liquid petroleum gas, natural gas, or biogas - or “solid fuels” - biomass fuels (wood, dung, and agricultural matter) and coal [36].

Exposure to indoor particulate matter
Particulate matter is the solid and liquid particles suspended in the air that comprise air pollution. Exposure to indoor particulate matter, regardless of its source, is associated with an increase in acute lower respiratory infections, including pneumonia and bronchitis, [37, 38] and asthma [39]. There is also evidence for a link between indoor air pollution and an increased risk of tuberculosis [40], pneumonia [41], low birth weight, and still births [38].

Exposure to solid fuel
Indoor use of solid fuels (biomass fuels and/or coal) is associated with lung cancer, respiratory illnesses, acute respiratory infections, and chronic obstructive pulmonary disease [COPD] [42]; there is some evidence of an association with lung function and immune system repair [42]. There is also an increased risk of cataract in women who cook with solid fuels [43].

Exposure to coal
Coal users have an increased risk of lung cancer [44] and children in these households tend to have smaller statures at 36 months after birth [45].

Exposure to biomass fuel
Exposure to biomass fuel pollution in pregnant women can lead to reduced birth weight [46-48], intrauterine growth restriction, respiratory mortality, and poor postpartum growth [48]. There is weak evidence for an association with stillbirth [48]. Among wood users, there is an increased risk for preterm delivery [49].

Children in biomass-using homes have an increased risk of acute lower respiratory tract infections [50], acute respiratory infections [51, 52] and prevalence of anemia and stunting [53].

Adults in households using biomass fuels have higher rates of COPD [50], interstitial lung disease [50], cough symptoms [54], age dependent cataract [55], active tuberculosis [56, 57], lung cancer [58], chronic bronchitis [59], and anemia in pregnant women [60]

Household air pollution from cooking fuels causes 4.3 million deaths yearly [8]. In DRC, the mortality rate attributed to household air pollution is 188.5 per 100,000, much higher than both the global rate of 92 and African regional average of 80 [8]. Lower respiratory infections are the second highest leading cause of burden of disease in Africa, comprising 9.9% of the total disability-adjusted life years [DALYs] in 2012; only HIV / AIDS ranks ahead of lower respiratory infections with 10.1% [8].

Lower respiratory infections account for between 15.5 and 16% of deaths of children under five globally [8, 61]. Over 51 million DALYs in children under five are attributable to lower respiratory infections; 143,000 are due to upper respiratory infections [62]. In 2012, over 2.8 million deaths of children under five in Africa were attributable to acute lower respiratory infections caused by exposure to household air pollution [8]. Of all lower respiratory infection globally, 33% were due to household air pollution [63].

Malnutrition and household air pollution

There have been few studies exploring a direct link between household air pollution exposure and child stunting. Studies have examined associations between indoor air pollution and: infection [37, 41, 48, 51, 52, 59], pregnancy outcomes [46-49], respiratory effects, [37, 42, 51, 52, 54], and tuberculosis [40, 56, 57]. Others have examined associations between malnutrition and infections [64, 65], diarrhea [18, 21, 66, 67], and water and sanitation [21, 35, 68]. The five studies which examined the relationship specifically between indoor air pollution and stunting are summarized below and in **Table 1**.

One study examined indoor coal use, a solid fuel but not a biomass fuel, and its association with stunting in a cohort of children in the Czech Republic [45]. Researchers found that the use of coal as an indoor fuel was significantly associated with a lower height-for-age z-score [HAZ] at 36 months (z score −0.37; 95% CI −0.60, −0.14).

A study in India analyzed the association between biomass fuel use and nutrition outcomes in children, including stunting and underweight [48]. While children exposed to biomass fuel smoke had an increased risk for both stunting and underweight, endline measurements for children were taken at six months after birth. As stunting is a cumulative effect over the first two years of life, and significant growth and development take place during this time period [7], measuring children after six months may not be reflective of the exposure's true effect. This is especially true if mothers are following the World Health Organization's recommendation to exclusively breastfeed infants for the first six months of life [69], as children's exposures and growth will change drastically when complementary foods are introduced [5, 29].

A pooled analysis using data from seven developing countries suggested a possible relationship between exposure to biofuel and tobacco smoke (separately) and stunting [70]. A relationship between maternal smoking and child HAZ was observed in only three of the countries; the relationship between biofuel smoke exposure and HAZ was significant for all countries and when pooled together (OR 1.25, 95% CI 1.08, 1.44).

The effects of biomass fuel exposure on both anemia and stunting were examined in 2007 in India. [53]. Anemia prevalence was significantly higher among children in households that used biomass fuels than among children in households that used clean fuels (relative risk ratio = 1.58; 95% CI: 1.28 to 1.94), as was severe stunting (relative risk ratio = 1.84; 95% CI: 1.44 to 2.36).

