THESIS

IMPACT OF AN IMPROVED STOVE INTERVENTION ON EXPOSURE AND HEALTH AMONG NICARAGUAN WOMEN

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2014

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ABSTRACT

IMPACT OF AN IMPROVED STOVE INTERVENTION ON EXPOSURE AND HEALTH AMONG NICARAGUAN WOMEN

Background

Approximately half of the world's population uses the combustion of solid fuels (wood, dung, agricultural residues) to meet energy needs (Rehfuess et al. 2006). The majority of solid fuel use occurs in developing countries, and in households with open fires or inadequately ventilated cookstoves (Bruce et al. 2008). Many pollutants, including carbon monoxide (CO), particulate matter (PM), and nitrogen oxides are generated from burning biomass fuels, and high concentrations of these pollutants have been observed in households using open fires or inefficient cookstoves (Zhang and Smith 1999, Budds et al. 2001). Improved cookstoves have been shown in studies to substantially reduce indoor air pollution (Albalak et al. 2001, Bruce et al. 2004). Improved cookstove studies have focused primarily on the respiratory effects of the combustion of solid fuels in a household, but it is also critical to determine the association between pollutants from indoor air pollution and cardiovascular health in order to more accurately calculate the burden of disease due to indoor air pollution from cookstove use (McCracken et al. 2007).

This project involved an improved cookstove intervention; exposure and health measurements were conducted at baseline (while participants were still using traditional open fires) and one year after all subjects received an improved, cleaner-burning stove. Every study participant received an improved cookstove, but not everyone completely adopted the improved

stove. As a result, participants were categorized as complete stove adopters or continued open fire users. The assessment of stove adoption was important for completing the aims of this study.

There were three primary aims for this study. The first aim (Aim 1) was to examine the association between improved stove adoption during the second year of the project and changes in health indicators. The health indicators of interest for this study were blood pressure (n=83), heart rate (n=83), and self-reported cough and headache symptoms (n=95). The second aim (Aim 2) of the study was to examine the presence of potential effect modification of the association between improved stove adoption and changes in the measured health indicators by several population characteristics: age and body mass index (BMI). The final aim (Aim 3) was to evaluate the change in the measured health indicators (from baseline to Year 2) in association with the change in pollution levels for a subset of households with pollution data for indoor CO (n=41), personal CO (n=39) and indoor $PM_{2.5}$ (n=33).

Methods

Baseline exposure and health measurements (blood pressure, heart rate, cough and headache) were conducted in a population of Nicaraguan women prior to receiving an improved cookstove in 2008. Improved cookstoves were then installed in the participant's home. Health measurements were repeated in Year 2 of the study (9-12 months after baseline). Exposure measurements were collected at baseline and Year 2 for indoor CO (n=41), personal CO (n=39), and indoor $PM_{2.5}$ (n=33). Forty-eight hour averages were calculated for each of the measured pollutants.

Adoption of the improved cookstove was evaluated by self-report in Year 2 of the study and assessed in relation to the change in health measurements (Aim 1). Paired t-tests were conducted to evaluate the difference between baseline and Year 2 for heart rate, systolic blood pressure, and diastolic blood pressure for the study population. Two sample t-tests were conducted to examine the relationship between stove adoption and the change in heart rate, systolic blood pressure, and diastolic blood pressure. McNemar's nonparametric test for two correlated proportions was used to determine whether there was a statistically significant difference in the frequency of self-reported symptoms from baseline to Year 2 for the entire population. Frequency and percent of the participants indicating cough and headache improvement were calculated. Mantel-Heanszel chi-square tests were conducted to examine the association between stove adoption (continued stove use versus improved stove adoption) and the proportion of those with an improvement in self-reported cough or headache.

Body mass index and age of the participants were then categorized for analyses of effect modification (Aim 2). Body mass index was categorized as obese and normal/overweight. Participants were also categorized based on median waist-to-hip ratio based on the median waist-to-hip ratio in our study population (less than or equal to 0.89 and greater than 0.89). Age was categorized based on the median age of the study participants (less than or equal to 34 years old and greater than 34 years old). Age was also categorized as less than or equal to 50 years old and greater than 50 years old based on the recent cookstove literature (Baumgartner et al. 2011; Clark et al. 2012). Logistic regression models were created for the improvement in cough and headache variables. An interaction term for obesity status (obese or non-obese) and stove adoption was added to each logistic regression model (improvement in cough and improvement in headache) and linear models were created to obtain probability values for additive interactions via the linear link function. The same methods were used for waist-to-hip ratio and age. Linear regression models were developed to investigate the potential effect modification of obesity status and age on the association of stove adoption and the change in blood pressure and heart rate. An interaction term for categorized obesity status (dichotomous variable) and stove adoption status was added to each model. The same method was used to investigate the potential effect modification of age and waist-to-hip ratio on the association of stove adoption and stove adoption.

The changes in pollution concentrations were then assessed in relation to the change in health measurements (Aim 3). Logistic regression was conducted to examine the association of the change in pollution concentrations and the improvement in self-reported cough and headache. Models were created for the changes in the pollutant concentrations based on the interquartile range (IQR) decrease in the pollutants. Linear regression was used to evaluate the association between the IQR decrease in pollutant concentrations and the change in heart rate, systolic blood pressure, and diastolic blood pressure from baseline to Year 2.

Results

The final samples sizes were 97 for general demographic information (94 for waist circumference due to missing data), 83 for heart rate and systolic and diastolic blood pressure, and 95 for the self-reported symptoms of headache and cough. During data collection in Year 2, 53.7% women reported completely adopting the improved stove; the other 47.3% reported either mixed stove use (participants reported adopting the improved stove, but also continued to use the traditional open fire) or sole use of the open fire. Large reductions in pollutant concentrations were observed in the total study population from baseline to Year 2 of the study. A reduction of 67.2% in 48-hour personal CO, 74.4% in 48-hour indoor CO, and 79.6% in 48-hour $PM_{2.5}$ from baseline to Year 2 was observed for the study population. These large reductions in pollutant concentrations were similar among both self-reported stove adopters and continued open fire users.

The prevalence of the self-reported symptom of headache significantly decreased from 62.9% at baseline to 25.3% in Year 2 (p-value=<0.0001). There were also small decreases in blood pressure and heart rate within the study population. There was a 1.8 mmHg decrease in systolic blood pressure, a 0.7 mmHg decrease in diastolic blood pressure, and 0.6 bpm decrease in heart rate. When stratified by stove adoption status, the changes in systolic blood pressure, diastolic blood pressure and heart rate were similar to the entire study population and were non-significant (p-value=0.54, p-value=0.56, p-value=0.21, respectively).

Our study did not find evidence of effect modification of obesity on the improvement in cough and headache symptoms, or the change in blood pressure. Though not statistically significant (p-value for interaction=0.66), we observed a trend of obese stove adopters having a stronger odds of improvement in self-reported cough (OR=1.63, 95% CI=0.26-10.32), as compared to non-obese participants (OR=0.93, 95% CI=0.17-5.01). This trend was not observed for the improvement of self-reported headache, which is likely due to the fact that many participants, regardless of stove adoption status, had an improvement in headache. Another trend, while not statistically significant, was that non-obese participants appeared to have a decrease in systolic blood pressure (p-value=0.43) and diastolic blood pressure (p-value=0.84) if they adopted the improved stove and had an increase in these health measurements if they continued open fire use.

Our study did observe a significant interaction of age on the association of stove adoption and change in headache (p-value=0.02). Participants > 34 years old were 6 times more likely to report an improvement in headache if they adopted the improved stove than if they continued the use of an open fire (OR=6.38, 95% CI=1.16-34.94). While age was observed to affect the improvement in headache symptoms, it did not affect the improvement in cough (p-value=0.99).

There was no significant effect of age on the change in blood pressure and heart rate by stove adoption.

Despite the large reductions in pollutant concentrations, there were no statistically significant associations observed in the linear regression analysis when examining the decrease in pollution and change in health endpoints (Aim 3). While many participants did have a decrease in air pollutant exposures, there was no clear trend in the change of health endpoints.

Discussion

There were large reductions in indoor $PM_{2.5}$ and indoor and personal CO for the study population, but we observed no difference in pollutant reductions among participants who adopted the improved stove compared to participants who reported continued open fire use. The difficulty in correctly categorizing study subjects based on stove adoption status likely explains the minimal differences in the improvement of the measured health outcomes observed between the stove use groups. We also used actual pollution concentrations as the exposure of interest instead of stove adoption status, but no significant associations were found between the a change in health endpoints and the decrease in air pollution concentrations.

Although there were limitations to our study, the study adds to the sparse literature of the impact of the adoption of an improved stove on cardiovascular health. Our study supports other work that has observed large reductions in indoor air pollution concentrations with the adoption of an improved stove, and also adds strength to the literature that improved cookstove interventions are capable of improving adverse cardiovascular and respiratory health. Additionally, our study is one of the few longitudinal cookstove intervention studies. While we only have one year of follow-up, the study still provides a better indication of temporality than many other cookstove studies that are often cross-sectional in nature.

ACKNOWLEDGEMENTS

I would like to thank my entire committee for their time and guidance. I would particularly like to thank Dr. Peel and Dr. Bachand for their continued patience and understanding throughout every step of my thesis. I would also like to thank the participants of the study, Pro Leña, Trees, Water, People, and all the students and faculty members who have been involved with the project from the beginning. A special thank you goes out to Judy Heiderscheidt and Erin Reichert for being great advisors throughout the years. There are so many other mentors and professors at who have been instrumental in making this journey a success. Thank you!

There are not enough words to express my thanks for my family and the friends who have been with me for this entire journey. Your support and never-ending words of encouragement were invaluable. I am so grateful to have had such a good support system.

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CHAPTER 1

OVERVIEW OF STUDY

Introduction

Approximately half of the world's population uses the combustion of solid fuels (coal, wood, dung, agricultural residues) to meet energy needs (Rehfuess et al. 2006). The World Health Organization ranked indoor air pollution as the 8th most important preventable risk factor contributing to the global burden of disease (Diaz et al. 2006). It has been estimated that approximately 1.6 million premature deaths per year worldwide and three percent of the global burden of disease can be attributed to indoor air pollution from solid fuel combustion (WHO 2002, Smith et al. 2004). In addition to premature deaths, acute respiratory infections, chronic obstructive pulmonary disease, cancer, asthma, tuberculosis, cataracts, low birth weight, and infant mortality have been associated with indoor air pollution in developing countries (Fullerton 2008).

The majority of solid fuel use occurs in developing countries, and in households with open fires or inadequately ventilated cookstoves (Bruce et al. 2008). Traditional indoor cookstoves generate particularly high levels of indoor air pollution (Ezzati 2002). Many pollutants including carbon monoxide (CO), particulate matter (PM), sulfur oxides and nitrous oxides are generated from burning biomass fuels, and high concentrations of these pollutants have been seen in households using open fires or inefficient cookstoves (Zhang and Smith 1999, Budds et al. 2001). In an attempt to substantially reduce indoor air pollution concentrations, improved cookstoves have been designed to burn fuel more efficiently, and usually include a chimney or flue. These improved cookstoves have been shown in studies to significantly reduce indoor air pollution (Albalak et al. 2001, Bruce et al. 2004), but there have been limited longitudinal evaluations of improved cookstove interventions and limited qualitative assessments of improved stoves (Smith 2002).

Many improved stove studies have focused primarily on the respiratory effects of the combustion of solid fuels in a household (McCracken et al. 2007). The World Health Organization's risk assessment of indoor air pollution attributes only respiratory diseases to indoor biomass burning (Smith et al. 2004). Cardiovascular disease is an under-studied disease in developing countries (Yusef et al. 2001). Given the high prevalence of both solid fuel combustion and cardiovascular disease in developing countries, it is important to conduct qualitative assessments of the potential cardiovascular effects of indoor biomass burning. Determining the association between pollutants from indoor air pollution and cardiovascular health could substantially affect the measurement of the burden of disease due to indoor air pollution from cookstove use. There have been limited studies of the effects of cookstove interventions on blood pressure and heart rate, but these studies do indicated that a cookstove intervention can successfully lower these health endpoints (Baumgartner et al. 2011; Clark et al. 2012; McCracken et al. 2007). Additional longitudinal evaluations of cookstove interventions are necessary to determine the effectiveness of cookstove intervention programs in the improvement of cardiovascular and respiratory health outcomes.

Hypothesis

Data collection was completed for a cookstove intervention study in a rural community outside of Granada, Nicaragua, during the summers of 2008 and 2009. We conducted a comprehensive analysis of the previously collected data from 143 households to ascertain the change in health outcomes due to the adoption of an improved cookstove. We hypothesized that the adoption of improved cookstoves would result in reduced exposure and improved health outcomes compared to the use of a traditional stove.

Specific Aims

1. Examine the association between improved stove adoption and changes in indicators of health.
    a. Improved stove use was examined in relation to changes in health indicators. The primary health indicators of interest for this study were blood pressure (n=83), heart rate (n=83), and self-reported cough and headache symptoms (n=95).
2. Examine the presence of potential effect modification of the associations described in Aim 1 by several population characteristics.
    a. Further analysis of the association between stove adoption and changes in the health outcomes was conducted to evaluate the presence of effect modification by age and body mass index (BMI) (n=83 for blood pressure and heart rate, n=95 for self-reported cough and headache).
3. For a subset of households with pollution data, compare indoor air pollution levels at baseline and Year 2 of the cookstove intervention study and evaluate the change in health outcomes in association with the change in pollution levels.
    a. We compared indoor particulate matter ($PM_{2.5}$) (n=33), indoor carbon monoxide (n=41) and personal carbon monoxide (n=39) among households using a traditional stove and those who have adopted the new stove. The change in pollution concentrations (from baseline to Year 2) was then examined in relation to the change in the health indicators described above in Aim 1.

Benefits and Outcomes

This cookstove intervention study adds to the knowledge of the relationship between cookstove use and health. Evaluation of the study's health outcomes helps justify similar cookstove intervention programs and demonstrates the effectiveness of these programs to improve health outcomes.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

Introduction

The World Health Organization ranked indoor air pollution as the 8th most important preventable risk factor contributing to the global burden of disease (Diaz et al. 2007). Roughly half of the world's population relies on the use of biomass fuel (coal, wood, dung, agricultural residues) to meet their domestic energy needs (Boy et al. 2000; Ezzati and Kammen 2002). In rural areas of developing countries, up to 95% of households use biomass fuels (Rehfuess et al. 2006). The overall attributable mortality of indoor air pollution is approximately 50% higher for women than men. Women are estimated to account for 70% of the people living in poverty worldwide, and tend to receive much higher exposures to indoor air pollutants because they spend more time in front of stoves to cook for their families (Budds et al. 2001; Diaz et al. 2006). The adverse health effects from biomass fuels are often exacerbated by the use of stoves that do not have a chimney or a flue in a home with poor ventilation (Fullerton et al. 2008).

