Atmospheric Environment 79 (2013) 380–384

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Short communication

A pilot study characterizing real time exposures to particulate matter and carbon monoxide from cookstove related woodsmoke in rural Peru

Adwoa A. Commodore[a], Stella M. Hartinger[b,c,d], Claudio F. Lanata[b], Daniel Mäusezahl[c,d], Ana I. Gil[b], Daniel B. Hall[e], Manuel Aguilar-Villalobos[f], Luke P. Naeher[a,*]

[a] Environmental Health Science Department, College of Public Health, University of Georgia, Athens, GA, USA
[b] Instituto de Investigación Nutricional, Lima, Peru
[c] Swiss Tropical and Public Health Institute, Basel, Switzerland
[d] University of Basel, Switzerland
[e] Department of Statistics, University of Georgia, Athens, GA, USA
[f] Asociacion del Aire Ambiental, Lima, Peru

HIGHLIGHTS

- Potential for lack of recovery time on a daily basis exist in study population.
- Mean personal $PM_{2.5}$ and CO measurements were well correlated in all study households.
- This was so particularly during 4 h cooking periods where HAP exposures were high.
- CO may be a useful indicator of PM during periods of high residential biomass smoke.
- Temporal $PM_{2.5}$ and CO patterns can be used to mitigate high exposure during cooking.

ARTICLE INFO

Article history:
Received 12 February 2013
Received in revised form
19 June 2013
Accepted 25 June 2013

Keywords:
Carbon monoxide
Cookstove
Exposure assessment
Household air pollution
Particulate matter
Peru

ABSTRACT

Nearly half of the world's population is exposed to household air pollution (HAP) due to long hours spent in close proximity to unvented cooking fires. We aimed to use $PM_{2.5}$ and CO measurements to characterize exposure to cookstove generated woodsmoke in real time among control ($n = 10$) and intervention ($n = 9$) households in San Marcos, Cajamarca Region, Peru. Real time personal particulate matter with an aerodynamic diameter ≤ 2.5 µm ($PM_{2.5}$), and personal and kitchen carbon monoxide (CO) samples were taken. Control households used a number of stoves including open fire and chimney stoves while intervention households used study-promoted chimney stoves. Measurements were categorized into lunch (9 am–1 pm) and dinner (3 pm–7 pm) periods, where applicable, to adjust for a wide range of sampling periods (2.8–13.1 h). During the 4-h time periods, mean personal $PM_{2.5}$ exposures were correlated with personal CO exposures during lunch ($r = 0.67$ $p = 0.024$ $n = 11$) and dinner ($r = 0.72$ $p = 0.0011$ $n = 17$) in all study households. Personal $PM_{2.5}$ exposures and kitchen CO concentrations were also correlated during lunch ($r = 0.76$ $p = 0.018$ $n = 9$) and dinner ($r = 0.60$ $p = 0.018$ $n = 15$). CO may be a useful indicator of PM during 4-h time scales measured in real time, particularly during high woodsmoke exposures, particularly during residential biomass cooking.

1. Introduction

Nearly three billion people worldwide employ biomass as fuel for cooking (Kurmi et al., 2010; Naeher et al., 2007; Smith, 1987). Cooking with solid fuels such as wood over inefficient stoves leads to exposure to products of incomplete combustion in the domestic environment (WHO, 2011). Particularly, women and their young infants experience high household air pollution (HAP) exposures

---

* Corresponding author. Department of Environmental Health, College of Public Health, University of Georgia, Room 150, Environmental Health Science Building, Athens, GA 30602–2102, USA.
E-mail addresses: lnaeher@uga.edu, lnaeher.uga@gmail.com (L.P. Naeher).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.06.047

due to long hours spent in close proximity to improperly vented cooking fires (Ezzati and Kammen, 2002; Martin et al., 2011).

HAP from solid fuels ranks 5th in the global burden of disease estimate in 2010 with annual cause-specific deaths exceeding 3.5 million incidents (Lozano et al., 2013). HAP from incomplete biomass combustion contains health-damaging pollutants such as polycyclic aromatic hydrocarbons (PAHs), carbon monoxide (CO) and particulate matter with an aerodynamic diameter of ≤ 2.5 μm ($PM_{2.5}$) (Bølling et al., 2009; Jalava et al., 2010). CO and $PM_{2.5}$ are major constituents and are considered chief inhalation hazards of woodsmoke exposure (Naeher et al., 2007).

Recent studies have successfully demonstrated the use of time integrated personal $PM_{2.5}$ and real time CO monitoring instruments to quantify woodsmoke exposure in the indoor environment (Armendáriz-Arnez et al., 2010; Chowdhury et al., 2013; Fitzgerald et al., 2012; Masera et al., 2007; McCracken et al., 2013; Mukhopadhyay et al., 2012; Northcross et al., 2010). There are only a few studies on real time monitoring of personal $PM_{2.5}$ exposures and examination of the correlations between $PM_{2.5}$ and CO are in the scientific literature (Li et al., 2012; Mukhopadhyay et al., 2012), particularly in the developing world where HAP can be relatively high during periods such as meal preparation.