An analysis of DHS data in Swaziland also examined the association between biomass fuel use and stunting and anemia [71]. After controlling for covariates, there was no significant relationship between biomass fuel use and stunting (RRR 1.1, 95% CI = 0.6, 2.0) among children 6-36 months. Covariates used were child's sex, age, birth weight, preceding birth interval, and wealth index.

Only three of these studies specifically examine the relationship between biomass fuel and stunting. One is a pooled analysis, and the other two use national data from more than 10 years ago. These studies also measure exposure based on type of fuel used, and don't account for the place where cooking occurred. Since the density of particulate matter can vary based on proximity to the source, this is an important factor to consider. Given the increasing use of biomass fuels in low- and middle- income countries, there is a need for a study using updated data that examines the relationship between biomass fuel and stunting.

Table 1: Summary of studies examining indoor air pollution and stunting

Study Title	Location	Year	Study design & target population	Exposure & outcome(s)	Effect size
Indoor Coal Use and Early Childhood Growth [45]	Czech Republic	2011 (data from 1994-1998)	• prospective, longitudinal • self-administered questionnaires and medical records • children 6-36 months	indoor coal use / height for age z score	• z score -0.37 (95% CI -0.60, -0.14)
Exposure to indoor biomass fuel and tobacco smoke and risk of adverse reproductive outcomes, mortality, respiratory morbidity and growth among newborn infants in south India [48]	rural south India	2009 (data from 1998-2000)	• cohort study, survival analysis • individual interviews with mothers • children followed from birth – 6 months	use of wood or dung for cooking fuel / stunting	• adjusted RR 1.30 (95% CI 1.06, 1.60)
Maternal smoking, biofuel smoke exposure and child height-for-age in seven developing countries [70]	Cambodia, Dominican Republic, Haiti, Jordan, Moldova, Namibia, Nepal	2009 (data from 2005 and 2007)	• DHS data, pooled regression analysis • children 0-59 months	use of biomass fuel for cooking / stunting	• stunting OR 1.25 (95% CI 1.08, 1.44) • severe stunting OR 1.27 (95% CI 1.02, 1.59)
Does biofuel smoke contribute to anaemia and stunting in early childhood? [53]	India	2007 (data from 1998-1999)	• National family health survey (cross-sectional) • children 0-35 months	use of biomass fuel, mixed fuel, or clean fuel / stunting	• only biofuels RRR = 1.25 • mixed fuels RRR = 1.28
Biomass fuel use for household cooking in Swaziland: is there an association with anaemia and stunting in children aged 6–36 months? [71]	Swaziland	2013 (data from 2006-2007)	• DHS data (cross-sectional) • children 6-36 months	biomass fuel use / stunting	• RRR 1.1 (95% CI = 0.6, 2.0)

Significance

What is already known?
Exposure to smoke from biomass fuel used for cooking has been shown to increase the odds of a child having respiratory infections and being stunted.

What does this study add?
Some studies have examined the relationship between fuel type used and stunting, however, this study accounts for the place cooking is taking place in or outside the household when measuring indoor air pollution exposure.

Introduction

The negative effects of childhood undernutrition are well-documented to be severe and long-lasting. Both the UN and WHO have adopted aims to reduce stunting globally [3, 4] . While large strides are being made in some areas of the world, the number of stunted children in west and central Africa has been increasing since 1990 [1].

Stunting is defined as a height to age z-score [HAZ] below -2 standard deviations from the mean, and is reflective of chronic malnutrition [6]. Most stunting occurs within the first two years of life [7]. An estimated 156 million, or 23.2%, of children under five worldwide are stunted [8]. Stunting has long term effects on a child's development; it is associated with lower school performance and educational outcomes, a decrease in cognitive development and skills [9-12], behavioral problems, a lower IQ, and reduced motor skills development [12]. Malnourished children suffer from more attention problems, lower social status, and lower standard of living as adults [12]. They also achieve lower schooling levels and educational outcomes [10, 13], which can lead to a decrease in adult income [13]. Each 1% loss in adult height due to stunting is associated with a 1.4% decrease in productivity [14]. Children born to stunted mothers have increased risks of perinatal and child mortality [9], and are more likely to be underweight and stunted themselves [15]. The effects of undernutrition can last for three generations [10].

Given the severe and long-lasting consequences of stunting, its widespread nature, universally acknowledged importance, and direct association with poverty [7], identifying potential determinants of stunting and low-cost interventions directed at this issue is a public health priority.

