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Women and girls in resource poor countries experience much greater exposure to household air pollutants than men: Results from Uganda and Ethiopia

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ABSTRACT

Household Air Pollution (HAP) from burning biomass fuels is a major cause of mortality and morbidity in low-income settings worldwide. Little is known about the differences in objective personal HAP exposure by age and gender.

We measured personal exposure to HAP across six groups defined by age and gender (young children, young males, young females, adult males, adult females, and elderly) in rural households in two sub-Saharan African countries.

Data on 24-hour personal exposure to HAP were collected from 215 participants from 85 households in Uganda and Ethiopia. HAP exposure was assessed by measuring carbon monoxide (CO) and/or fine particulate matter ($PM_{2.5}$) concentrations using five types of devices.

24 h $PM_{2.5}$ personal exposure was highest among adult females with Geometric Mean (GM) and Geometric Standard Deviation (GSD) concentrations of 205 μg/m^3 (1.67) in Ethiopia; 177 μg/m^3 (1.61 GSD) in Uganda. The lowest $PM_{2.5}$ exposures were recorded among young males GM (GSD) 30.2 μg/m^3 (1.89) in Ethiopia; 26.3 μg/m^3 (1.48) in Uganda. Young females had exposures about two-thirds of the adult female group. Adult males, young children and the elderly experienced lower exposures reflecting their limited involvement in cooking. There was a similar pattern of exposure by age and gender in both countries and when assessed by CO measurement.

There are substantial differences in exposure to HAP depending on age and gender in sub-Saharan Africa rural households reflecting differences in household cooking activity and time spent indoors. Future work should consider these differences when implementing exposure reduction interventions. There was a strong agreement between optical and gravimetric devices measurements although optical devices tended to overestimate exposure. There is need to calibrate optical devices against a gravimetric standard prior to quantifying exposure.

1. Introduction

The World Health Organisation (WHO) estimates that over 4 million deaths annually are attributable to exposure to Household Air Pollution (HAP) from biomass fuel smoke making it a leading cause of global mortality (Lim et al., 2012; WHO, 2016). Exposure to HAP is also a leading cause of disability, being associated with a range of illnesses including acute and chronic respiratory diseases, cardiovascular diseases, low-birth weight and cataracts (Gordon et al., 2014). HAP is generated from the incomplete combustion of biomass fuels such as wood, charcoal and crop residues and contains fine particulates often measured as Particulate Matter < 2.5 μm in diameter ($PM_{2.5}$) and gases such as Carbon Monoxide (CO).

Current estimates suggest that almost half of the world's population, including 700 million people in sub-Saharan Africa (SSA) rely on biomass fuels for cooking and heating, with burning typically taking place in simple three-stone traditional stoves or other similar inefficient arrangements (Mortimer et al., 2017). The global health burden resulting from exposure to the resulting HAP has placed interventions to reduce exposure to HAP high on the agenda of public health organizations and international development bodies (Bruce et al., 1998; Ezzati and Kammen, 2001; Gordon et al., 2014).

Currently there are a lack of high quality data on personal exposure to HAP in SSA with the limited data available generally collected by

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non-comparable, study-specific methods. Most epidemiologic studies have utilized indirect methods of exposure assessment such as comparing household fuel use or housing type as proxies for personal exposure (Bruce et al., 1998) whilst others have conducted fixed monitoring within homes to estimate personal exposures to HAP constituents (Fullerton et al., 2011; Keil et al., 2010; Klasen et al., 2015; McCord et al., 2017). Only a few studies have measured personal exposure to HAP in SSA (Ezzati et al., 2000; Van Vliet et al., 2013).

Research on exposure to HAP in Low and Medium Income Countries (LMICs) has tended to use a range of methods developed from occupational health or environmental sciences, making it difficult to compare the data because of short sampling times, poor calibration and positioning of devices (Gordon et al., 2014). Personal monitoring provides the opportunity to understand an individual's exposure in a specified microenvironment that may differ substantially from traditional methods used to generate population level exposure estimates, using fixed-site monitoring (FSM) networks and location of residence (Steinle et al., 2013).

To successfully design interventions to reduce exposure to HAP, it is important to understand the factors that influence an individual's exposure. Investigating variations of individual exposure to pollutants of concern by gender, age, household characteristics and household roles may provide intervention science with effective tools for the design of measures to reduce exposure to HAP.

We are not aware of any studies that have investigated differences in HAP exposure by age and gender in SSA using 24-hour average exposure measurements. The aim of this study was to determine if there are age and gender differences in HAP exposure by gathering personal exposure data from study participants in two rural settings in Uganda and Ethiopia.