Approximately 1.6 million premature deaths per year worldwide and three percent of the global burden of disease can be attributed to indoor air pollution from solid fuel combustion (WHO 2004; Smith et al. 2004). A study conducted in India observed that the disease burden from household solid fuel use is greater than India's national disease burden of malaria, tuberculosis, tobacco, AIDS, heart disease, and cancer and is almost as large as the disease burden from poor sanitation (Murray and Lopez 1996). However, the World Health Organization's risk assessment of indoor air pollution attributes only respiratory diseases to indoor biomass burning (Smith et al. 2004). Few studies have examined the relationship between indoor air pollution and cardiovascular disease (McCracken et al. 2007; Smith and Peel 2010; Baumgartner et al. 2011l Clark et al. 2011).

Combustion of Biomass Fuels

In developing countries, biomass fuels are typically burned using an open fire or in an inefficient stove without adequate ventilation (Bruce et al. 2002). Many pollutants including carbon monoxide (CO), particulate matter (PM), sulfur oxides and nitrous oxides are generated from burning biomass fuels, and high concentrations of these pollutants have been seen in households using open fires or inefficient cookstoves (Zhang et al. 1999; Budds et al. 2001). Studies in developing countries have observed that the average particulate concentrations can be more than ten times higher than the United States Environmental Protection Agency standards for ambient air pollution (Albalak et al. 2001). Despite the knowledge of high levels of indoor air pollution in developing countries, little is known about the constituents of indoor air pollution from the combustion of biomass fuels in comparison to those in ambient air pollution (Budds 2001). Studies have not simultaneously measured all the possible pollutants. As a result, there is little information on pollutants other than PM and CO (Budds et al. 2001).

Our study focuses on the effects of the combustion of wood. Wood is composed of 50-70% cellulose and 30% lignin by weight, and small quantities of inorganic salts and organic compounds (Simoneit et al. 1999). The primary constituents of wood smoke are carbon monoxide, nitrous oxides, and particulate matter (Naeher et al. 2007). Many of the potential pollutants from the combustion of wood have been shown to cause adverse health effects and some of the compounds are irritants, known or suspected carcinogens, cause oxidative stress, or are asphyxiants (Smith 2006). Wood smoke emissions differ from ambient air pollution emissions and the emissions from other sources of biomass fuels, such as coal and animal waste

(Naeher et al. 2007). Emission factors also differ due to the moisture content of the wood undergoing combustion and the burn efficiency of the wood (Khalil and Rasmussen 2003).

Particulate Matter

Particulate matter (PM) is a heterogeneous mixture of solid and liquid particles that are suspended in air. This mixture continually varies in size and composition in space and time. Many different chemicals have been detected in particulate matter. The most common constituents are sulfates, nitrates, carbon, biological compounds, organic compounds, and metals (Brook et. al, 2010; Naeher et al. 2007; Pope and Dockery 2006). Primary particles are emitted directly into the air, whereas secondary particles are created though the transformation of gasses, such as sulfur dioxide or gaseous nitric acid (Brook et al. 2010). The many sources of PM include industrial combustion, construction activities, motor vehicle emissions, and agricultural debris. In the developing world, PM is a concern for indoor air pollution due to the combustion of solid fuels (Naeher et al. 2007). Because the composition of PM varies greatly, size ranges have been defined for regulatory purposes. PM_{10} (PM with a median aerodynamic diameter of < 10 μm) has been the focus of several air pollution studies and can readily deposit into the tracheobronchial tree. From ambient air pollution studies, Dockery and Pope (1994) estimated that mortality will increase by 1% for every 10 μg/m3 in PM_{10} concentration. Fine particulate matter, or $PM_{2.5}$ (PM with a median aerodynamic diameter of < 2.5 μm), originates mostly from combustion sources and is thought to be of greater concern for adverse health effects because it is within the size fraction that can reach the small airways and the alveoli (Brook et al. 2004). $PM_{2.5}$ is believed to be a more relevant exposure to assess when evaluating the health effects of biomass fuel combustion, due to its ability to deposit material deeper in the lungs (Naeher et al. 2007).

The biologic mechanisms linking inhaled particulate matter to adverse cardiovascular health conditions are not definitive, but may involve either the direct effect of the pollutants on the cardiovascular system, blood and lung receptors or the indirect effects of the pollutants mediated by pulmonary oxidative stress and inflammatory responses (Brook et al. 2004). Studies have suggested that the possible links between acute and/or chronic exposure to PM and cardiovascular events may be related to increases in heart rate and blood pressure, fibrinogen, and blood coagulation factors, alone with arterial vasoconstriction, inflammatory mediators, endothelial injury, and decreases in heart rate variability (Donaldson et al. 2001). Other ambient air pollution studies suggest that inhaled particulates may affect the autonomic nervous system through either eliciting a sympathetic stress response or by causing the production of inflammatory cytokines in the lung that are then released into the bloodstream (Magari et al. 2001). Studies have also shown that inhaled particulate matter can result in an increased blood plasma viscosity, reduced lung function, and decreased heart rate variability, particularly among those with preexisting cardiovascular conditions (Pope et al. 2004). Additionally, there is a well-established association between active and passive smoking with heart disease and stroke. This supports the plausibility that exposure to particulate matter (PM) can cause adverse effects to the cardiovascular system (Brook et. al, 2004).

Carbon Monoxide

Carbon monoxide (CO) is an odorless, colorless, and tasteless gas, and is a nearly ubiquitous product of incomplete combustion of carbon-containing fuels (Brook et. al, 2004). Current estimates indicate that combustion of fossil fuels and biomass fuels contributes about 44% of the total global CO budget (Zhang et al. 1999). Ambient CO is one of the primary pollutants regulated in many countries which have focused on controlling CO from industrial and ambient sources (Naeher et al. 2007). The combustion of solid fuels in cookstoves generates high CO concentrations in kitchens, which often result in exposures greater than those from large outdoor sources (Zhang et al. 1999).

Carbon monoxide results in adverse health via two exposure types: acute CO exposure and chronic CO exposure (Zhang et al. 1999). CO binds to hemoglobin with an affinity 250 times that of oxygen, thereby interfering with the systematic delivery of oxygen to tissues (Brook et. al, 2004). The adverse health effects of exposure to carbon monoxide are due to the prevention of blood oxygenation. Without adequate levels of oxygen in the blood, the body's tissues cannot function normally (Kirkpatrick 1987). The amount of carboxyhemoglobin (COHb) in the blood is a function of the carbon monoxide concentration in the air, the duration of the exposure, and the physiologic status of the individual. Normal levels of COHb are around 0.5% for non smokers (Smith 1987). Exposure to CO can cause headache, fatigue, dizziness, nausea, decrease cognitive function, heart palpitations and sleep disturbance; these symptoms begin to present themselves around 3% COHb. Adverse health effects are not generally seen for COHb levels lower than 2%, but COHb levels greater than 40% can cause fatal asphyxiation (Kirkpatrick 1987).

Stove Types and Improved Stove Interventions

Typical PM_{10} concentrations in homes using biomass fuels can range from 200 to 5,000 ug/m^3 (Ezzati and Kammen 2002). In an attempt to substantially reduce indoor air pollution concentrations, improved cookstoves have been designed to burn fuel more efficiently, and usually include a chimney or flue. The most commonly evaluated stoves are the traditional stoves, and improved stoves with and without a flue (Budds et al. 2001). Traditional stoves are typically homemade elevated combustion areas, without a form of chimney (Clark et al. 2011;

Budds et al. 2001). A variety of improved stoves have been designed to address the needs of the specific region. Some improved stoves are the chulha in India, the upesi in Kenya, and the plancha in Central America. The chuhla stove that is used in India is a two-pot mud stove without a chimney and the upesi stove in Kenya is an improved single-pot stove with a fired ceramic liner (Budds et al. 2001).The plancha stove in Central America is an improved stove that is built from a variety of materials, such as brick, cement or metal. A flat metal sheet covers the top of the stove, contains the smoke, and functions as the burner. The stove has a metal or brick flue to remove smoke from the stove without entering the kitchen (Budds et al.2001; McCracken and Charron 2003; Diaz et al. 2007). The Justa cookstove is used in Honduras and has a chimney and an improved combustion chamber (Clark et al. 2009).

These improved cookstoves have been shown in studies to significantly reduce indoor air pollution (Albalak et al. 2001; Bruce et al. 2004; Clark et al. 2012), but there have been limited longitudinal evaluations of improved cookstove interventions (Smith 2002). A study in rural Guatemala observed that the use of a cookstove with a plancha had an 85% reduction in $PM_{2.5}$ concentrations as compared to the households using a traditional open fire (Albalak et al. 2001). Three other studies in the same study area also observed significant pollution reductions with the implementation of cookstoves with planchas (Naeher et al. 2000). A study in Honduras comparing women with improved cookstoves and women with traditional stoves observed that women with the improved stoves had 63% lower personal $PM_{2.5}$ concentrations, 73% lower indoor $PM_{2.5}$ concentrations, and 90% lower indoor carbon monoxide levels (Clark et al. 2009). A study of improved chimney stoves in India observed that one year after implementation of the stoves, CO concentrations were reduced by 70% and $PM_{2.5}$ concentrations were reduced by 44% in the homes using the improved stoves (Chengappa et al. 2007). Another study in India observed similar reductions in CO and $PM_{2.5}$ concentrations (Dutta et al. 2007). Studies of wood burning cookstoves in also Mexico and Guatemala reported similar reductions in exposure concentrations (Masera et al. 2007; Albalak et al. 2001; McCracken et al. 2007; Smith-Sivertsen et al. 2009). A study of various cookstove models in Nicaragua observed that levels of $PM_{2.5}$ were significantly reduced in all improved stove models, and this reduction was significantly greater in a closed stove model than with the semi-open stove model (McCracken and Charron 2003). In contrast, a study of improved stoves in Mexico did not find a significant difference in the mean PM_{10} concentrations of households using traditional stone fires and households using improved stoves (Riojas-Rodriguez et al. 2001). However, the timeframe of this study was much longer and differences over a five year period were evaluated as compared to an average of three to six months in the above studies (Budds et al. 2001). A study of smoke free stoves in Paskistan observed only a small difference in CO concentrations, but this result may be due to the high air-exchange rate in the area, as supported by the low CO levels observed in a cookstove study in Malaysia (Khushk et al. 2005; Lodhi and Zain-al-Abidin 1999). A field test in Kenya observed that improved wood stoves without a flue reduced total suspended particles by 48% compared to an open fire (1822 ug/m3) and improved charcoal stoves were observed to decrease total suspended particles by approximately 64% (559 ug/m3) (Ezzati et al 2000a). From the literature it appears that closed stoves (or stoves with a plancha) are the most successful in achieving substantial reductions in indoor air pollution levels, although cost of implementation and stove maintenance remain important issues to be addressed (Albalak et. al, 2001).

Health Endpoints

Heart rate is the number of heartbeats per unit of time, and is typically expressed in beats per minute (bpm). A person’s resting heart rate is the heart rate while at rest and not immediately after physical exertion. A healthy resting heart rate for an adult is considered to be 60-80 bpm. Heart rate can be measured in a variety of ways. It can be measured at any point on the body where the pulse of an artery is transmitted to the surface (Widmaier et al. 2005). Pulse oximeters, used to report blood oxygen saturation, often also report heart rate. A person's heart rate can change to meet the body's need for oxygen absorption and excretion of carbon dioxide (Widmaier et al. 2005).

Studies have shown that a higher resting heart rate is associated with an increased risk for cardiovascular disease. A study of patients with cardiovascular disease observed those with a resting heart rate above 70 bpm had a higher incidence of myocardial infarction (Kolloch et al. 2008).This is likely due to the higher heart rate leading to an increased production of reactive oxygen specises in the cardiovascular system, increased inflammation, and increased mechanical stress to the heart (Kolloch et al. 2008). Several ambient air pollution studies observed an association between ambient air pollution and heart rate (decreased heart rate with decreased levels of ambient air pollution), but there are no known studies of heart rate and indoor air pollution.

Blood pressure is the force of circulating blood on the walls of the arteries (Widmaier et al. 2005). Blood pressure varies between a maximum (systolic) and minimum (diastolic) pressure during each heart beat. Blood pressure is typically expressed as systolic pressure over diastolic pressure in millimeters of mercury (mmHg). Blood pressure is typically measured on the inside of the elbow at the brachial artery via a sphygmomanometer. The auscultatory method is the main method of measuring blood pressure, which is done by increasing the pressure of a cuff, then listening with a stethoscope at the brachial artery as the pressure is released. The pressure at the first sound of blood flow, the first Korotkoff sound, is recorded as the systolic pressure and the pressure when no sound can be heard, the fifth Korotkoff sound, is recorded as the diastolic pressure (Widmaier et al. 2005). Blood pressure changes in response to stress, nutritional factors, drugs, disease, activity patterns and generally varies largely from person to person. Factors such as age, gender and height can influence blood pressure levels (Urch et al. 2005). Elevated blood pressure has been shown to be a predictor of cardiovascular morbidity and mortality. The reduction of blood pressure has been shown to reduce risk of cardiovascular morbidity and mortality (McCracken et al. 2007).

Studies have investigated whether headache and cough are correlated to higher levels of ambient and indoor air pollution. Information on headache and cough is typically collected via self-report. Headache is a symptom from acute exposures to high concentrations of pollutants, especially carbon monoxide (Diaz et al. 2006; Kirkpatrick 1987). A persistent or recurrent headache may be an indication of carbon monoxide poisoning and is often overlooked (Kirkpatrick 1987). Headaches from carbon monoxide occur with elevated COHb levels (greater than approximately 3%) (Kirkpatrick 1987; Raub 2000; Heckerling 1987). Cough is a symptom from acute and chronic exposures to elevated concentrations of air pollutants. Cough occurs when the lungs work to clear particles deposited in the trachea and the bronchioles. Particles rise due to a mucociliary response and are expelled by coughing or swallowing (Dockery and Pope 1994). Chronic cough can also be a symptom indicating lung disease. Chronic cough can indicate chronic obstructive pulmonary disease, asthma, tuberculosis, lung cancer and respiratory infections (Bruce et al. 2002; Dockery and Pope 1994; Budds et al. 2001). The weighted mean effect from several ambient air pollution studies estimates a 1.2% increase in cough with every 10 ug/m^3 increase in daily mean PM_{10} (Dockery and Pope 1994).

Evidence from Ambient Air Pollution Literature

Evidence of adverse respiratory effects from ambient air pollution has been well established in the literature. Ambient air pollution has been associated with an increase in mortality from respiratory effects and an increase in asthma attacks, Epidemiologic studies also support the hypothesis that chronic PM exposure is associated with deficits in lung function (Bruce et al. 2002; Anderson 1978; Behera et al. 1994). It has been hypothesized that particulate matter air pollution contributes to a more rapid progression of airflow obstruction, which is measured by deficits in FEV_1 as well as PEF (Pope and Dockery 2006). Chronic PM exposure has been hypothesized to result in more rapid progression of COPD and acute PM exposure exacerbates existing pulmonary disease (Pope and Dockery 2006). Studies have also shown that chronic PM exposures increases the symptoms of COPD, such as chronic cough, bronchitis, and chest illness (Dockery et al. 1989, Pope and Dockery 1996; Peters et al. 1999).