Due to their underdeveloped immune systems, children are at increased risk for infections, which leads to mucosal enteropathy, inflammation of the small intestine membrane [23]. This results in decreased intestinal absorption of nutrients and malnutrition [17].

Respiratory infections are common among children in developing countries, especially those in biomass-fuel using households [50-53]. Many residents in low- and middle- income countries rely on biomass fuels for cooking, exposure to which has been associated with infection [37, 41, 48, 51, 52, 59], adverse pregnancy outcomes [46-49], respiratory effects, [37, 42, 51, 52, 54], and tuberculosis [40, 56, 57].

There have been few studies exploring a direct link between household air pollution exposure and child stunting. Some have measured coal, wood, and/or dung use as a proxy of air pollution [45, 48], while others examine all biomass fuels [53, 70, 71]. These three studies all found significant associations between biomass fuel use and stunting. Measures of exposure, however, were solely based on reported type of fuel used and did not account for the place where cooking occurs. Given the increasing use of biomass fuel in developing countries and the limited information regarding the effects of cooking fuel and place on child stunting, there is a need to investigate this relationship further to inform future interventions aiming to reduce childhood stunting.

Methods

Study area and population

The 2013-2014 DHS in Democratic Republic of Congo [DRC] was used for this analysis. The Demographic Healthy Surveys [DHS] are national cross-sectional household surveys. The surveys aim to produce representative country-level data.

Data Collection and sample size

DHS uses a multi-stage clustered sampling procedure. For the 2013-2014 sampling frame, the country was geographically split into its 26 provinces, and each province was further divided into three strata: cities, towns, and rural areas. Each stratum was further divided into neighborhoods; out of each neighborhood 34 household were chosen for the survey based on equal probability. A total of 5,474 households were sampled from the city and town strata, and 12,886 from the rural strata, for a total of 18,360 households. While 540 clusters were selected, four were unable to be sampled because of regional instability [72].

Three questionnaires were administered: household, women's, and men's; all questions were translated into the four national languages of DRC and adapted for local context. Standard procedures for measuring child weight and height/length were followed [72].

Ethical considerations

This is a secondary analysis based on publically available data with all identifying information removed. Informed consent was obtained from all participants and additional consent was obtained for biological tests performed (hemoglobin, malaria, HIV). Consent was obtained from a parent for children who were tested. Children who tested positive for anemia or malaria were referred to a local health clinic. Children were not tested for HIV.

Analysis

A total of 18,827 women aged 15-49 years completed the DHS women's questionnaire. The dataset includes one record for every child of an interviewed woman born in the last five years; these totaled 26,459.

Inclusion criteria for the current analysis included: singleton birth, child height/weight measured accurately, and household information available on cooking location/fuel. Of the sampled households, 50% were selected for anthropometric measures of children (n=8,397). During analysis, 722 records with improbable or missing data, and those of multiple births were deleted for a final sample size of 7,675.

Children were classified as stunted if they had a HAZ of below -2 SD from the mean and severely stunted if the z-score was below -3 SD. Children were classified as wasted if they had a weight-to-height z-score of below -2 SD from the mean and severely wasted if the z-score was below -3 SD. Children were classified as underweight if they had a weight-to-age z-score below -2 SD from the median and severely underweight if the z-score was below -3 SD.