2. Materials and methods

2.1. Study location and overview

A cross-sectional study was conducted in Kikati, Uganda and Kumbursa in Ethiopia, both villages are typical of rural villages in these countries. Kikati village is situated approximately 45 km from Kampala along the Kampala-Jinja highway. The village has approximately 400 households with most using biomass fuel for cooking purposes. Kumbursa is situated in Ude Kebele, Ada'a District in East Shoa Zone, Oromia National Regional State, Ethiopia. The village is located about 55.5 km south-east of Addis Ababa along the Addis Ababa – Adama old highway. The village has in total about 258 households with most using dung cake and crop residues for cooking.

In Kikati, houses are typically of brick construction whilst homes in Kumbursa are mostly constructed from soil/mud and wood/timber. Cow dung was the primary source of fuel used for cooking in the Ethiopian setting whereas wood was the primary fuel in the Ugandan homes. In addition to cooking food, roasting coffee beans was also common in Ethiopia. The main food cooked in Kumbursa homes was Injera (a sour flatbread common in Ethiopia) using traditional open stoves. The main food cooked in Kikati was Matooke (a banana based meal) with beans and groundnut sauce.

The study was conducted between February and June 2016 in Uganda and between July and September 2016 in Ethiopia – the rainy season in both regions. Ethical approval for the study was gained from the University of Aberdeen, College of Life Sciences Ethical Review Board (Application No. CERB/2016/2/1264).

2.2. Recruitment of participants

We conducted a multi stage sampling process where households in Kikati and Kumbursa villages were invited for a meeting with the help of community leaders and research assistants through market day announcements, worship day announcements and door to door messages. A brief presentation explained the objectives and methodology of the study to all those who voluntarily attended the meeting. An interpreter was used in Ethiopia. We also conducted demonstrations using the various instruments with volunteers from the meetings. From those households expressing an interest in participating, a random sample of those using biomass fuel as the main fuel for cooking and/or heating was taken to identify those who would participate in the study. The make-up of the household was confirmed by a personal visit and where possible one person from each of the six age-gender groupings was then invited to take part in the study. Age-gender groups were as follows: young children below 5 years of age (YC); young males (YM) and young females (YF) between 6 and 17 years; adult males (AM) and adult females (AF) aged between 18 and 49 years; and elderly adults (EL) aged 50 years or over. All participants provided written informed consent and for children, parental/guardian consent and assent of the child was obtained.

Based primarily on resource availability, a pragmatic target of 17 participants were recruited from each gender-age grouping in Ethiopia and Uganda. Measurement of personal exposure to $PM_{2.5}$ and/or CO took place in a particular household, if one or more people in that household consented.

2.3. Household information

An interviewer administered questionnaire was completed with the head of the household to record details of household and kitchen size, fuel type, stove type, availability of windows, roof type, hours of cooking and time spent at home. Information on cooking patterns was also obtained. The questionnaire additionally contained questions regarding other non-cooking sources of HAP including tobacco smoking and use of candles/hurricane lamps. After appropriate training adult participants completed a simple time-activity dairy (TAD) for the day when the measuring device was worn. All TADs were checked with the participant.

2.4. Measurement of $PM_{2.5}$ and CO

Personal $PM_{2.5}$ exposure data were obtained from measurements over a 24-hour period using one or more of five types of air monitoring devices. The days of monitoring were chosen to be typical of the daily lives of the participants. The monitoring devices included: TSI SidePak AM510 Personal Aerosol Monitor (TSI Inc., CA, USA), the Dylos DC1700 (Dylos Inc., CA USA), RTI Micro Personal Exposure Monitor (MicroPEM) (RTI, NC, USA) and the Berkerely Air Group Particle and Temperature Sensor (PATS+) (Berkerely Air Group, CA, USA). To obtain 24 h of measurement, both the Dylos and SidePak instruments were connected to an Astro Pro2 power bank. Real-time carbon monoxide levels were measured every minute using a CO data logger (LASCAR EL-USB-CO) with a measurement range of 0–1000 ppm and a resolution of 0.5 ppm.

The Dylos 1700 measured the number of particles at minute intervals for two particle size ranges: > 0.5 μm and > 2.5 μm; with particles between 0.5 and 2.5 μm being calculated by subtraction. Particle counts are expressed as a concentration per 0.01 ft^3 of sampled air. The Dylos particle count for particle sizes ≤ 2.5 μm was calculated subtracting the > 2.5 mm fraction from the total count number for particles > 0.5 mm. Dylos particle count concentrations were converted to $PM_{2.5}$ mass concentrations using a previously published conversion equation for combustion aerosol (Semple et al., 2015).

Two versions of Dylos devices were used for the study. One model was modified to have a slower fan speed and could measure to approximately 6000 μg/m^3 whilst the standard version had a fan speed that provides maximum particle concentration data equivalent to about 1000 μg/m^3.

The SidePak Personal Aerosol Monitor (AM510) measured airborne particle mass-concentration in mg/m^3. TSI Sidepak AM510 was fitted