A review of ambient air pollution literature has observed that acute and chronic exposure to $PM_{2.5}$ increase the risk for cardiovascular morbidity and mortality (Brook et al. 2010). The review observed that in ambient pollution studies, exposure to $PM_{2.5}$ is associated with an elevated risk for a variety of cardiovascular events. An increased risk for myocardial infarction, stroke, arrhythmia, and heart failure has been shown (Brook et al. 2010). Ambient air pollution has also been associated with an increase in blood pressure, decrease in heart rate variability, and the progression of atherosclerosis (Brook et al. 2010; Magari et al. 2001; Gold et al. 2000). Studies estimate that a 10 ug/m3 increase in 24-hour $PM_{2.5}$ concentration significantly increases the relative risk for cardiovascular mortality (Brook et al. 2010). Cohort studies estimate that the relative risk of cardiovascular mortality associated with living in areas with higher PM levels over the long term is of greater magnitude that that observed from short-term exposure increases (Brook et al. 2010).

The ambient air pollution and cardiovascular health effects literature suggests that there is effect modification by obesity, and stronger effects are observed among those that are obese (Kannan et al. 2009; Delfino et al. 2010; Dubowsky et al. 2006). A study of indoor air pollution from biomass fuels in Nicaragua observed that increases in systolic blood pressure were associated with indoor CO and $PM_{2.5}$ concentrations, and this association was stronger among obese women (Clark et al. 2011).This is particularly relevant to the current study because there is a growing percentage of obesity in developing countries (Bautista et al. 2009; Yusuf et al. 2001). Approximately 34% of Nicaraguan women in the study population are overweight and 34% are obese (Clark et al. 2011).

Health Effects of Indoor Biomass Fuel Combustion

A number of studies have examined the association of adverse respiratory health with indoor biomass burning. Several studies have reported the association of the exposure to indoor air pollution from biomass burning with acute lower respiratory infections (ALRI) in children in developing countries (Bruce et al. 1998). Acute lower respiratory infections contribute greatly to the disease burden from exposure to indoor air pollution (Ezzati and Kammen 2002). Acute lower respiratory infections are the top contributor globally to childhood mortality under the age of five, and annually account for approximately two million deaths in this age category (Bruce et al. 2002). Several studies have observed that exposure to pollutants from biomass fuels increases the risk for other respiratory infections, such as tuberculosis and pneumonia (Perez-Padilla et al. 2001; Dockery and Pope 1994).

Lung function effects

Respiratory symptoms from biomass fuels have been well established in the literature (Smith-Sivertsen et al. 2009). Studies have shown that more adverse respiratory symptoms are seen in women that have long term exposure to high levels or indoor air pollution from the combustion of biomass fuels (Smith et al. 2004; Smith-Sivertsen et al. 2009; Regalado et al. 2006; Romieu et al. 2009). The use of biomass fuels has also been associated with the decline in lung function, as measured by the reduction of forced expiratory volume in one second (FEV_1) and peak expiratory flow (PEF) in several cross-sectional studies (Romieu et al. 2009; Torres-Duque et al. 2008). A decline in lung function has also been associated with levoglucosan, which is a marker of the combustion of wood (Allen et al. 2008).

A reduction of reported respiratory symptoms has been observed in several studies. A case-control study in rural Mexico observed that women who used a gas stove were less likely to have chronic cough, phlegm, and low lung function compared to women using traditional stoves (Perez-Padilla et al. 1996). A study of women in rural Mexico observed that women cooking with biomass fuels had increased respiratory symptoms than women cooking with gas (Regalado et al. 2006). A randomized community trial in Guatemala observed that there was a significant reduction in the report of the symptom of wheezing and the number of respiratory symptoms reported among the women using a plancha woodstove (Smith-Sivertsen et al. 2009). Another randomized trial observed that the use of an improved stove was significantly associated with the reduction of respiratory symptoms and the reduction of respiratory decline (Romieu et al. 2009). However, these lung function results for these two studies were small and variable (Smith-Sivertsen et al. 2009; Romieu et al. 2009).

Throughout the literature, frequent cough is a common symptom among women using traditional stone fires (Regalado et al. 2006; Perez-Padilla et al. 1996; Bruce et al. 1998). In highland Guatemala, the prevalence of cough was approximately 67% (Smith-Sivertsen et al. 2009). Another study of women in highland Guatemala observed that the prevalence of cough and was significantly higher among women using open fires (Bruce et al. 1998). However, a study in highland Papua New Guinea did not find a difference in cough symptoms among those with varying levels of exposure to biomass fuels (Anderson 1978). Another study observed no effect of improved stoves on respiratory symptoms, such as cough, but the adherence to the cookstove intervention was only 50% (Romieu et al. 2009). The differences in findings related to cough symptoms highlights the need to gather more information about the characteristics of the solid fuels being used, continued used of improved cookstoves, and the different characteristics of the populations being studied.

Cardiovascular effects

Several long-term prospective studies of large populations have demonstrated an association of ambient air pollution with heart disease (Dockery 1993, Borja-Aburto 1998). Epidemiological and clinical evidence have evaluated the potential adverse effects of ambient air pollution on health and its relation to heart disease and stroke (Brook et al. 2004; Urch et al. 2005). The studies of ambient air pollution and adverse cardiovascular effects propose various mechanisms for how air pollution can cause adverse cardiovascular effects. Several studies suggest that air pollution may accelerate the development of coronary atherosclerosis and worsen its progression (Brook et al. 2004). A study of ambient air pollutions suggested that exposure to $PM_{2.5}$ could cause vasoconstriction, which may contribute to air pollution mediated acute cardiac events (Brook et al. 2002). The same study also observed that individuals at increased risk for acute air pollution-related cardiac events generally have pre-exisiting cardiovascular disease, which when exposure to pollutants occurs, could promote cardiac ischemia (Brook et al. 2002). Unfortunately, there have been limited studies of the cardiovascular effects of exposure to the combustion of biofuels (McCracken and Charron, 2003). As a result, Smith et al. recommended applying conservative risk estimates gathered from ambient air pollution studies to indoor air pollution exposures in developing countries. They stated that in India, where the typical indoor air pollution exposure is 160 μg/m3, the estimated risk of increased heart disease is 10-40% (Smith 2000).

Elevated blood pressure is an important predictor of cardiovascular disease (Lewington et al. 2002). A reduction of even 2 mmHg blood pressure has been shown to reduce risk of cardiovascular disease (McCracken et al. 2007). An increase in blood pressure associated with exposure to various pollutants has been reported in several studies of ambient air pollution, but other studies did not find such an association (Brook et al. 2004; Ibald-Mulli et al. 2001; Linn et al. 1999). A study of Guatemalan women observed an increase in diastolic blood pressure for those exposed to biomass emissions (McCracken et al. 2007). A recent study in Nicaragua, which used the same study population as the baseline population in this study, observed that there were non-significant increases in systolic blood pressure associated with increases in CO concentrations, and this association was stronger among obese study participants (Clark et al. 2011). These differences in findings could be due to the fact that ambient air pollution studies look primarily at short-term changes in blood pressure. The known adverse health effects are linked to long-term blood pressure differences (McCracken et al. 2007). Unfortunately, there has been limited research on the relationship of indoor air pollution from biomass cookstoves and blood pressure (McCracken et al. 2007; Baumgartner et al. 2011; Clark et al. 2011; Clark et al.

2012). Additionally, only one known study has evaluated the relationship between blood pressure and indoor air pollution with obesity as an effect modifier (Clark et al. 2012).

Ambient air pollution studies have shown an association of increased heart rate and exposure to pollutants (Gold et al. 2000). Heart rate has been shown to increase with exposure to high concentrations of sulfur dioxide, total suspended particulates, and carbon monoxide, and the elevated heart rate was shown to be greater among women (Peters et al. 1999). Short-term increased in inhaled particulates have been shown to cause heart rate abnormalities in humans and animals (Gold et al. 2000). As a result, it has been proposed that airborne particulates could influence adverse cardiovascular outcomes though an increase in heart rate and a decrease in heart rate variability (Magari et al. 2001). During an air pollution episode in 1985, increases in heart rate were observed when compared to non-episode days. Researchers also observed that heart rate increased with high concentrations of sulfur dioxide, total suspended particulates, and carbon monoxide (Peters et al. 1999). Only one known indoor air pollution study has evaluated the effects of biomass fuel emissions on heart rate. Evaluation of the baseline health endpoints and exposure concentrations in the Nicaragua study observed a 1.97 beats per minute increase in heart rate per 2 ppm increase in 48-hour average personal CO levels. There were similar, but non-significant results for heart rate and indoor $PM_{2.5}$ concentrations (Clark et al. 2011).

Additional Health Effects

Additionally, studies have suggested that biomass fuel exposures are linked to an increased risk of lung cancer, cataracts, asthma and tuberculosis (Budds et al. 2001; Bruce et al. 2002). There is an established association in the literature of household biomass fuel combustion and lung cancer, but the majority of these studies have been of women using open coal stoves (Behera and Balamugesh 2005; He et al. 1991, Lissowska et al. 2005). There have also been several studies linking exposure to pollutants from biomass fuels and cataracts. Two studies conducted in India observed that the odds of developing blindness from cataracts due to the use of biomass fuels were increased (Zodpey and Ughade 1999; Mohan et al. 1999). Asthma has also been associated with exposure to pollutants from biomass fuels (Budds et al. 2001; Bruce et al. 2002).

Headache has also been reported as a symptom by those using biomass fuels. Carbon monoxide is known to cause headache, but there is little evidence of headache and its association with indoor air pollution (Ellegard 1997; McCracken et al. 2007). A randomized, controlled trial was performed on the health effects from solid fuel use in Guatemala. The study examined whether indoor air pollution was reduced with the implementation of cookstoves with planchas, and evaluated self-reported headaches and exhaled CO. The study observed that the prevalence of headache prior to the intervention was approximately 70%, and saw a decrease of about 30% of reported headaches among the women using planchas, as compared to the women using an open fire (Smith-Sivertsen et al. 2009; Diaz et al. 2007). A randomized controlled trial in Mexico observed a significant decrease in the relative risk for headache among women using an improved stove as compared to the women using a traditional open fire (Romieu et al. 2009). No other studies assessing indoor air pollution from biomass stoves and headache have been published to date (Clark et al. 2011).

Mechanisms

Ambient air pollution is a complex mixture of gases, liquids, and particles (Brook et al. 2010). Health impacts of the pollutants in ambient air pollution have been well established in the literature. The majority of the adverse cardiovascular effects due to ambient air pollution are believed to be caused primarily by exposure to $PM_{2.5}$. The mechanisms of cardiovascular effects are endothelial disfunction and vascoconstriction. Respiratory effects are generally caused by the deposition of particles in the lungs, which can lead to bronchial irritation and inflammation, and reduced mucociliary clearance (Pope and Dockery 2006).

Smoke from the combustion of biomass fuels have been shown to emit significant quantities of pollutants that cause adverse health effects (Naeher et al. 2007; Bruce et al. 2002; Fullerton et al. 2008). The constituents of emissions from biomass fuels vary greatly based on the materials burned, stove type, and time since generation (Naeher et al. 2007). Wood burning stoves are commonly used in developing countries and the principal pollutants of these stoves are carbon monoxide and particulate matter. Research has been conducted to determine the chemical and physical nature of wood smoke and the toxicity of the many different constituents of wood smoke (Naeher et al. 2007). Wood smoke has also been observed to contain nitrogen oxides, hydrocarbons, and various organic compounds, such as benzene and formaldehyde (Budds et al. 2001; Smith et al. 2000).

Health impacts of the pollutants in wood smoke have been thoroughly characterized in the literature. Several biological mechanisms have been proposed to explain how biomass fuels can cause adverse health effects. Generally, there are two ways that indoor air pollution can affect health. The pollutants can directly be responsible for an adverse health outcome or the pollutants can lead to infection by damaging the respiratory system's mechanical and immune defenses (Budds et al. 2001). Biological mechanisms include bronchial irritation and inflammation, reduced mucociliary clearance, oxidative stress and reduced macrophage response (Bruce et al. 2002).

Summary

Studies of indoor air pollution have observed high exposures associated with the combustion of biomass fuels. Research has shown that cookstove interventions have promising results in terms of the reduction of pollutant concentrations and adverse health effects. However, there have been few longitudinal studies of indoor stove interventions and limited qualitative assessments of improved stoves (Smith 2002). More research needs to be conducted to reduce indoor air pollutions exposures and the associated adverse health outcomes. There have been mixed results regarding the effectiveness of cookstove interventions, which indicates that additional research is needed. Additionally, there have been limited indoor air pollution studies on health effects such as headache, blood pressure, and heart rate. Gathering additional information on these health effects could add to the knowledge of the effectiveness of cookstove interventions on improving health.

In our cookstove intervention study in Nicaragua, information on various health outcomes was collected via measurement and self-report, as well as exposure information for a subset of the population. The health outcomes and exposure data were compared between women who adopted the improved cookstove and those that continued to use a traditional fire. This project will contribute to the knowledge of the relationship between cookstove use and the several health outcomes. Determining the association between pollutants from indoor air pollution and cardiovascular health could significantly affect the measurement of the burden of disease due to indoor air pollution from cookstove use. The study may also justify similar cookstove intervention programs and elucidate the effectiveness of these programs to improve various health outcomes.

CHAPTER 3

GENERAL RESEARCH DESIGN AND METHODS

Introduction

An improved cookstove intervention study was conducted in Nicaragua to assess the association of the adoption of an improved cookstove and changes in health. Participants, who were the primary cooks in the household, non-smokers, and currently using traditional open fires, were recruited, and baseline health measurements were conducted in 2008. The improved cookstoves were then installed in the homes of the participants. During the second year of the study (2009), health measurements were repeated and participants were asked about their stove use.

The purpose of this chapter is to explain, in detail, the overall study design and methods used for the study. The subsequent chapters will address the three primary study aims that were discussed in Chapter 1. The three aims were to 1) examine the association between improved stove adoption and changes in indicators health, 2) examine the presence of potential effect modification by several population characteristics, and 3) evaluate the change in health outcomes in association with the change in pollution levels, for a subset of households with pollution data.

Study site and population

Baseline (May-July 2008) and Year 2 (May-July 2009) measurements were collected for non-smoking women in El Fortin, Nicaragua (a neighborhood outside of Granada). These women were the primary cooks in their households. They were recruited though a volunteer women's organization, Casa de la Mujer. Approval for this study was obtained from the

Colorado State University Institutional Review Board and Biohazards Committee. Approval was also obtained from the Nicaraguan Ministry of Health

Improved cookstove design

At baseline, the participants were all using traditional three-stone open fires (Figure 3.1). Generally, the traditional stoves were homemade, elevated structures without a chimney in an enclosed kitchen. Most kitchens were detached from the main living area and were semi-enclosed or completely enclosed. However, the size of kitchen eaves, kitchen construction materials, and kitchen layout varied among participants. After baseline health measurements were conducted, improved cookstoves (EcoFogon from Proleña [Figure 3.2]) with a chimney and a more efficient combustion chamber were installed in the participants' homes. The EcoFogon has a completely closed steel stovetop griddle, referred to as the plancha, which sits on top of a stove body that is made of cement and pumice stone. The stove has a ceramic combustion chamber and a metal tube chimney with a rocket elbow for increased efficiency. The stove also has an opening in the front for feeding wood.