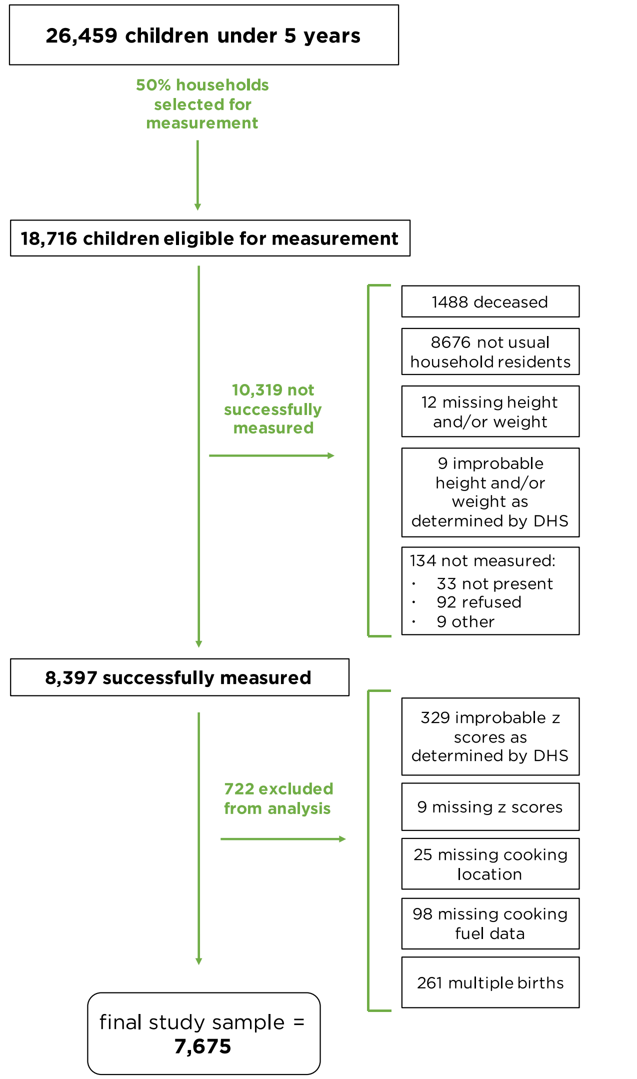


Figure 1: Sample selection and data cleaning flowchart

Households were coded as using either biomass fuels (wood, straw, shrubs, grass), mixed fuels (charcoal), or clean fuels (electricity, kerosene) based on levels of air pollution associated with these each type [73]. Households were then categorized into the following three levels of air pollution exposure: 1) No air pollution: household uses biomass fuels outside, biomass fuels in a separate building, all clean fuels, mixed fuels outside, or mixed fuels in a separate building; 2) Some air pollution: household uses biomass fuels inside in a separate room, or mixed inside the house (regardless of the presence of a separate cooking room); 3) High air pollution: household uses biomass fuel inside but not in a separate room.

A variable for minimum dietary diversity was created based on WHO recommendations [74]. Children over six months were coded as "yes" if they ate from at least four of seven food groups in the past 24 hours and "no" if they ate from three or fewer.

Analysis was performed in Statistical Analysis Software (SAS version 9.4). Logistical regression was used to estimate the odds ratios for having been exposed to indoor air pollution from biomass fuel use (none, some, and full) among stunted and not stunted children. Linear regression was used to estimate the association between HAZ and exposure to indoor air pollution. Analyses were weighted in accordance with DHS reported sampling weights.

Based on the literature and exploratory data analysis, the following covariates were examined: maternal education level, child age in months, type of residence (urban or rural), wealth index, maternal height, minimum dietary diversity, if a household member smokes inside the house, young maternal age at first birth, parity, and sex of child.

After looking at each factor individually, multivariate logistic regression models were examined. Multicollinearity was examined in multivariate models (VIF < 10).

Wealth index was calculated using household data on water source, toilet type, household assets, floor, wall, and roof materials, livestock owned, and household crowding (≥ 3 household residents per sleeping room). Traditionally, the type of fuel used for cooking is included in DHS wealth index calculations; however, given this is the key exposure in the study, this was not included in the composite wealth index.

Results

Table 1: Demographics of the study sample: DHS 2013-2014, children under five years (n=7675)

Characteristics	% or mean (SD)
Sex of child	
Male	49.6
Female	50.3
Place of residence	
Urban	28.7
Rural	71.2
Age of child	
Months	28.4 (17.3)
Maternal factors	
Maternal education level	
No education / preschool	21.8
Primary	44.6
Secondary or higher	33.5
Parity	4.3 (2.5)
Preceding birth interval (months)	34.3 (18.0)
Height (cm)	156.6 (7.1)
• Short stature (≤ 150 cm)	• 17.4
Age at first birth	19.1 (3.5)
• 18 years and younger	• 47.2
IYCF	
Breastfed within one hour of birth	41.6
Children < 6 months being exclusively breastfed	77.2
Children < 2 years currently being breastfed	89.6
Children ≥ 6 months receiving minimum dietary diversity	9.5
Ever breastfed	96.9
Total number of children	*7675*

As shown in Table 1, a total of 7675 child records were included in the final analysis. Children were fairly evenly split between males and females and on average were 28 months old. Most households were located in rural areas.

Rates of breastfeeding were high; 41% of children were breastfed within the first hour of birth and 77% of children under six months were exclusively breastfed. Of children under two years, 89% were currently breastfed and overall 97% of children were ever breastfed.

Table 2: Air pollution characteristics of the study sample

Characteristics	%
Place where food is cooked	
In the house	39.7
• Of those cooking in the house, those with a separate room used for cooking	40.9
In a separate building	23.7
Outdoors	36.4
Household resident smokes cigarettes inside	31.5
Cooking fuel type	
Biomass	78.8
• Wood	• 78.2
• Straw / shrubs / grass / agricultural crop	• 0.52
Mixed (charcoal)	20.1
Clean (electricity or kerosene)	1.1
Household air pollution	
No air pollution	60.9
Some air pollution	21.9
High air pollution	17.1

Most households reported using biomass fuels for cooking (78%); a majority of these used wood, while some used shrubs and other crops. Cooking location was spread fairly evenly, with 39% of respondents reporting cooking inside the main house, 23% in a separate building, and 36% outdoors. The “no air pollution” category encompassed 61% of households, while 22% had some air pollution and 17% high air pollution.