In a developing country such as Peru which has a population of 27 million, almost 30% of the inhabitants still use wood as fuel for cooking on a daily basis (INEI, 2007). In 2009, several organizations aimed to deploy 500,000 certified biomass improved chimney stoves in Peru (Bodereau, 2011); as of December 2011 around 300,000 improved stoves were built. However, the success of these HAP mitigation programs, such as the Peru national stove program, is often measured by the number of installed stoves rather than adoption, continuous utilization, maintenance and improved health over time (Armendáriz-Arnez et al., 2010).

Large-scale interventions need to be carefully informed by conducting pilot studies to address multiple methodological as well as sociocultural concerns (Mukhopadhyay et al., 2012). This study attempts to generate exploratory data and questions for such endeavors in Peru and similar settings in the developing world. Our objective was to use $PM_{2.5}$ and CO measurements in a convenience sample of Peruvian households to characterize exposure to cookstove generated woodsmoke in real time. Additionally, we investigated the association between personal $PM_{2.5}$ and CO exposures and kitchen concentrations in this population during 4-h periods when subjects are involved in meal preparation.

2. Methods

2.1. Study design and study homes

We report a cross sectional study conducted within the framework of a community-randomized controlled trial (c-RCT) by the Instituto de Investigación Nutricional (IIN) and the Swiss Tropical and Public Health Institute. The c-RCT involved 51 community clusters who used wood as cooking fuel in the Province of San Marcos, Cajamarca region, Peru. For this study, control and intervention households were from participating households in the c-RCT ($n = 250$ and 253 for intervention and controls respectively). Mean altitudes ± SD for intervention and control households are 2684 ± 284 and 2727 ± 438 m above sea level respectively (Hartinger et al., 2013). Measurements presented in this manuscript occurred between June and August of 2009.

Intervention households used OPTIMA-improved stoves (OPTIMA stoves). Several months after air sampling had occurred; OPTIMA stoves were categorized based on their levels of functionality (FL). OPTIMA FL-I refers to OPTIMA stoves in good conditions and OPTIMA FL-II refers to OPTIMA stoves in need of minor repairs (e.g. re-plastering) or major repairs (e.g. chimney valve replacement). Air sampling did not take place to measure HAP levels after the OPTIMA stoves were repaired.

Control households in the c-RCT used various stoves including chimney stoves whose raw materials are provided by nongovernmental organizations (NGO), chimney stoves built by the members of the households (self-improved by household), gas stoves, and non-vented stoves with openings at the top for pots including the common three stone open fire stove (traditional).

In this pilot study, households were conveniently selected from households in the c-RCT enrolled for $PM_{2.5}$ and CO measurements during a 48 h air sampling period (Hartinger et al., 2013). Twenty subjects (11 control and 9 intervention stove users) were measured for cookstove related $PM_{2.5}$ and CO exposures in real time. Exposure monitoring equipment was placed in vests worn in the breathing zone of the subjects.

Study subjects' kitchens were also assessed for HAP. One of the requirements for participation in the c-RCT was for households to have stoves which were located in an in-house kitchen environment (at least three full walls and a roof over the kitchen) (Hartinger et al., 2011). Households in our study had three main kitchen types: completely enclosed (4/9 and 4/10 for intervention and control households respectively); enclosed with windows (4/9 and 5/10 for intervention and control households respectively); and three walls and a roof (1/9 and 1/10 for intervention and control households respectively). Data from one control subject has been excluded from the final data set due to a short sampling duration (17 min).

2.2. Exposure monitoring

Real time $PM_{2.5}$ exposure was monitored with the Sidepak AM510 (TSI Inc, Shoreview, MN). The equipment is a size selective laser photometer designed to read the mass concentration of particulate matter (TSI Inc, 2006). Sidepaks used in this study were fitted with a 2.5 micron impactor, and set to log $PM_{2.5}$ concentrations every 30 s. Sidepaks were zero calibrated with a high efficiency particulate air (HEPA) filter before each use. Data was only available for as long as the Sidepaks battery power lasted (range of sampling duration presented in Table 1). Logged data were retrieved from the equipment using *Trakpro v. 4.4.0.5*.

Real time exposure to CO was measured using Dräger Pac III single gas monitors (Draeger Safety Inc, Pittsburgh, PA) outfitted with CO sensors. The CO monitors were calibrated before the study at 0 and 50 ppm using pure nitrogen and 50 ppm CO gases respectively (Calgaz, Air Liquide America Corp, Cambridge, MA). CO monitors were also set to log data every 30 s. Personal CO monitors were worn in the breathing zones of subjects while kitchen monitors were placed 1.5 m from the ground in the subject's kitchen. Logged data were retrieved from the equipment using *Gas Vision v. 4.5*. Unlike the Sidepak measurements, real time CO data was available for a total of 48 h (Hartinger et al., 2013). Data presented for each household in this study ($n = 19$) reports the sampling durations with corresponding real time $PM_{2.5}$ measurements. Baseline questionnaires were also administered (Hartinger et al., 2013; Commodore et al., 2013).

3. Statistical analysis

SAS version 9.2 (SAS Institute, NC, USA) was used for all data analysis. Raw personal $PM_{2.5}$ exposures ranged from 0 to 20,000 $\mu g\ m^{-3}$ (upper and lower limit of the Sidepak), and after a calibration factor of 0.77 was applied (Jiang et al., 2011), the upper limit was 15, 400 $\mu g\ m^{-3}$. Real time exposures were averaged over the corresponding sampling duration in each household (hence a