Assessment of Stove Adoption

In Year 2, a stove use survey was administered to ascertain whether participants had adopted the improved cookstoves and to identify their preferences with regard to using traditional and improved stoves. Closed and open-ended questions were used to determine whether the traditional stove was still being used, how often the traditional stove was used, and the reasons for preferring one stove type over the other (traditional stove or improved cookstove). To assess stove adoption, participants were asked "Are you still using your open fire?" Participants responding "no" (I am not still using the traditional open fire) were categorized as 'complete improved stove adopters'. Participants responding "yes" (I am still using the traditional open fire) were categorized as ‘continued open fire users’. Because of the format of the question, participants responding “yes” could have been using the improved cookstove but could also still be using the open fire; therefore these participants could not be referred to as ‘complete improved stove adopters’.

Measurement of Blood Pressure, Heart Rate and Reported Symptoms

Health endpoints were assessed at baseline and Year 2 of the study. Information on additional health measurements was collected, but was not the focus of this study. Blood pressure was measured using an aneroid sphygmomanometer. A cuff was placed on the upper arm of the participant, the pressure of a cuff was increased, and as the pressure was released, researchers listened with a stethoscope that was placed at the brachial artery. The pressure at the first sound of blood flow, the first Korotkoff sound, was recorded as the systolic pressure and when no sound could be heard, the fifth Korotkoff sound, the pressure was recorded as the diastolic pressure. Systolic and diastolic blood pressure measurements were taken manually between the hours of 8am and 12pm (to account for known diurnal variations) after the participant had been seated and at-rest for ten minutes. Three repeat measures were taken within a ten minute period of continued rest. An average of the second and third blood pressure measurements was used for subsequent analyses; this method is consistent with other indoor air pollution studies (McCracken et al. 2007; Baumgartner 2011) and was used because the first blood pressure measurement is known to be generally higher than additional measurements (Pickering et al. 2005). There were participants that did not have all three measurements of blood pressure (n=3). For these participants, an average of the measurements that the participant did have was used instead of an average of the second and third measurements. Each of the three individual measurements among participants for blood pressure were highly correlated with each other (Tables 3.1 and 3.2).

Heart rate was measured via a portable PulseOx 5500 digital finger pulse oximeter. Participants placed a finger into the pulse oximeter for several seconds while remaining seated and at-rest. Three heart rate measurements were recorded and an average of the second and third heart rate measurements was used for later analyses evaluating the potential association of heart rate and changes in pollutant concentrations and stove adoption. An average of the second and third blood heart rate measurements was used for the same reasons as discussed for blood pressure. As with blood pressure, there were participants that did not have all three measurements of heart rate (n=2). An average of the measurements that the participant did have was used instead of an average of the second and third measurements because each of the three individual measurements among participants for heart rate were highly correlated with each other (Tables 3.1 and 3.2).

We also measured participants' height, weight and waist circumference. A standardized respiratory symptoms and disease questionnaire, developed and validated by the American Thoracic Society, was translated into Spanish and was verbally administered to participants and consisted of a variety of questions to ascertain the absence or presence of a symptom, including the symptoms of cough and headache.

Air Pollution Measurements

Air pollution measurements were collected at baseline and year 2 for a subset of households (n=41 for indoor CO, n=39 for personal CO, n=33 for indoor $PM_{2.5}$). Data were collected for indoor and personal CO concentrations and indoor $PM_{2.5}$ concentrations. Indoor carbon monoxide (CO) concentrations were measured continuously for 48 hours in each home using the Drager Pac 7000 (SKC, Inc; Eighty Four, PA, USA). Participants wore a Drager Pac 7000 for the entire 48-hour sampling period to measure personal indoor carbon monoxide levels. The monitor was attached to the collar of the participant's shirt via a clip and lanyard. Participants were instructed to wear the monitor at all times, unless sleeping or bathing, in which case they were asked to keep the monitors nearby. Fine particulate matter ($PM_{2.5}$) concentrations were measured continuously for 48 hours in each home using UCB Particle Monitors (Berkeley Air Monitoring Group; Berkeley, CA, USA). The UCB particle monitors are modified smoke detectors that continuously log data. The monitors were placed in a location representative of the breathing zone inside the kitchen. An indoor CO monitor was also placed in a location that was representative of the breathing zone (hung next to the UCB monitor). Forty-eight hour averages were calculated for each of the measured pollutants. Dimensions of the cooking area (kitchen volume, building materials, size of windows, and size of eaves) were recorded to give additional information about the cooking area.

Subject Exclusions

Data were entered into Excel, imported into SAS, and analyzed using the SAS computer program (SAS 9.2, SAS Institute, Cary, NC). Measurements were collected from 143 participants. Participants who did not have data for both years were removed from the study (n=35), as well as participants who reported smoking (n=3). Participants who reported working in the textile factory (n=8), the Zona Franca, were also removed from the study because they were likely to have a very different exposure than the rest of the study population (exposures from the factory were likely impacting their respiratory health more than the use of traditional stoves at home and they spent less time cooking in the home than the study participants). Participants who did not have both baseline and Year 2 blood pressure measurements were removed from analyses involving blood pressure (n=1) and participants who did not have baseline and Year 2 heart rate measurements were removed from analyses involving heart rate (n=1). Participants who were pregnant (n=8) or on blood pressure medications (n=5) were removed from the analyses of blood pressure and heart rate. Blood pressure measurements for participants who were pregnant would likely not be comparable of their blood pressure when not pregnant. Participants who did not have both baseline and Year 2 self-reported cough and headache information were removed from analyses involving those symptoms (n=2). The final samples sizes were 97 for general demographic information (94 for waist circumference due to missing data), 83 for heart rate and systolic and diastolic blood pressure, and 95 for the symptoms of headache and cough.

Individual observations were also assessed for accuracy by looking at minimum and maximum values recorded for each variable. No obviously incorrect values were identified; missing data were replaced if it was recorded on the participant's raw data sheets.

Variable Creation

Because the study aims were to assess the change in health outcomes in relation to stove adoption, the health endpoint variables were converted to change from baseline to Year 2. The continuous variables of heart rate, systolic blood pressure, and diastolic blood pressure were created in this format by subtracting baseline measurements from Year 2 measurements, so that a negative number meant a reduction in blood pressure or heart rate.

To assess the symptoms of cough and headache, participants were asked "Do you usually have a cough?" and "Do you usually develop a headache while cooking?" Dichotomous variables for the improvement in cough and headache were created by developing if/then statements to reflect whether the symptoms got worse or stayed the same from baseline to Year 2 (coded as 0) or improved from baseline to Year 2 (coded as 1). For example, if a participant reported usually having a cough at baseline and usually having a cough at Year 2, that participant's cough symptom variable was categorized as remaining the same (coded as 0). If a participant reported not usually having a cough at baseline and usually having a cough at Year 2, that participant's cough symptom variable was categorized as having worsened (coded as 0). If a participant reported usually having a cough at baseline and not usually having a cough at Year 2, that participant's cough symptom variable was categorized as having improved (coded as 1).

A variable for body mass index (kg/m^2) was created by converting height from inches to meters and converting weight from pounds to kilograms. Stove adoption was considered the exposure variable of interest in the analyses and the change from baseline to Year 2 (as assessed above) of blood pressure, heart rate, and the improvement in cough and headache was considered as the outcome (dependent variables) in the statistical analyses. Specific methods and results are presented in Chapters 4 -6.

Power Calculations

Power calculations were performed in SAS for the changes in blood pressure and heart rate prior to data analysis and are presented in Table 3.3. A two-sample t-test for mean differences was used to estimate power to detect differences in the mean changes from baseline to Year 2 of those adopting the new stove and those continuing to use a traditional stone fire for blood pressure and heart rate (n=83). To estimate power, an alpha of 0.05 was used, as well as an adoption rate of 53.6 (observed in our study). There was 89.2% power to detect a change of 10 mmHg, 35.9% power to detect a change of 5 mmHg in this study, and only 9.8% power to detect a change in systolic blood pressure of 2 mmHg (SD=14 mmHg). There was 99.9% power to detect a change of 10 mmHg, 70.0% power to detect a change of 5 mmHg in this study, and only

16.9% power to detect a change in diastolic blood pressure of 2 mmHg (SD=9 mmHg). A change of 2-5 mmHg for systolic and diastolic blood pressure was more feasible for the short follow-up period of the study and is supported by the change in blood pressure seen in other cookstove studies (McCracken et al. 2007). There was 80.2% power to detect a difference of 5 beats per minute and 20.2% power to detect a difference of 2 beats per minute (SD=8 beats per minute).

Power of the dichotomous variables of the self-reported symptoms of cough and headache were calculated in Epi Info, version 3.5.1, and presented in Table 3.4. A ratio of 1:1 exposed to unexposed was used based on adoption rates of 53.6%, as stated above. Assuming about 25% of the population still using a traditional stone fire reported an improvement in a symptom and that there was a sample size of 95, an alpha of 0.05 and 80% power, the minimum detectable odds ratio for change in headache and cough was 3.6. To detect an odds ratio of 2.0 for a change in cough or headache, there was only 27% power, and there was 50% power to detect an odds ratio of 2.5.

Summary

An improved cookstove intervention study was conducted in Nicaragua. The primary goal was to assess changes health and the association of the adoption of an improved cookstove. Baseline health measurements were conducted in a population of Nicaraguan women prior to receiving an improved cookstove. Health measurements were repeated in Year 2 of the study (9-12 months after baseline and receipt of an improved cookstove). Indoor and personal carbon monoxide concentrations and indoor $PM_{2.5}$ concentrations were also measured at baseline and year 2 for a subset of households and stove adoption was ascertained in Year 2 via a stove use questionnaire. This report focused on the effects of the cookstove intervention on blood pressure, heart rate and self-reported cough and headache.

Results of this study are presented in the following chapters according to the aims provided Chapter 1. The association between improved stove adoption and changes in the measured health indicators is examined in Chapter 4. Potential effect modification by several population characteristics is investigated in Chapter 5. A comparison of indoor air pollution levels at baseline and Year 2 of the cookstove intervention study and an evaluation of the change in health outcomes in association with the change in pollution levels, for a subset of households with pollution data is discussed in Chapter 6. Chapter 7 summarizes the results from the study and provides additional discussion and conclusion based on the results.

Table 3.1. Spearman correlation coefficients, baseline endpoints, sample size=83

	Baseline								
	SBP1	**SBP 2**	**SBP 3**	**DBP1**	**DBP 2**	**DBP 3**	**HR1**	**HR2**	**HR3**
SBP 1	1.00	0.93	0.94	---	---	---	---	---	---
SBP 2	0.93	1.00	0.95	---	---	---	---	---	---
SBP 3	0.94	0.95	1.00	---	---	----	---	---	----
DBP 1	---	---	---	1.00	0.88	0.91	---	---	---
DBP 2	---	---	---	0.88	1.00	0.91	---	---	---
DBP 3	---	---	---	0.91	0.91	1.00	---	---	----
HR1	---	---	---	---	---	---	1.00	0.88	0.84
HR2	---	---	---	---	---	---	0.88	1.00	0.81
HR3	---	---	----	---	---	----	0.84	0.81	1.00

SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate

Table 3.2. Spearman correlation coefficients, Year 2 endpoints, sample size=83

	Year 2								
	SBP1	**SBP 2**	**SBP 3**	**DBP1**	**DBP 2**	**DBP 3**	**HR1**	**HR2**	**HR3**
SBP 1	1.00	0.93	0.94	---	---	---	---	---	---
SBP 2	0.93	1.00	0.95	---	---	---	---	---	---
SBP 3	0.94	0.95	1.00	---	---	---	---	---	----
DBP 1	---	---	---	1.00	0.88	0.87	---	---	---
DBP 2	---	---	---	0.89	1.00	0.91	---	---	---
DBP 3	---	---	---	0.87	0.91	1.00	---	---	----
HR1	---	---	---	---	---	---	1.00	0.73	0.76
HR2	---	---	---	---	---	---	0.73	1.00	0.79
HR3	---	---	----	---	---	----	0.78	0.79	1.00

SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate

Table 3.3. Power estimates to detect change in systolic blood pressure, diastolic blood pressure, and heart rate among stove adopters and non-adopters in two-sample t-tests, with an alpha of 0.05

Variable	**Sample size**	**Difference in mean**	**Power**
Systolic blood pressure	83	10 mmHg 5 mmHg 2 mmHg	89.2% 35.9% 9.8%
Diastolic blood pressure	83	10 mmHg 5 mmHg 2 mmHg	99.9% 70.0% 16.9%
Heart rate	83	5 bpm 2 bpm	80.2% 20.2%

Table 3.4. Power estimates to detect differences in change of cough and headache among improved stove adopters and traditional stove users with a sample size=95 and alpha=0.05

Odds Ratio	Power
2.0	27%
2.5	50%
3.6	80%

Figure 3.1. Traditional three-stone fire in use in a participants' household

Figure 3.2. The improved stove: Proleña's Eco Fogon Stove in a participants' household

CHAPTER 4

IMPROVED STOVE ADOPTION AND CHANGES IN BLOOD PRESSURE, HEART RATE AND SELF-REPORTED SYMPTOMS (AIM 1)

Introduction

Heart rate, systolic blood pressure, diastolic blood pressure and reported symptoms of headache and cough were collected from participants of the improved cookstove study before the new stoves were installed (baseline data) and approximately one year after the improved stove installation (Year 2). Approximately half of the participants reported complete adoption of the improved stove. The goal of Aim 1 was to examine the association of self-reported improved stove adoption and changes in blood pressure, heart rate, and symptoms of cough and headache. The reductions in concentrations of 48-hour indoor carbon monoxide, 48-hour personal carbon monoxide, and 48 hour $PM_{2.5}$ by stove adoption status were also evaluated in Aim 1. This chapter gives a brief synopsis of the background literature, describes the specific statistical methods conducted, and provides results specific to Aim 1.

Background Literature

Change in Pollutant Concentrations in Cookstove Studies

Improved cookstoves have been shown in studies to significantly reduce indoor air pollution (Albalak et al. 2001; Bruce et al. 2004). A study in rural Guatemala observed that the use of a cookstove with a plancha had an 85% reduction in 24-hour $PM_{2.5}$ concentrations as compared to the households using a traditional open fire (mean=1560 $\mu g/m^3$ $PM_{2.5}$ for the traditional open fire and 280 $\mu g/m^3$ for the stove with a plancha) (Albalak et al. 2001). A study in Honduras comparing women with improved cookstoves and women with traditional stoves observed that women with the improved stoves had 63% lower personal 48-hour $PM_{2.5}$ concentrations (mean=198 $\mu g/m^3$ for the traditional stoves and 74 $\mu g/m^3$ for the improved stoves), 73% lower indoor 48-hour $PM_{2.5}$ concentrations (mean=1002 $\mu g/m^3$ for the traditional stoves and 266 $\mu g/m^3$ for the improved stoves), and 90% lower 48-hour indoor carbon monoxide levels (mean=14.3 ppm for the traditional stoves and 1.8 ppm for the improved stoves) (Clark et al. 2010). Studies of wood burning cookstoves in Mexico and Guatemala also reported large reductions in exposure concentrations (Masera et al. 2007; Albalak et al. 2001; McCracken et al. 2007; Smith-Sivertsen et al. 2009). A study of closed and semi-open improved cookstove models in Nicaragua observed that indoor 24-hour $PM_{2.5}$ levels were significantly reduced in both improved stove models, and this reduction was greater in a closed stove model than with the semi-open stove model (a reduction from 514 $\mu g/m^3$ to 53 $\mu g/m^3$ for the closed stove and a reduction from 639 $\mu g/m^3$ to 121 $\mu g/m^3$ for the semi-open stove) (McCracken and Charron 2003). The literature provides evidence that closed stoves (or stoves with a plancha) are successful in achieving substantial reductions in indoor air pollution levels (Albalak et. al, 2001).