Table 3: Anthropometric calculations and measure distribution

Measure		
Anthropometric measures	**Mean**	**SD**
height for age Z-score	- 1.63	1.83
weight for age Z-score	- 1.09	1.27
weight for height Z-score	- 0.19	1.32
Stunting distribution	**Percent**	**Number**
stunted (< -2SD)	43.1	3355
severely stunted (< -3SD)	22.8	1753
Underweight distribution	**Percent**	**Number**
underweight (< -2SD)	22.7	1743
severely underweight (< -3SD)	7.3	561
Wasting distribution	**Percent**	**Number**
wasted (< -2SD)	7.7	598
severely wasted (< -3SD)	2.8	217

43% of children were stunted and 23% severely stunted. Rates of underweight (23%) and wasting (7.7%) were much lower [table 3].

A crude analysis of key factors associated with stunting classification is provided in Table 4. The variables with statistically significant crude relationships with stunting were full air pollution, maternal education level, age of child, type of residence, maternal height, wealth index, minimum dietary diversity, household member smokes inside, sex of child, parity, and young age at first birth. Exposure to indoor air pollution from biomass fuel smoke had a significant and positive effect on stunting only when comparing no pollution to full pollution children [1.67 (95% CI 1.40, 1.99)].

Table 4: Crude & adjusted odds rations (ORs) and corresponding 95% confidence intervals (CIs) for the association between stunting and multiple factors in children under five

Covariate	**Crude OR (95% CI)**	**Model 1 OR (95% CI)**	**Model 2 OR (95% CI)**
air pollution			
no air pollution [reference]	1	1	1
some air pollution	1.04 (0.88, 1.23)	1.13 (0.95, 1.34)	1.13 (0.94, 1.36)
full air pollution	1.67 (1.40, 1.99)*	1.23 (1.01, 1.50)*	1.22 (0.98, 1.52)
maternal education level			
none [reference]	1	1	1
primary school	0.84 (0.73, 0.97)*	0.98 (0.83, 1.15)	1.04 (0.87, 1.24)
secondary and higher	0.44 (0.38, 0.52)*	0.72 (0.60, 0.88)*	0.78 (0.64, 0.95)*
age (months)	1.04 (1.03, 1.04)*	1.04 (1.03, 1.04)*	1.03 (1.02, 1.03)*
type of residence [urban is reference]	2.03 (1.72, 2.40)*	1.17 (0.93, 1.47)	1.15 (0.91, 1.46)
maternal height (cm)	0.94 (0.93,0.95)*	0.95 (0.94, 0.96)*	0.95 (0.94, 0.96)*
wealth index quintiles			
1 [reference]	1	1	1
2	0.78 (0.67, 0.92)*	0.85 (0.72, 1.02)	0.84 (0.69, 1.02)
3	0.72 (0.57, 0.91)*	0.76 (0.58, 1.01)	0.74 (0.56, 0.96)*
4	0.77 (0.61, 0.97)*	0.88 (0.68, 1.14)	0.81 (0.62, 1.06)
5	0.32 (0.26, 0.40)*	0.46 (0.34, 0.61)*	0.44 (0.33, 0.60)*
minimum dietary diversity	0.54 (0.41, 0.70)*	-	0.78 (0.60, 1.01)
household member smokes inside	1.20 (1.03, 1.39)*	-	1.01 (0.86, 1.18)
sex of child [reference is males]	0.85 (0.74, 0.97)*	-	0.79 (0.69, 0.91)*
parity	1.05 (1.02, 1.08)*	-	1.02 (0.99, 1.05)
young age at first birth (≤ 18 years)	1.20 (1.04, 1.39)*	-	1.20 (1.02, 1.39)*

* CI does not include 1, $p < 0.05$

Model 1 was comprised of the following basic confounding factors: air pollution level, maternal education level, age of child, type of residence, and maternal height. The strength of the relationship between stunting and full air pollution decreased from the crude estimate but remained significant [1.23 (1.01, 1.50)]. The effect of no maternal education versus primary education became insignificant when compared to the crude effect but the secondary or higher level remained significant and effect size increased versus the crude [0.72 (0.60, 0.88)]. The relationship between stunting and child age remained significant and similar [1.04 (1.03, 1.04)], as did maternal height [0.95 (0.94, 0.96)]. The effect size for type of residence decreased and became insignificant [1.17 (0.93, 1.47)].

Model 2 included more determinants of stunting: whether the child received the WHO recommended dietary diversity, if a household member smokes inside the house, sex of the child, parity, and if the mother was younger than 19 years at her first birth. With this addition, the OR for exposure to full air pollution became insignificant with a slightly wider CI [1.22 (0.98, 1.52)].

Children of mothers with a secondary or higher education had an 22% reduced odds of stunting compared with children of mothers with no education [0.78 (0.64, 0.95)]. Stunting increased with child age [1.03 (1.02, 1.03)]. Only the highest wealth index level was significantly different when compared with the lowest [0.44 (0.33, 0.60)]. Maternal height was also significant; for every one centimeter in maternal height, a child's odds of stunting decreased by 5% [0.95 (0.94, 0.96)]. Boys were more likely to be stunted than girls [0.79 (0.69, 0.91)], as were children of young mothers [1.20 (1.02, 1.39)]. The odds ratios for type of residence, dietary diversity, a household member smoking, and parity were not significant.

An analysis of these same key factors on HAZ is provided in Table 5. The variables with statistically significant crude relationships with HAZ were the same as those with significant relationships with stunting classification: full air pollution, maternal education level, age of child, type of residence, maternal height, wealth index, minimum dietary diversity, household member smokes inside, sex of child, parity, and young age at first birth. Exposure to indoor air pollution from biomass fuel smoke had a significant and positive effect on stunting only when comparing no pollution to full pollution children [-0.562, p<0.0001].

Table 5: Crude & adjusted model estimates for the association between height-for-age z-score and multiple factors in children under five

Covariate	Unadjusted β (p-value)	Model 1 adjusted β (p-value)	Model 2 adjusted β (p-value)
air pollution			
no air pollution [reference]	1	1	1
some air pollution	-0.056 (0.475)	-0.121 (0.101)	-0.103 (0.194)
full air pollution	-0.562 (<0.0001)*	-0.275 (0.0004)*	-0.280 (0.0003)*
maternal education level			
none [reference]	1	1	1
primary school	0.216 (0.0029)*	0.064 (0.397)	0.021 (0.793)
secondary and higher	0.791 (<0.0001)*	0.305 (0.0003)*	0.266 (0.001)*
age (months)	-0.036 (<0.0001)*	-0.035 (<0.0001)*	-0.028 (<0.0001)*

type of residence [urban is reference]	-0.615 (<0.0001)*	-0.098 (0.262)	-0.098 (0.294)
maternal height (cm)	0.055 (<0.0001)*	0.047 (<0.0001)*	0.049 (<0.0001)*
wealth index quintiles			
1 [reference]	1	1	1
2	0.296 (0.0001)*	0.179 (0.015)*	0.194 (0.010)*
3	0.325 (0.002)*	0.217 (0.045)*	0.216 (0.044)*
4	0.259 (0.012)*	0.091 (0.357)	0.172 (0.114)
5	0.966 (<0.0001)*	0.511 (<0.0001)*	0.568 (<0.0001)*
minimum dietary diversity	0.657 (<0.0001)*	-	0.254 (0.003)*
household member smokes inside	-0.146 (0.035)*	-	-0.018 (0.768)
sex of child	.0196 (<0.0001)*	-	0.224 (<0.0001)*
parity	-0.042 (0.001)*	-	-0.006 (0.611)
young age at first birth (≤ 18 years)	-0.158 (0.016)*	-	-0.154 (0.016)*

* p < 0.05

The models used in the logistic regression were also used for linear regression analyzing HAZ. After adding in covariates in Model 1, the strength of the relationship between stunting and full air pollution decreased from the crude estimate but remained significant [-0.275, p=0.0004]. The effect of no maternal education versus primary education became insignificant when compared to the crude effect but the secondary or higher level remained significant and effect size increased versus the crude [0.305, p=0.0003]. The relationship between stunting and age in months remained significant and similar [-0.035, p<0.0001], as did maternal height [0.047, p<0.0001]. The effect size for type of residence decreased and became insignificant [-0.098 p=0.262].

When adding in Model 2 covariates, the relationship between HAZ and full air pollution remains significant; children exposed to full air pollution had HAZ scores 0.280 SD lower than those exposed to no air pollution [p=0.0003].

Children of mothers with a secondary or higher education had HAZ scores 0.266 higher than those with no education [p=0.001]. Stunting increased with child age [-0.028, p<0.0001]. All wealth quintiles but the fourth were significant when compared with the lowest. Maternal height was also significant; for every one centimeter in maternal height, a child's odds of HAZ decreased by 0.049 SD [p<0.0001]. Boys had lower HAZ scores than girls [0.224, p<0.0001], as did children of young mothers [-0.154, p=0.016]. Children receiving the minimum dietary diversity had larger HAZ scores [0.254, p=0.003]. The estimates for type of residence, a household member smoking and parity were not significant.