Change in Health Outcomes

Few studies have examined the relationship between indoor air pollution and cardiovascular disease; much of the cookstove research has instead involved the effects of indoor air pollution on respiratory disease, although evidence for cardiovascular effects can be found in the ambient air pollution literature (McCracken et al. 2007; Smith and Peel 2010; McCracken et al. 2011; Clark et al. 2011; Baumgartner et al. 2011). Heart rate variability has been evaluated in several ambient air pollution studies, and the results of an indoor air pollution study suggest that there is a relationship between increased levels of indoor air pollution and decreased heart rate variability (McCracken et al. 2011). No known studies have been conducted on the change in the resting heart rate of the study population in a cookstove intervention. Blood pressure has been evaluated in several indoor air pollution studies, including a study of the association of blood pressure and pollution concentration in our Nicaragua study population at baseline (McCracken et al 2007; Baumgartner et al. 2011; Clark et al. 2011). Elevated blood pressure has been shown to be a predictor of cardiovascular morbidity, and a reduction blood pressure has been shown to reduce risk of cardiovascular disease (Sesso et al. 2003; Lewington et al. 2002).

Previous studies have examined the association of the presence of symptoms with ambient and indoor air pollution. Respiratory symptoms from biomass fuels have been well established in the literature (Smith-Sivertsen et al. 2009). Throughout the literature, frequent cough is a common symptom among women using traditional stone fires (Regalado et al. 2006; Perez-Padilla et al. 1996; Bruce et al. 1998). Another study observed no effect of improved stoves on respiratory symptoms, such as cough, but the adherence to the cookstove intervention was only 50% (Romieu et al. 2009). Headache is a symptom from acute exposures to high concentrations of pollutants, especially CO, but there is little evidence of headache and its association with indoor air pollution (Ellegard 1997; McCracken et al. 2007). One study observed that the prevalence of headache after a cookstove intervention decreased about 30% among the women using planchas, compared to the women using an open fire (Smith-Sivertsen et al. 2009; Diaz et al. 2007). A randomized controlled trial in Mexico also observed a significant decrease in the reporting of headache among women using an improved stove compared to the women using a traditional open fire (Romieu et al. 2009). No other known studies assessing indoor air pollution from biomass stoves and headache have been published to date. Additional information on these health effects, such as headache, blood pressure, and heart rate, could add to the knowledge of the relationship between indoor air pollution and health. In our cookstove intervention study in Nicaragua, information on blood pressure, heart rate, and the symptoms of cough and headache was collected. The change in these health outcomes were compared between women who adopted the improved cookstove and those who reported continued open fire use.

Methods

Air Pollution Measurements:

The concentrations of indoor $PM_{2.5}$ and indoor and personal carbon monoxide CO were measured in a subset of the population using the methods previously discussed in Chapter 3. The subset consisted of a convenience sample of households based on a sample of participants that had data for indoor particulate matter (n=33) and indoor (n=41) and personal (n=39) carbon monoxide data for baseline and Year 2. Stove adoption status was assessed using the methods previously discussed in Chapter 3 (question ascertaining whether the subject was still using an open fire).

Statistical analysis for air pollution measurements:

Forty-eight hour averages were calculated for each of the measured pollutants. Descriptive statistics were calculated for the baseline and Year 2 measurements of $PM_{2.5}$, personal carbon monoxide and indoor carbon monoxide concentrations (means, standard deviations, minima, maxima and quartiles). The distributions for the change in pollutant concentrations (indoor $PM_{2.5}$, indoor CO and personal CO) from baseline to Year 2 were evaluated through box-plots and normal probability plots and were found to have normal distributions, and thus remained untransformed. Paired t-tests were conducted to determine whether mean 48-hour baseline pollutant concentrations differed significantly from Year 2 pollutant concentrations. Two-sample t-tests were conducted to determine whether the changes in mean pollutant concentrations were significantly different between self-reported improved stove adopters and continued open fire users.

Statistical analysis for demographic and health measures:

Descriptive statistics (mean, median, standard deviation, minimum, maximum) were calculated for the general demographics of the study population at baseline (age, weight, height, and waist circumference). Descriptive statistics (mean, median, standard deviation, minimum, maximum) were also calculated for heart rate, systolic blood pressure, and diastolic blood pressure (an average of the second and third blood pressure and heart rate measurements was used).

Paired t-tests were conducted to evaluate the difference between baseline and Year 2 for heart rate, systolic blood pressure, and diastolic blood pressure. Normality was assessed by evaluation of histograms and normal probability plots and the Shapiro-Wilk test. The changes in systolic blood pressure and heart rate were determined to have a non-normal distribution. As a result, non-parametric tests (Wilcoxon ranked sum tests) were used in analyses involving the change in systolic blood pressure and heart rate. Paired t-tests were conducted to examine the relationship between stove adoption and the change in heart rate, and diastolic blood pressure (individually).

McNemar's nonparametric test for two correlated proportions was used for the symptom responses where a participant indicated the absence or presence of cough and headache to determine whether there was a statistically significant difference in the symptoms from baseline to Year 2 for the entire population. McNemar's test was used because the assumption of independence of variables for a general chi-squared analysis was not met. McNemar's test has been used for similar pre and post intervention data (Goodman et al. 2007).

Frequency and percent of the dichotomous variables indicating cough and headache improvement (as described in Chapter 3) were calculated. Mantel-Heanszel chi-square tests were conducted to examine the association between stove adoption (continued stove use versus improved stove adoption) and the proportion improved self-reported symptoms of cough and headache (defined as improvement in the symptom versus no improvement). Mantel-Heanszel chi-square probability values, odds ratios and 95% confidence intervals were calculated.

Results

The personal characteristics at baseline are presented for the study population in Table 4.1. At baseline, the average age of the study population (n=97) was 34.5 years (SD=15.4), the average weight was 143 pounds (SD=36), the average height was 59.8 inches (SD=2.5), the average waist circumference was 37.0 inches (SD=6.3), the average waist-to-hip ratio was 0.9 (SD=0.1), and the average body mass index was 28.2 kg/m^2 (SD=6.9). During data collection in Year 2, 53.6% women reported completely adopting the improved stove. After stratification by improved stove adoption status, the average age of the participants, weight, height, waist circumference, waist-to-hip ratio, and body mass index were similar between groups (Table. 4.2).

The mean concentrations of 48-hour indoor carbon monoxide (n=41), 48-hour personal carbon monoxide (n=39) and 48-hour indoor $PM_{2.5}$ (n=33) were high for both baseline and Year 2 of the study in the subset of study participants (Table 4.3). However, there was a large, statistically significant mean reduction in the pollutant concentrations from baseline to Year 2 for the total population (p-value<0.0001 for 48-hour indoor CO and indoor $PM_{2.5}$, p-value=0.001 for 48-hour personal CO); 48-hour indoor CO was reduced by 75.4%, 48-hour personal CO was reduced by 67.2%, and 48-hour indoor $PM_{2.5}$ was reduced by 79.6%.

Similar reductions in pollutant concentrations were observed among self-reported improved stove adopters and continued open fire users (Table 4.4). A reduction of 80.4% in 48-hour personal CO, 77.7% in 48-hour indoor CO, and 85.0% in 48-hour $PM_{2.5}$ from baseline to Year 2 was observed for improved stove adopters. A reduction of 80.4% in 48-hour personal CO, 73.6% in 48-hour indoor CO, and 74.6% in $PM_{2.5}$ from baseline to Year 2 was observed for continued open fire users. Those participants who adopted the improved stove did not have significantly different changes in pollutant concentrations compared to those reporting continued open fire use (p-value=0.67 for 48-hour personal CO, p-value=0.49 for 48-hour personal CO, and p-value=0.97 for 48-hour indoor $PM_{2.5}$).

Blood pressure and heart rate measurements for the study participants for baseline and Year 2 are presented in Table 4.5. Changes in systolic blood pressure, diastolic blood pressure, and heart rate from baseline to Year 2 for the study participants for the total study population and stratified by stove adoption status are presented in Table 4.6. For the total population, mean systolic blood pressure decreased by 1.8 mmHg, mean diastolic blood pressure decreased by 0.7 mmHg, and mean heart rate decreased by 0.6 bpm; these differences were not statistically significant (p-value=0.22 for systolic blood pressure, 0.51 for diastolic blood pressure, and 0.55 for heart rate). The changes in blood pressure and heart rate by were similar among subjects who adopted the improved stove and those subjects who reported continued open fire use (Table 4.6, p-values=0.54, 0.56, 0.21, respectively).

The self-reported symptoms of cough and headache in the study population for baseline and Year 2 are presented in Table 4.7. At baseline 22.7% of participants reported that they usually have a cough, while during Year 2, 26.3% of participants reported that they usually have cough; this difference was not statistically significant (p-value=0.55). The prevalence of self-reported headache during cooking was markedly decreased in Year 2 compared to baseline (62.9% at baseline and 25.3% in Year 2, p-value=<0.01).

The change in self-reported cough symptoms was similar among subjects who adopted the improved stove and those who reported continued open fire use (Table 4.8). The odds of an improvement in cough for improved stove adopters was 1.24 (95% CI=0.36-4.23) times the odds of improvement in cough among continued open fire users. Additionally, the change in self-reported headache was similar among those who adopted the improved stove and those who reporting continued open fire use (Table 4.8). The odds of an improvement in headache while cooking for those that adopting the improved stove was 1.30 (95% CI=0.57-2.96) as compared to those subjects who reported continued open fire use.

Discussion

Large reductions (ranging from 74% to 85%) in pollutant concentrations were observed in the total study population from baseline to Year 2 of the study; these large reductions were observed among both self-reported stove adopters and continued open fire users. Small, non-statistically significant reductions in systolic blood pressure and heart rate were observed for the entire study population; these reductions were similar for both stove use groups. A large, statistically significant (p-value=<0.01) reduction in the prevalence of self-reported headache was observed for the entire study group. The prevalence of the self-reported symptom of headache decreased from 63% at baseline to 25% in Year 2.

The complete stove adoption rate in our study is similar to adoption rates reported in other improved cookstove studies in Central America (Romieu et al. 2009; Schei et al. 2004). In our study, 53.6% of subjects reported that they were no longer using an open fire (complete improved stove adoption). The remaining subjects reported using an open fire in Year 2. Due to the way the question was phrased, reported use of an open fire in Year 2 could mean than those subjects were either entirely using an open fire or only partially using an open fire. Because the continued open fire group was actually a mixed use group of partial adopters and complete non-adopters, it is difficult to determine the true impact of the improved stove because there is no 'control' group of participants exclusively using the traditional open fire. There was also some mixed stove use among the complete stove adopters. The mixed stove use was therefore likely non-differential and led to an attenuation of the change in health endpoints when stratified by stove use.

The cookstove intervention achieved large reductions in the pollutant concentrations in our study population. For the entire study population, 48-hour personal CO concentrations were reduced by 67.24%, 48-hour indoor CO concentrations were reduced by 75.4%, and 48-hour $PM_{2.5}$ concentrations were reduced by 79.6%. The reduction of pollutants in our study is similar to reductions observed in other cookstove intervention studies. A randomized, cookstove intervention study involving a stove with a plancha observed a 62% reduction in personal CO exposure levels (Smith-Sivertsen et al. 2009). A study of improved stoves in Honduras observed a 63% reduction in personal $PM_{2.5}$ concentrations, 73% lower indoor $PM_{2.5}$ concentrations, and a 90% reduction in indoor carbon monoxide concentrations among participants using improved stoves (Clark et al. 2010).

The mean body mass index at baseline was 28 kg/m^2, and over one-third of participants were obese (body mass index greater or equal to 30 kg/m^2) at baseline. The high percentage of obese participants is typical of many Central American populations (Romieu et al. 2009; Finucane et al., 2011; Smith-Sivertsen et al. 2009). Additionally, our study population had an 'apple shaped' body type, as shown by the mean waist-to-hip ratio of our study population. An apple-shaped body type is typically associated with an excess accumulation of abdominal fat. An excess in abdominal fat has been shown to increase the risk of cardiovascular disease (Caprio et al. 1996; Dalton et al. 2003). The mean waist-to-hip ratio in our study population was 0.89 (SD=0.08). A study of U.S. women found that a waist-to-hip ratio of 0.88 or greater was associated with more than a three-fold higher risk of coronary heart disease compared to women with a waist-to-hip ratio less than 0.72 (Rexrode et al. 1998). Due to the high waist-to-hip ratio in our study population and the association of high waist-to-hip ratio and risk of coronary heart disease, the assessment of cardiovascular disease in this study is particularly relevant.

Systolic blood pressure for the entire study population (both improved stove adopters and those who reported continued open fire use) decreased on average by 1.8 mmHg, which, although non-significant, is similar to results observed in other studies (Baumgartner et al. 2011; McCracken et al. 2011). The decrease in systolic blood pressure in our study population could be an indicator of decreased cardiovascular risk (Sesso et al. 2003; McCracken et al 2007). A decrease as small as 2 mmHg in the population mean for systolic blood pressure can lead to a 10% decline in stroke mortality and a 7% decrease in mortality from ischemic heart disease or other vascular causes in middle age (Lewington et al. 2002). Although non-significant, the reductions in diastolic blood pressure and heart rate from baseline to Year 2 were greater among subjects who adopted the improved stove compared to those subjects who reported the continued use of an open fire, though it is unclear whether the small reductions are meaningful in affecting cardiovascular health.

The prevalence of self-reported headache during cooking decreased from 63% at baseline to 25% in Year 2. However, when examined by stove adoption status, the change in self-reported headache was not statistically significant, though the odds ratio was in the expected direction (improvement of headache more likely among improved stove adopters). There is a higher odds of improvement in self-reported headache among stove adopters than those subjects who reported the continued use of an open fire (OR=1.3, 95% CI=0.57-2.96). A reduction of reported symptoms in stove adopters and continued open fire users was also observed in studies of headache and other non-respiratory symptoms (Diaz et al.2007; Romieu et a. 2009). While our study did not find a significant difference in the change in self-reported headache among stove adopters and continued open fire users, it is notable how dramatically headache changed in the total population. The reduction in headache in both stove use groups can likely be explained by the large reductions in carbon monoxide among both improved stove adopters and those who reported continued open fire use. Headache is a symptom from acute exposures to high concentrations of pollutants, especially carbon monoxide (Diaz et al. 2006; Kirkpatrick 1987). Headaches from carbon monoxide occur with elevated carboxyhemoglobin (COHb) levels, and it is possible that carbon monoxide levels in our study population were decreased enough to decrease the occurrence of headache among participants.