Discussion

When adjusting for potential confounders, children exposed to biomass fuel smoke not in a separate household kitchen had a 23% increased odds of stunting [1.01, 1.50] and HAZ scores 0.275 SD lower [p=0.0004] than children not exposed to this smoke, either from cooking outside, in a separate household room, or with clean fuel. This effect is similar in size to those found in previous studies. One study examining the use of wood or dung fuel study reported an adjusted risk ratio for stunting of 1.30 (1.06, 1.60) [48]; others examining all biomass fuels reported an odds ratio for stunting of 1.25 (1.08, 1.44) [70], relative risk ratio of 1.25 [53], and 1.1 (0.6, 2.0) [71]. In the present study, only HAZ was significant in the fully adjusted model.

Higher maternal education level was associated with a reduced risk of child stunting and lower HAZ scores. Previous research has confirmed this association, though the pathway for this effect could be through socio-economic factors [75], healthcare knowledge and utilization [75-77], household sanitation [77], or a combination of factors.

Stunting tends to become more prevalent as age increases. This pattern is consistent with exiting literature; older children more likely to be stunted than younger children [78, 79]. Growth faltering is commonly seen when children are introduced to complementary foods, as they are at an increased risk for infection due to increased exposure to pathogens [78, 79]. Older children also have been exposed to air pollution and other potentially harmful pathogens for a longer time.

When stratified by wealth index quintiles, the associations varied in strength and significance. Children in the richest quintile had a 54-56% decreased odds of stunting and an increase in HAZ of 0.511-0.568 SD when compared to those in the poorest quintile. Children in the second and third quintiles also had significantly higher HAZs compared with the poorest quintile. Poverty is a basic cause of child malnutrition, relating to food insecurity, sanitation and hygiene, lack of household resources, and other factors [7, 9, 80]. Poverty has been shown to be associated with malnutrition through food insecurity and reduced hygiene and sanitation [80].

For every one centimeter in maternal height, a child's odds of stunting decreased by 5% and HAZ increased by .05 SD. Women with short stature have an increased risk of having children with intrauterine growth restriction [15, 81]; transfer of nutrients to the fetus is impaired due to the mother's malnourishment and fetal growth is restricted [15, 82]. A smaller pelvis size may also cause more labor complications, resulting in an increase in both neonatal and maternal mortality and morbidity [9, 15]. Maternal short stature is often a manifestation of poor nutrition status during childhood; stunted children grow up to be stunted mothers [15].

While not significant in the categorical model, receiving the minimum dietary diversity was associated with an increase of 0.254 SD in HAZ. Dietary diversity has been previously found to be associated with child growth [83, 84], but also is related to household wealth and food security [85, 86].

Having a household member who smokes inside the house and parity were not related to stunting or HAZ. Previous research on this effect is mixed and inconclusive. A 2009 analysis examining data from seven countries found that current maternal smoking status was associated with HAZ in only three countries [70]. Studies in Indonesia have found a positive correlation between paternal smoking and stunting, though they also found that families of smoking fathers spent less money on food because of increased expenditure on tobacco [87, 88]. More research is needed to see if the reduction in HAZ is due to a biological effect, relation to food security, or a combination of both.

Exposure to air pollution from biomass fuels cooked in the same room was found to significantly increase children's odds of stunting, compared to children in households where food was cooked outside, in a separate building, or clean fuel was used. The mechanism for this association was thought to be an effect of the malnutrition / infection cycle, though this cannot be examined with cross-sectional data. This study sample has high rates of anemia; 40% of mothers and 62.5% of children under five were anemic. The majority of children, over 80%, had diarrhea in the previous two weeks. Given these high rates of sicknesses, it's not surprising that child growth suffers in this context.

Stunted children have long-term cognitive effects and achieve lower schooling rates and reduced income levels as adults [9-13]. Stunted girls become stunted women, and as mothers of short stature, their children are at an increased risk for stunting prior to birth [15]. Post-natally, children continue to be at an increased risk for malnutrition due to the far-reaching effects of poverty [7]. The effects of malnutrition have been stated to last three generations [10], though given the cyclical nature of poverty, malnutrition, and growth, this may in practice be longer. Breaking this cycle calls for efforts on a global scale to explore comprehensive health interventions addressing all these factors.

Limitations
The data used for this study are cross-sectional, and a cause/effect relationship cannot be established in analysis. This is an especially important limitation given the large amount of factors that affect child nutrition and the intricate relationships between them. This study uses type of cooking fuel and cooking place as a proxy for air pollution levels. The surveys rely on self-reporting which can result in misclassification. Four selected clusters were unable to be sampled due to regional instability. About 2.6% of the children selected for anthropometric measures by DHS were not measured, and of those measured, 8.5% were excluded from analysis due to implausible or missing data.

Strengths
The study of effects of indoor air pollution on child malnutrition is an emerging field of research and this study adds to the few other papers examining this relationship. This is the first study to incorporate cooking place as a factor in air pollution in addition to cooking fuel. DHS data is recognized to be comprehensive and nation-wide representative; this is reinforced by the large sample size included in this analysis.

Conclusion
This paper examines the effect of exposure to indoor air pollution from biomass fuels and increased risk of child stunting. More research on this effect is needed. This study should be viewed with other evidence to inform future interventions aiming to reduce childhood stunting.

Chapter 4: Discussion

Stunting is a major public health problem. Given that 156 million children under five worldwide are stunted [8], and the detrimental effects stunting has on cognitive development [9-12], adult income and standard of living [12, 13], and overall productivity [14], identifying low-cost interventions aimed at this issue is a public health priority. Since stunting and child growth is not just affected by nutritional intake, but is instead influenced by many factors, nutritional and environmental interventions should be developed. The Lancet Maternal and Child Nutrition series in 2013 proposed both nutrition-specific and nutrition-sensitive interventions aimed at improving child growth [89, 90].

Nutrition-specific interventions

Nutrition specific-interventions are aimed at the immediate determinants of health and include supplement provision, malnutrition treatment, and complementary feeding education. Those aimed at improving child health beginning at pregnancy include provision of anti-malaria drugs, protein-energy supplements, or multiple-micronutrient supplements to pregnancy women. Malaria prophylaxis was found to reduce the risk of anemia in pregnant women and increase mean birth weight [91]. Both protein-energy supplements and multi-micronutrient supplements reduce the risk for low birth weight and small-for-gestational-age births [92, 93]. Their effect on overall childhood growth, however, has not been examined.

Breastfeeding education increases rates of breastfeeding and exclusive breastfeeding [94]. For food insecure populations, education alone has a significant impact on HAZ and significantly reduced, though this evidence comes from only one study [95].

Nutrition-sensitive interventions

Nutrition-sensitive interventions are aimed at the determinants of health and include food security, access to health services, and water, sanitation, and hygiene interventions. The recent development of ready-to-use therapeutic food [RUTF] has enabled home-based treatment of acute malnutrition. Pooled estimates show that RUTF increases chances of recovery from acute malnutrition but does not significantly decrease the risk of mortality, though evidence for this was sparse and the limitations of these data restrict further evaluation of the interventions [96].

Interventions involving financial incentives have also been explored given the strong relationship between poverty and poor health. The quality of evidence on the effects of these programs on child growth, however, is low and limited [97].

Stunting is not simply a product of poor nutrition, but is also determined by exposure to pathogens and childhood infections and diseases. Open defecation may explain some malnutrition, through exposure to fecal pathogens and contamination of water sources. Interventions aimed at decreasing open defecation are difficult to measure, as open defecation on an individual level affects exposure on a population level [98].

Indoor air pollution and health

Indoor air pollution is a large public health threat, associated with a number of adverse health effects and 2.9 million deaths. [99]. This study confirms previous research on the potential link between indoor air pollution and increased risk of child stunting. Environmental risk factors generally, including use of biomass fuels, water quality, and sanitation conditions, have a large impact on stunting in sub-Saharan Africa [21]. Despite this growing evidence, many of the world's poor, especially in developing countries, continue to use biomass fuels [100]. The move to cleaner fuels, especially in rural areas, will take time given the strong relationship between poverty and fuel choice [100]. Interventions or programs aimed at general development may unintentionally also accelerate this transition.

Women and girls are at a disproportionate risk for exposure to cooking fuel smoke because of gender roles [101, 102]. Women and girls are often burdened with cooking duties and have the largest exposure to air pollution, but often are not able to change their household exposures and risks because of cultural and gender factors [101].

Conclusion

There is lacking evidence of the effectiveness of nutrition-sensitive interventions on child growth. Given the multi-sectoral nature of child growth, a multi-sectoral approach is needed to improve child growth worldwide. Future research should examine combinations of nutrition-specific and sensitive interventions aiming to address both short-term and long-term determinants of child growth. This project provides insight on the potential role of indoor air pollution and child growth and risk of stunting, and evidence for including environmental components in multidisciplinary approaches to address child stunting.

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