Although our cookstove intervention study achieved large reductions in the pollutant concentrations (48-hour indoor CO was reduced by 75.4%, 48-hour personal CO was reduced by 67.2%, and 48-hour indoor $PM_{2.5}$ was reduced by 79.6%), the concentrations were still relatively high in Year 2 compared to air pollution standards. A World Health Organization working group for indoor air quality guidelines determined that the appropriate 24-hour limit for carbon monoxide was 5.68 ppm (WHO, 2010). The World Health Organization 24-hour air quality guideline for ambient $PM_{2.5}$ exposures is 25 $\mu g/m^3$ (WHO, 2005). Comparatively, the Year 2 mean concentration of indoor carbon monoxide for our study population was 6.68 ppm and the mean concentration of indoor $PM_{2.5}$ was 361 $\mu g/m^3$. Pollutant concentrations may have remained too high for an observed decrease in adverse health effects outcomes. Similar high exposure concentrations following a cookstove intervention have been observed in other studies (Chengappa et al. 2007; Masera et al. 2007; Alabak et al. 2007; McCracken et al. 2007).

In our study, those subjects who completely adopted the improved stove and those who reported continued open fire use experienced similar reductions in the measured pollutants (48-hour indoor and personal CO and 48-hour indoor $PM_{2.5}$). Though not statistically significant, the largest reductions were generally observed among improved stove adopters, though those subjects who reported continued open fire use had a slightly larger decrease in indoor carbon monoxide. The lack of a significant difference in pollutant concentrations between improved stove adopters and continued open fire users may be due to the mixed used of stoves in the both stove use groups (those classified as self-reported improved stove adopters may still be using an open fire and those who reported continued open fire use may use the improved stove to some extent), as well as possible lifestyle changes, such as knowledge that exposure to smoke from the stoves is harmful. For example, women learned about the study aims during the first year of the study, and although they may not have completely adopted the improved stove, they may have made efforts to decrease exposure, such as spending less time in the kitchen, cooking for shorter time periods, or creating additional ventilation in the kitchen. This measurement error could have led to an underestimation of the effect of the improved stove adoption on the measured health endpoints and outcomes if participants similarly changed their habits while cooking, such as a majority of participants spending less time in front of the stove while cooking.

The average age of study participants at baseline was 34 years, with a median age of 32 years. The age range in our population was large, ranging from 11 to 80 years of age. Because many of the measured health endpoints change with age, such as resting systolic blood pressure, it is difficult to determine whether the any observed changes in the endpoints were related to increasing age instead of the cookstove intervention. For example, systolic blood pressure typically remains relatively stable until age forty-five, then increases approximately 5-8 mmHg per decade until approximately age 70, when it may begin to decline or stabilize again in women (Pearson et al. 1997). Because of this, if any age-related increases in blood pressure occurred during the study group, the effects of the adoption of an improved cookstove were likely underestimated. Additionally, it is likely that younger women would respond differently to the changes in exposure concentrations than older women; perhaps older women have a greater ability to respond to the change, whereas younger women may not be as sensitive to change, and their health outcomes are not as easily affected by a cookstove intervention. This could potentially influence the measure of the effect of stove adoption on the change in systolic and diastolic blood pressure in our results; age is investigated as a potential effect modifier in Chapter 5.

The results did not provide evidence that self-reported cough decreased after the improved stove intervention. The lack of evidence could be due to participants having an irreversible condition with a symptom of cough. If the cause of cough, such as chronic obstructive pulmonary disease, is irreversible, the participant would not be likely to have a reduction in this symptom (Romieu et al. 2009). Improved cookstove studies in Mexico have demonstrated greater decreases in respiratory symptoms among those using improved stoves compared to those subjects continuing to use a traditional open wood fire (Regalado et al. 2006; Romieu et al. 2009).

Limitations:

It is possible that there is measurement error and exposure misclassification in our study. Personal $PM_{2.5}$ measurements are likely to be influenced by daily variation, such as changes in living habits or outdoor conditions, which could lead to some misclassification of exposure because the measurements were only for a 48-hour period and may not be representative of the usual exposure (i.e. participants could have avoided standing near smoke during the 48-hour timeframe, but do not typically avoid exposure to smoke). This potential limitation is expected to be non-differential and lead to an attenuation of the effect of the cookstove intervention on health measures. It is possible that the particle monitors were also measuring other sources of $PM_{2.5}$, such as trash being burned near the household. Monitor readings could have also been affected by ambient conditions such as temperature, wind, or humidity. These conditions were not accounted for in our analyses and could have resulted in an underestimation of the sole effect of the cookstove intervention on health measures.

An important limitation in this study may be in the measurement of stove adoption. Women were asked in Year 2 if they were still using their open fire. The measurement of stove adoption was based on self-report, which may have led to substantial misclassification of stove adoption status. Based on personal observation and other measurement data not included in this study (data on cookstove temperatures was collected for a subset of participant during the 48-hour measurement period), we know that both groups, improved stove adopters and continued open fire users, were a mixed group of stove usage. However, we did not keep systematic records of these observations, and true stove usage would need to be observed over a longer period of time. There may be participants classified as improved stove adopters who were not using their improved stove at all, as well as some participants that chose to use both of their stoves (the traditional stove and the improved cookstove). There may also be women in the group categorized as continued open fire users who were using both stoves or solely using the improved stove. Additionally, women who reported complete adoption may not have been using their improved stove correctly. Some participants removed the plancha while cooking, or did not have a good seal on their plancha. While they adopted the improved cookstove, they were still exposed to more smoke from their improved cookstoves than the stove adopters who were using their stoves correctly. The mixed stove use and the incorrect use of the stove likely led to an underestimation of the effect of the cookstove intervention on the measured health endpoints in our study population due to a non-differential misclassification error.

There is also possible observation bias in our study. In general, the team member administering the questionnaire and taking health measurements could see who was using either traditional or improved cookstoves. It is possible that more effort was made to determine improvement of a symptom of a participant using their improved stove. If this were the case, it could have resulted in a bias resulting in an inflated effect of stove adoption on the improvement in symptoms. However, this was likely not an issue due to the fact that not all symptoms improved from baseline to Year 2.

The measurement of self-reported cough and headache was not very specific. Participants were asked “Do you usually have a cough?” and “Do you usually develop a headache while cooking?” Participants may have had difficulty determining what it meant to usually have a cough or headache, and may have responded yes even if they had only recently developed a cough or headache, possibly because they had not noted how long they had the symptom in question. Additionally, participants may not have wanted to say they had cough or headache because this response shortened the questionnaire (reporting the presence of a symptom led to additional questions in our questionnaire to ascertain duration and severity of the symptom). This limitation has been suggested in several cookstove intervention studies (Romieu et al. 2009; Diaz et al. 2007; Smith-Sivertsen et al. 2009). This could have resulted in non-differential error and an underestimation of the effect of stove adoption on the self-reported symptoms of cough and headache if participants frequently reported an absence of the symptom to shorten the interview. It is also possible that participants did not want to report a symptom because they believed an improvement of symptoms was expected from the improved cookstoves. In this case, it is possible that participants using their improved stove may have reported fewer symptoms than those participants continuing the use of an open fire, leading to an overestimation of the effect of stove adoption on the self-reported symptoms of cough and headache. However, this underreporting was likely not an issue, because not all participants knew the purpose of the study.

There was a low refusal rate in our study population, but the participants were not randomly selected to participate in the study and receive an improved stove. Instead, a convenience sample was used in this study. As a result, it is possible that our use of a convenience sample limits the generalizability of our study to other communities because participants with adverse health conditions may have been recruited before other members of the community.

The measurements of blood pressure, heart rate, and the symptoms of cough and headache were one-time measurements of health (from one day) and may not be reflective of the participant's actual health status. There could be factors unrelated to the cookstoves, such as an infection or stress, which might have affected the participant's health measurements on that day. If the measures on the one day of each year's measurement were not typical of the study participant, this could have resulted in non-differential misclassification of any of measured health endpoints, resulting in an underestimate of the effect of stove adoption on heath. Taking periodic repeat measurements throughout the entirety of the study period would improve confidence in the self-reported symptoms and changes in blood pressure and heart rate. Having a one-time measurement of health at both baseline and the second year of the study is still a stronger design than a cross-sectional study, which relies on prevalence data and does not show temporality because it only has one measurement at one time point. Additionally, because the health measurements were all conducted during the same season for baseline and Year 2, there is some confidence that the variability in symptoms that is known to occur in different seasons (such as more cough in the rainy season) was eliminated.

It is also possible that larger changes in the health measures were not observed because of the short follow-up period of our study. The Year 2 measurements were conducted nine to twelve months after the baseline assessment, which may not have been enough time for the health effects from the improved cookstoves to be observed. Other studies have suggested that one year of follow-up is not long enough to see long-term effects from cookstove interventions, though an ideal time period was not proposed (Khushk et al. 2005; Romieu et al. 2009). Additionally, the study did not have a control arm due to feasibility and logistical constraints. Each participant that had baseline measurements received the improved cookstove, unlike other studies that have included a control group (McCracken et al. 2007; Smith-Sivertsen et al. 2009; Diaz et al. 2007). The use of a control arm could have would have allowed for a more distinct difference in stove use groups and provided a distinction on which baseline to Year 2 changes were related to the adoption of the improved stove and which were due to other factors, such as increasing blood pressure due to age or a general change in air pollution concentrations in the community.

The measurement of blood pressure was conducted manually. This has some limitations because the Korotkoff sounds were determined by the team member's judgment of what consisted of the correct sounds for systolic and diastolic blood pressure. At some households, it was difficult to hear while taking blood pressure measurements. It is possible that the blood pressure recorded for a participant was not accurate due to interference from other sounds in the household. Taking three measurements of blood pressure may have mitigated some of this potential problem. It is likely that both those that adopted the improved stove and those that continued open fire use had similar degrees of measurement error, and therefore the bias was likely non-differential and an underestimation of the effect of the improved stove on blood pressure. Participants were eliminated from blood pressure and heart rate analyses if they were on blood pressure medications or were pregnant. Both of these conditions were self-reported. Participants may have been eliminated when they should not have (were not actually on blood pressure medications or were pregnant, but misreported due to confusion with the question), and participants may not have reported that they were pregnant or on blood pressure medications, and should have been eliminated from the appropriate analyses. This is possible especially because women were not asked whether they were pregnant at baseline; this question was asked only in Year 2 of the study. This could have affected the blood pressure and heart rate results in either direction, depending on how participants were misclassified.

Strengths:

A key strength of our study is that we were able to obtain information on blood pressure and heart rate as well as self-reported symptoms. We were able to evaluate changes in self-reported symptoms, but also evaluated changes in measured blood pressure and heart rate that did not rely solely on self-report, which reduced some potential bias. We were also able to obtain longitudinal health measurements at baseline and Year 2, which gives some indication of temporality as compared to many biomass fuel studies that are cross-sectional in nature. Though our study was only one year of follow-up, our study period was still able to provide some information on change in health over time, compared to the cross-sectional studies in the cookstove literature We were also able to collect measurements during the same season and approximate time of day, which minimizes the influence of factors such as dusty conditions during dry versus wet seasons.

Additionally, our study investigated the stove adoption as the exposure of interest, whereas many cookstove studies focus on the actual change in pollutants. The use of this exposure was a strength because it minimized the potential for confounding. None of the measured factors (age, weight, height, and hip circumference) are associated with both a one year change in the measured health outcome (change in self-reported cough and headache symptoms and change in blood pressure and heart rate) and stove adoption.

Table 4.1. Selected personal characteristics of the study population at baseline

Personal Characteristics	**N**	**Mean**	**SD**	**Min**	**Max**
Age (years)	97	34.5	15.4	11	80
Weight (lbs)	97	143.2	36.2	62.5	305
Height (in)	97	59.8	2.5	52.8	65.8
Waist circumference (in)	94	37.0	6.3	25	53
Waist-to-hip ratio	97	0.89	0.08	0.68	1.06
BMI (kg/m^2)	97	28.2	6.9	14.0	55.0

SD, standard deviation; BMI, body mass index

Table 4.2. Selected personal characteristics of the study population at baseline

	Adopted improved stove					Continued open fire use					P-value*
Personal Characteristics	**N**	**Mean**	**SD**	**Min**	**Max**	**N**	**Mean**	**SD**	**Min**	**Max**	
Age (years)	51	34.3	16.9	13	73	46	34.7	13.9	11	80	0.88
Weight (lbs)	51	146.2	39.2	86	305	46	139.9	35.6	62.5	210.5	0.39
Height (in)	51	59.6	2.7	52.8	65.8	46	59.9	2.4	54.3	65	0.57
Hip circumference (in)	50	41.9	5.6	33	63	44	41.1	4.8	28	51	0.49
Waist circumference (in)	50	37.8	6.5	26	53	44	36.1	5.9	25	46	0.17
Waist-to-hip ratio	50	0.9	0.1	0.8	1.1	44	0.9	0.1	0.7	1.0	0.97
BMI (kg/m^2)	51	29.0	7.4	17.2	54.9	46	27.4	6.2	14	39.1	0.27

SD, standard deviation; BMI, body mass index

*Paired t-test p-value

Table 4.3. Pollutant measurements for the study population at baseline and Year 2

Pollutant	N	Mean	SD	Min	Max	IQR	P-value*
48-hour carbon monoxide, indoor (ppm)	41						
Baseline		27.14	24.16	0.40	112.20	26.00	
Year 2		6.68	10.35	0.01	42.61	7.53	
Change		-20.47					<0.0001
48-hour carbon monoxide, personal (ppm)	39						
Baseline		2.35	2.50	0.09	14.08	1.88	
Year 2		0.77	1.11	0.01	6.55	1.08	
Change		-1.59					0.001
48-hour $PM_{2.5}$, indoor ($\mu g/m^3$)	33						
Baseline		1,773	1,581	154	5,246	2,070	
Year 2		361	478	22	2,207	290	
Change		-1,412					<0.0001

SD, standard deviation; IQR, interquartile range; PM, particulate matter; ppm, parts per million

*Paired t-test p-value

Table 4.4. Pollutant measurements for the study population by stove adoption, Year 2

	Adopted improved stove						Continued open fire use						P-value
Pollutant	**N**	**Mean**	**SD**	**Min**	**Max**	**IQR**	**N**	**Mean**	**SD**	**Min**	**Max**	**IQR**	
48-hour carbon monoxide, indoor (ppm)	21						18						
Baseline		30.73	28.47	0.40	112.20	25.26		25.92	20.57	5.45	83.53	30.75	
Year 2		8.11	10.22	0.13	36.53	8.24		6.00	10.95	0.01	42.61	7.64	
Avg Change		-22.62						-19.92					0.67
48-hours carbon monoxide, personal (ppm)	21						16						
Baseline		1.84	1.82	0.09	7.68	1.80		2.19	1.52	0.28	6.37	1.77	
Year 2		1.20	1.56	0.01	6.55	1.02		0.43	0.48	0.01	1.63	0.53	
Avg Change		-0.64						-1.76					0.49
48-hour $PM_{2.5}$, indoor ($\mu g/m^3$)	16						15						
Baseline		2,000	1,676	154	5,246	2,136		1692	1,574	246	4,731	2,313	
Year 2		508	612	22	2,207	674		253	309	26	1,223	77	
Avg Change		-1,492						-1,439					0.97

SD, standard deviation; IQR, interquartile range; PM, particulate matter; ppm, parts per million

*Two-sample t-test p-value

Table 4.5. Blood pressure and heart rate measurements for the study population at baseline and Year 2

		Baseline				Year 2				
Health Endpoint	**N**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**P-value***
Systolic blood pressure (mmHg)	83	120.0	20.1	95	202.5	118.1	14.6	90	175.0	0.22
Diastolic blood pressure (mmHg)	83	75.4	11.1	57	110.5	75.7	8.9	54.5	97.0	0.51
Heart rate (bpm)	83	76.0	11.0	55	112	75.0	9.5	50.5	97	0.55

SD, standard deviation;

*Paired t-test p-value

Table 4.6. Change in blood pressure and heart rate by stove type

	Total Population					**Adopted Stove**					**Continued Open Fire Use**					
Health Endpoint	**N**	**Mean change**	**SD**	**Min**	**Max**	**N**	**Mean change**	**SD**	**Min**	**Max**	**N**	**Mean change**	**SD**	**Min**	**Max**	**P-value**
Systolic blood pressure (mmHg)	83	-1.8	14.1	-49.5	32.0	43	-1.9	13.6	-45.5	32.0	40	-2.0	14.8	-49.5	16	0.54*
Diastolic blood pressure (mmHg)	83	-0.7	9.4	-20.5	23.0	43	-1.3	9.2	-20.0	22.2	40	-0.06	9.6	-20.5	23.0	0.56#
Heart rate (bpm)	83	-0.6	8.4	-17	22	43	-1.8	8.1	-16.5	22.0	40	0.8	8.5	-17.0	21	0.21*

Mean change, Year 2 measurement-baseline measurement; SD, standard deviation; P-value, probability value for the difference of mean changes between stove adopters and continued open fire users

*Wilcoxon ranked sums p-value
#Paired t-test p-value

Table 4.7. Reported symptoms of the study population at baseline and Year 2

	Baseline			**Year 2**			
Reported Symptom	**N**	**Frequency**	**Percent**	**N**	**Frequency**	**Percent**	**P-value***
Cough	95			95			0.55
Yes		22	22.7%		25	26.3%	
No		75	77.3%		70	73.7%	
Headache	95			95			<0.0001
Yes		61	62.9%		24	25.3%	
No		36	37.1%		71	74.7%	

*McNemar's p-value for agreement

Table 4.8. Association of stove adoption status and improvement in symptoms, n=95

	Cough Improved					**Headache Improved**				
Stove Adoption	**N**	**Percent**	**P-value***	**OR**	**95% CI**	**N**	**Percent**	**P-value***	**OR**	**95% CI**
Adopted Stove	7	13.7%	0.73	1.24	0.36-4.23	23	45.1%	0.53	1.30	0.57-2.96
Continued open fire use	5	11.4%	---	1.00	---	17	39.6%	---	1.00	---

*Mantel-Haenszel chi-squared p-value

CHAPTER 5

EXAMINATION OF THE POTENTIAL MODIFYING EFFECTS OF AGE AND BODY MASS INDEX ON THE RELATIONSHIP OF STOVE ADOPTION AND HEALTH (AIM 2)

Introduction

Obesity (body mass index greater than or equal to 30 kg/m^2) is a growing concern in developing countries, including Nicaragua (Finucane et al. 2011). It is hypothesized that the effects from air pollution exposures may be stronger among the obese population (Dubowsky et al. 2006). The primary aim of this chapter was to examine the presence of effect modification by age and obesity. Specifically, the goal was to investigate whether baseline obesity modified the effect of the adoption of an improved stove on participant's health. A second goal was to investigate whether age modified the effect of indoor air pollution on health. To address these aims, further analysis of the association between stove adoption and changes in the measured indicators of cardiovascular and respiratory heath (self-reported cough and headache, blood pressure, and heart rate) was conducted. This chapter gives a brief synopsis of the background literature, describes the specific statistical methods conducted, and provides results specific to the above aim.

Background Literature

The ambient air pollution and cardiovascular health effects literature suggests that there is effect modification by obesity, with stronger effects observed among those that are obese (Kannan et al. 2009; Delfino et al. 2010; Dubowsky et al. 2006). Previously published research regarding the same study population as the current study observed that increases in systolic blood pressure were associated with indoor CO and $PM_{2.5}$ concentrations at baseline, and this association was stronger among obese women (Clark et al. 2011; Clark et al. 2012). These findings are particularly relevant because there is a growing percentage of obesity in developing countries (Bautista et al. 2009; Yusuf et al. 2001). In Central America, approximately 30% of women are obese (Finucane et al. 2011). Approximately 34% of Nicaraguan women in the study population at baseline were overweight and 34% were obese (Clark et al. 2011). These findings are also relevant because the mean systolic blood pressure of women in Central America is 123 mmHg (95% CI=120.0-126.6), whereas the mean systolic blood pressure of women in North America is 118 mm Hg (95% CI=115.1-121.8) (Danaei et al., 2011). Given the high prevalence of solid fuel combustion, obesity, and cardiovascular disease in developing countries, it is important to conduct assessments of the potential effect modification of obesity on stove adoption and health.

The ambient air pollution literature has also suggested that there is effect modification by age. Studies have shown that elderly populations are more vulnerable to effects from ambient air pollution (Stieb et al. 2002; Dockery et al. 1994). Although the mechanisms are not well understood, there appears to be a higher rate of cardiovascular and lung related mortality associated with air pollution exposures among older populations (Kelsall et al. 1997). Older populations may be more sensitive to effects from pollutants because the elderly are generally frailer and have a higher prevalence of cardiovascular and respiratory conditions (Stieb et al. 2002; Kelsall et al. 1997). An examination of the same study population as the current study observed that increases in systolic blood pressure were associated with indoor CO and $PM_{2.5}$ concentrations at baseline, and this association was stronger among women greater than 50 years of age (Clark et al. 2012).

Methods

As detailed in previous chapters, baseline air pollution (indoor carbon monoxide, personal carbon monoxide, and indoor $PM_{2.5}$) and health measurements (blood pressure, heart rate, cough and headache) were conducted in a population of Nicaraguan women prior to receiving an improved cookstove. Approximately 9-12 months later, after cookstoves had been installed, the same exposure and health measurements were repeated. Participants were then categorized according to their self-reported stove adoption status (improved stove adopters or continued open fire users). The previous chapter investigated whether there was a difference in the exposure and health measurements by stove adoption status. This chapter will continue to investigate the differences in participant's health endpoints by stove adoption status; potential effect modification by obesity and age is the specific focus.

Variable creation:

Age and body mass index were categorized for analyses of effect modification. Age was initially categorized into two categories (less than or equal to 34 years old and greater than 34 years old) based on the median age of the study participants. Age was also categorized as less than or equal to 50 years old and greater than 50 years old based on the age that an effect was seen in the recent cookstove literature (Baumgartner et al. 2011; Clark et al. 2012). Body mass index was categorized as obese and normal/overweight, based on the international classification of body mass index (WHO 1995). Normal/overweight was defined as body mass index of 18.5-<30 kg/m^2. Obesity was defined as body mass index of greater than or equal to 30 kg/m^2. Participants were also categorized based on median waist-to-hip ratio because our study population had a high mean waist-to-hip ratio, which is associated with an excess accumulation of abdominal fat (Rexrode et al. 1998). Participants were categorized into two groups (waist-to-hip ratio less than or equal to 0.89 and greater than 0.89) based on the median waist-to-hip ratio in our study population.

Statistical analysis for health measures:

Logistic regression models were developed for the improvement in self-reported cough and headache variables as described in Chapter 4. To assess multiplicative interactions, an interaction term between the dichotomous age variable and stove adoption was added to each model (improvement in cough and improvement in headache). The same method was used for obesity status and waist-to-hip ratio as effect modifiers of the association between stove adoption and the improvement in self-reported cough and headache. Odds ratios and 95% confidence intervals and p-values were calculated in the logistic regression models. A p-value of 0.1 was considered statistically significant for this evaluation. Multiplicative interactions were also assessed using two-by-two tables to compare the odds of an improvement in self-reported cough or headache by stove adoption status in each stratum of the potential effect modifier (i.e. obese versus non-obese participants). Linear link models were created to obtain probability values for additive interactions via the linear link function.

To investigate effect modification of age, body mass index, and waist-to-hip ratio, linear regression models of stove adoption and the change in systolic blood pressure, diastolic blood pressure and heart rate were developed as described in Chapter 4. Additive interactions were assessed by adding an interaction term for categorized age and stove adoption status to each model. The same method was used for categorized obesity status and waist-to-hip ratio as potential effect modifiers. Estimates for the mean change and 95% confidence intervals for systolic blood pressure, diastolic blood pressure, and heart rate by the interaction term of stove adoption and the effect modifier (age, body mass index, and waist-to-hip ratio) were determined.

The p-value derived from the F test was used to evaluate the presence of effect modification on the continuous health outcomes and a p-value of 0.1 was considered statistically significant in these analyses. Multiplicative interactions were not assessed.

Results

Obesity and waist-to-hip ratio:

Results from logistic regression of the interaction of stove adoption and obesity status on the improvement in self-reported cough are presented in Tables 5.1. Based on the results in Table 5.1, there is no evidence of an additive interaction between obesity and stove adoption (p-value for the additive interaction = 0.98). Additionally, the p-value for the multiplicative interaction between the improvement of self-reported cough and stove adoption status by obesity status was not statistically significant (p-value for the multiplicative interaction = 0.66). Though the interaction was not statistically significant, the odds ratio of the improvement in self-reported cough for stove adopters was stronger among obese participants (OR=1.63, 95% CI=0.26-10.32) than among non-obese participants (OR=0.93, 95% CI=0.17-5.01). When assessing the improvement of self-reported cough using waist-to-hip ratio in place of obesity status, there was no evidence of a multiplicative interaction (p-value for the interaction = 0.96) and the odds ratio of improvement in self-reported cough among stove adopters with a waist-to-hip ratio ≤ 0.89 (OR=1.48, 95% CI=0.29-7.54) was similar to the odds ratio of improvement in self-reported cough among stove adopters with a waist-to-hip ratio > 0.89 (OR=1.38, 95% CI=0.12-16.44) (Table 5.2).

The potential interaction of stove adoption and obesity status on the improvement in self-reported headache is presented in Tables 5.1. There is no evidence of an interaction between the improvement of self-reported headache and stove adoption status by obesity status (p-value for the additive interaction = 0.45, p-value for the multiplicative interaction = 0.99). Additionally, the odds of improvement in self-reported headache among obese stove adopters (OR=1.33, 95% CI=0.48-3.69) was the same as the odds of improvement in self-reported headache among non-obese stove adopters (OR=1.33, 95% CI=0.33-5.39). A different trend was observed when the potential effect modifier of waist-to-hip ratio was used in place of obesity status. The p-value for this multiplicative interaction was marginally non-significant (p-value=0.12). Although the p-value was not statistically significant, there was some suggestion that the odds ratio of improvement in self-reported headache among stove adopters with a waist-to-hip ratio > 0.89 (OR=2.8, 95% CI=0.79-9.89) was greater than the odds ratio of improvement in self-reported cough among stove adopters with a waist-to-hip ratio ≤ 0.89 (OR=0.75, 95% CI=0.23-2.46).

Results from linear regression for the relationship of stove adoption and obesity status on systolic blood pressure, diastolic blood pressure, and heart rate are presented in Table 5.3. There were no statistically significant additive interactions observed between obesity status and stove adoption for these health measurements, though several trends were observed. In general, non-obese stove adopters had a decrease in systolic blood pressure (mean change = -3.3 mmHg), whereas non-obese continued open fire users had an increase in systolic blood pressure (mean change = 1.1 mmHg). Among obese subjects, this trend was reversed and the mean differences in the change of systolic blood pressure was significant (p-value = 0.12). Obese stove adopters had a slight increase in systolic blood pressure (mean change = 0.6 mmHg) and obese continued open fire users had a decrease (mean change = -7.5 mmHg). A similar trend was observed for change in heart rate by obesity and stove adoption status (Table 5.3). While there was no evidence of additive interaction between obesity and stove adoption status on the change in heart rate, the mean differences in heart rate change were significantly different among non-obese participants (p-value = 0.09); non-obese stove adopters experienced a decrease in heart rate (mean change = -3.1 bpm), whereas non-obese continued open fire users had an increase in heart rate (mean change = 2.1 bpm). The trend in the change of diastolic pressure was less clear when evaluated by obesity and stove adoption status and no interaction was observed (p-value = 0.84). When the potential effect modifier of waist-to-hip ratio was used in place of obesity status, it was difficult to identify clear trends (Table 5.4). Generally, both stove adopters and continued open fire users experienced a decrease in systolic blood pressure and heart rate, regardless of waist-to-hip ratio, though these decreases are small. Regardless of stove adoption status, subjects with a waist-to-hip ratio > 0.89 appeared to have a decrease in diastolic blood pressure, whereas subjects with a waist-to-hip ratio ≤ 0.89 had a slight increase in diastolic blood pressure. There were no significant differences in mean changes by stove adoption status or waist-to-hip ratio and no multiplicative interactions were observed (Table 5.4).

Age:

Results from logistic regression of stove adoption and age category on the improvement in cough are presented in Table 5.5. There is no evidence of an interaction between the improvement of self-reported cough and stove adoption status by age category (p-value for the additive interaction=0.86, p-value for the multiplicative interaction = 0.99). The odds of improvement in self-reported cough among subjects >34 years old (OR=1.25, 95% CI=0.24-6.50) was similar to the odds of improvement in self-reported cough among subjects ≤ 34 years old (OR=1.28, 95% CI=0.20-8.32). A different trend was observed when the improvement in self-reported headache was evaluated (Table 5.5). Among subjects > 34 years old, stove adoption significantly increased the odds of improvement in self-reported headache (OR=6.38, 95% CI=1.16-34.94). Comparatively, stove adoption did not affect the odds of the improvement in self-reported headache among subjects ≤ 34 years old (OR=0.58, 95% CI=0.19-1.71). The p-value for this multiplicative interaction was 0.02.

Though not a direct aim of this study, participants were also categorized based on age greater than 50 years old and less than or equal to 50 years old in order to be more comparable to other cookstove studies. Results were similar to those observed using the previous age categorization. There was not a significant interaction of stove adoption by age category (age >50 or age ≤ 50) for the improvement in cough (p-value=0.86) or the improvement in headache (p-value=0.95) (Table 5.6). Though the multiplicative interactions were not statistically significant, the stove adopters who were > 50 years old did have an increased odds of an improvement for both self-reported cough and headache, whereas the stove adopters ≤ 50 years old did not have an increased odds of improvement for either health measurement. In particular, the odds of the improvement of self-reported headache in stove adopters > 50 years old (OR= 8.00, 95% CI=1.46-16.29) was much stronger than the odds of improvement for stove adopters ≤ 50 years old (OR=1.40, 95% CI=0.44-2.58). However, due to the small sample size of women aged 50 or older, the models that were created were unstable, which led to odds ratios with large confidence intervals.

There were no significant differences of stove adoption on systolic blood pressure among participants ≤ 34 years old and participants greater than 34 years old (Table 5.7). Subjects > 34 years old had a larger decrease in systolic blood pressure, especially among subjects who continued open fire use (mean change = -6.4 mmHg), though the additive interaction was not statistically significant (p-value = 0.56). Similarly, subjects > 34 years old had a larger decrease in diastolic blood pressure, though there was no evidence that there was an interaction between age and stove adoption for this measurement (p-value = 0.70). A clear trend was not observed regarding the change in heart rate among study participants and there was no evidence of an interaction (p-value= 0.65).

Results from linear regression for the relationship of stove adoption and age category (age >50 or age ≤ 50) on systolic blood pressure, diastolic blood pressure, and heart rate are presented in Table 5.8. There were no significant differences of stove adoption on systolic or diastolic blood pressure or heart rate among participants ≤ 50 years old and participants >50 years old. No significant additive interactions between age and stove adoption were found for systolic blood pressure (p-value = 0.39), diastolic blood pressure (p-value = 0.81), or heart rate (p-value = 0.92), though several trends were observed). While not statistically significant, participants who were >50 years old had slightly larger decreases in systolic and diastolic blood pressure and heart rate than participants who were ≤ 50 years old, regardless of stove adoption status.

Discussion

Obesity and waist-to-hip ratio:

Thirty-seven percent of participants were obese (body mass index greater than 30) at baseline. Effect modification by obesity has been reported in the ambient air pollution literature (Kannan et al. 2009; Delfino et al. 2010; Dubowsky et al. 2006). Our study did not find evidence of effect modification of obesity and stove adoption status on the improvement of self-reported cough or headache. While our study did not find significant effect modification of obesity on the improvement in cough or headache symptoms, it is possible that our results were influenced by a small sample size. The number of participants having an improvement in their cough or headache symptom was small, particularly for cough. A larger sample size may have given more precise information on the potential effect modification of obesity on cough and headache.

Though not statistically significant, we observed a trend of obese stove adopters having stronger odds of improvement in self-reported cough, as compared to non-obese participants. This trend was not observed for the improvement of self-reported headache, which is likely due to the fact that many participants, regardless of stove adoption status, had an improvement in headache. The results discussed in Chapter 4 are supportive of this finding.

The study also investigated waist-to-hip ratio as a possible effect modifier because our study population had a high mean waist-to-hip ratio, which is associated with an excess accumulation of abdominal fat (Rexrode et al. 1998). As with obesity status, there was not a significant effect modification by waist-to-hip ratio on the improvement of cough or headache, but the difference between odds ratios among stove adopters with a waist-to-hip ratio > 0.89 and ≤ 0.89 is notable for self-reported headache. The odds of an improvement in headache among improved stove adopters with a waist-to-hip ratio greater than 0.89 was 2.8 (95% CI=0.79-9.89), whereas the odds of improvement of headache among subjects with a waist-to-hip ratio greater than 0.89 was not markedly different from the reference group (continued open fire users) (OR=0.75, 95% CI=0.23-2.46). This multiplicative interaction was marginally non-significant, suggesting that the odds of an improvement in headache may have been stronger among stove adopters with a waist-to-hip ratio greater than 0.89. Potentially, subjects with a higher waist-to-hip ratio may have had higher levels of inflammation, and were therefore more able to experience a greater change that could influence the improvement in headache as carbon monoxide levels decreased. This mechanism is biologically plausible because neurogenic inflammation can be caused by exposure to carbon monoxide and is linked to migraine headaches in the air pollution literature (Szyszkowicz et al. 2009; Nattero et al. 1996).

Our study also evaluated the potential effect modification of obesity on the change in blood pressure and heart rate. While no multiplicative interactions were observed, a significant effect of obesity on the change in heart rate was found (p-value = 0.09). Participants who were not obese at baseline had a decrease in heart rate if they adopted the stove and an increase in heart rate if they continued open fire use. This change in heart rate was three beats per minute, and it is unclear whether this is a meaningful difference in terms of decreasing adverse cardiovascular health outcomes in our study population. Though not statistically significant, non-obese participants appear to have a decrease in systolic blood pressure and diastolic blood pressure if they adopted the improved stove and had an increase in these health measurements if they continued open fire use. However, this may be a product of small sample size in our study. Due to the small sample size, our results have large confidence intervals and it is possible that the change of one or two study subjects could have driven the results in a particular direction.

Previously published results of our study population demonstrated that there were increases in systolic blood pressure associated with indoor carbon monoxide and $PM_{2.5}$ among obese women (Clark et al. 2011; Clark et al. 2012). Our study used stove adoption instead of actual pollution measurements to investigate the potential effect modification of obesity and waist-to-hip ratio. It is possible that we did not observe effect modification by obesity on blood pressure due to the small sample size and/or error in the measurement of blood pressure (likely non-differential and an underestimation of the effect of stove adoption and obesity on blood pressure). It is also possible that we did not observe effect modification by obesity or wait-to-hip ratio on blood pressure due to the use of stove adoption as our indicator of exposure to pollutants in the home. Because our classification of stove adoption included mixed stove use (participants may have used both the improved cookstove and traditional open fire), it may have led to a less distinguishable difference between improved stove adopters and continued open fire users because each stove use group experienced a decrease in actual exposure (see Chapter 4). The potential misclassification of stove adoption status was likely non-differential and likely led to an underestimation of the effect of the stove adoption and obesity and waist-to-hip ratio on the health measures.

Age:

The potential effect of age on respiratory and cardiovascular health outcomes is also important to investigate in relation to exposure to air pollutants. Cardiovascular and respiratory conditions are known to increase with age, and it is believed that older people are more sensitive to the effects of pollutants, possibly due to a higher degree of inflammation and oxidative stress or underlying cardiovascular disease (Stieb et al. 2002; Brook et al. 2010; Kelsall et al. 1997). In our study population, age had a significant interaction with stove adoption status improvement on the improvement of self-reported headache, but did not have a significant effect on the improvement in self-reported cough. Improved stove adopters were more likely to have an improvement in self-reported headache if they were greater than 34 years old than stove adopters ≤ 34 years old. A similar trend was observed when age was categorized using age 50 as the cut-off, though this interaction was not statistically significant, perhaps due to extremely small sample sizes. This second age categorization also did not find a significant effect of the interaction of age and stove adoption on the improvement in cough. While our study looked at several indicators of health, our results were generally non-significant and only provided an indication of effect modification on the change in headache. It could be that headache is generally more of an acute symptom of exposure to pollutants, and because our study period was short, we were only able to observe acute changes in health.

A recent cross-sectional study evaluated the effect of indoor air pollution and age on blood pressure. Baumgartner et al. reported that the relationship between $PM_{2.5}$ exposures and blood pressure was stronger among women greater than 50 years of age (Baumgartner et al. 2011). A study of our same study population found that larger, thought not statistically significant, reductions in blood pressure were found in participants greater than 50 years of age, but this study did not use stove adoption status as the exposure variable (actual pollution concentrations were used) (Clark et al. 2012). In the present study, there was not a significant interaction of stove adoption by this age category (age >50 or age ≤ 50) for the change of cough, headache, blood pressure, or heart rate, though there is some suggestion that study subjects aged ≤ 50 were more likely to have an improvement in both cough and headache than study subjects > 50 years.

Limitations:

Limitations of health outcome measurements and the assessment of stove adoption have been described in Chapter 4. The same limitations apply to this chapter because the same health outcomes and methods to ascertain stove adoption were used. As discussed previously, the short follow-up period of the study may have limited the ability to observe changes in health outcomes. The short follow-up period may not have been long enough for changes in health outcomes to occur, which may have been a factor in our results. Additionally, the number of participants who experienced an improvement in cough or headache was very small. Because the sample sizes were so small, our results have large confidence intervals and may not have had the power to detect small differences in the improvement in symptoms in relation to stove adoption when stratified by age or obesity. In terms of the continuous outcomes of blood pressure and heart rate, the small sample size could have led to the chance of one or two study subjects driving the results in a certain direction. While our study population was larger than many improved cookstove studies, a larger sample size would have provided greater precision in the results (narrower confidence intervals).

It is also possible that study subjects experienced a small degree of age-related increases in blood pressure over the year of follow up. Systolic blood pressure has been found to remain relatively stable until approximately 40 years of age in healthy women, then increases each decade by approximately 5-8 mmHg per decade (Pearson et al. 1997). If small increases did occur over the study period, then the impact of the improved stove intervention on blood pressure was likely underestimated.

An additional limitation is the possibility of unmeasured confounders in the analyses. Because the exposure considered in this study was stove adoption status, rather than actual air pollution measurements, no measured factors (age, weight, height, and hip circumference) were associated with a one year change in the measured health outcome (change in self-reported cough and headache symptoms and change in blood pressure and heart rate) and stove adoption. However, unmeasured factors, such as diet, could have been a relevant risk factor. Diet was not assessed during the study, but it is possible that cooking habits, and thus, eating habits, changed with the adoption of a new cookstove.

Strengths:

This is one of the few improved cookstove studies to investigate the effect modification by age and obesity. Though our results are limited by our small sample size, our results support the cookstove literature, which has demonstrated that cookstove interventions can impact cardiovascular and respiratory health, and even stronger changes in health (reduction in adverse health measurements) may be observed among obese and older participants. Additionally, while many cookstove studies focus on the actual change in pollutants as the exposure, our study investigated the stove adoption as the exposure of interest. The use of this exposure was astrength because it minimized the potential for confounding (as discussed previously in the methods).

Summary:

This study did not find evidence of effect modification of obesity and stove adoption status on the improvement in self-reported cough or headache, or the change in blood pressure, but did find that there was a significant difference in the mean change of heart rate among obese participants (p-value = 0.09). Participants who were not obese at baseline had a decrease in heart rate (-3.1 bpm) if they adopted the stove and an increase in heart rate if they continued the use of an open fire (2.1 bpm).

The potential effect modification of age was also examined in this study. This study found evidence that age modified the effect of stove adoption on the change in self-reported headache while cooking (p-value = 0.02), but did not have an effect on the improvement in self-reported cough (p-value = 0.99). Participants > 34 years old were 6 times more likely to report an improvement in headache if they adopted the improved stove than if they continued the use of an open fire.

Table 5.1. Improvement in cough* and headache** by obesity and stove adoption status, n=95

Obese	Adopted stove	Cough did not improve (N)	Cough improved (N)	Total (N)	OR# (95% CI)	OR## (95% CI)
Yes	No	13	2	15	0.70 (0.03-2.53)	1.63 (0.26-10.32)
	Yes	16	4	20	0.43 (0.01-3.96)	1.00
No	No	26	3	29	0.93 (0.28-3.80)	0.93 (0.17-5.01)
	Yes	28	3	31	1.00	1.00
Obese	**Adopted stove**	**Headache did not improve (N)**	**Headache improved (N)**	**Total (N)**	**OR# (95% CI)**	**OR## (95% CI**
Yes	No	10	5	15	1.88 (0.14-4.80)	1.33 (0.33-5.39)
	Yes	12	8	20	1.41 (0.17-3.21)	1.00
No	No	17	12	29	1.33 (0.58-4.41)	1.33 (0.48-3.69)
	Yes	16	15	31	1.00	1.00

*Probability value for the additive interaction = 0.98
**Probability value for the additive interaction = 0.45
Reference category is obese=no, adopted stove=yes
Reference category is adopted stove=yes in each obesity stratum

Table 5.2. Improvement in cough* and headache** by waist-to-hip ratio and stove adoption status, n=95

WHR > 0.89	**Adopted stove**	**Cough did not improve (N)**	**Cough improved (N)**	**Total (N)**	**OR# (95% CI)**	**OR## (95% CI)**
Yes	No	18	1	19	4.00 (0.08-6.77)	1.38 (0.12-16.44)
	Yes	26	2	28	2.89 (0.04-3.89)	1.00
No	No	20	3	23	1.48 (0.29-7.54)	1.48 (0.29-7.54)
	Yes	18	4	22	1.00	1.00
WHR > 0.89	**Adopted stove**	**Headache did not improve (N)**	**Headache improved (N)**	**Total (N)**	**OR# (95% CI)**	**OR## (95% CI)**
Yes	No	14	5	19	1.94 (0.36-3.29)	2.80 (0.79-9.89)
	Yes	14	14	28	0.69 (0.11-1.44)	1.00
No	No	12	11	23	0.76 (0.23-2.46)	0.75 (0.23-2.46)
	Yes	13	9	22	1.00	1.00

*Probability value for the additive interaction = 0.80
**Probability value for the additive interaction = 0.13
Reference category is WHR > 0=no, adopted stove=yes
Reference category is adopted stove=yes in each WHR stratum

Table 5.3. Change in systolic and diastolic blood pressure and heart rate by stove adoption and obesity status

	Adopted improved stove	**Continued open fire use**			
Health Endpoint (N)	**Estimate of Mean Change (95% CI)**	**Estimate of Mean Change (95% CI)**	**Mean Difference (95% CI)**	**P-value for difference in means**	**P-value for interaction***
Systolic blood pressure (mmHg)					
Not Obese (54)	-3.3 (-8.5, 2.0)	1.1 (-4.4. 6.5)	4.4 (-3.2, 11.9)	0.25	0.43
Obese (29)	0.6 (-6.5, 7.8)	-7.5 (-15.0, -0.1)	-8.2 (-18.5, 2.2)	0.12	
Diastolic blood pressure (mmHg)					
Not Obese (54)	-1.1 (-4.6, 2.5)	1.3 (-2.4, 5.0)	2.4 (-2.7, 7.5)	0.36	0.84
Obese (29)	-1.6 (-6.4, 3.2)	-2.6 (-7.6, 2.4)	-1.0 (-8.0, 4.6)	0.77	
Heart rate (bpm)					
Not Obese (54)	-3.1 (-6.2, 0.0)	2.1 (-1.1, 5.3)	5.25 (0.8, 9.7)	0.09	0.76
Obese (29)	0.7 (-3.5, 5.0)	-1.8 (-6.2, 2.6)	-2.51 (-8.6, 3.6)	0.41	

CI, confidence interval

*Probability value from two-way ANOVA F test statistic

Table 5.4. Change in systolic and diastolic blood pressure and heart rate by stove adoption and waist-hip ratio (waist-to-hip ratio) category

	Adopted improved stove	**Continued open fire use**			
Health Endpoint (N)	**Estimate of Mean Change (95% CI)**	**Estimate of Mean Change (95% CI)**	**Mean Difference (95% CI)**	**P-value for difference in means**	**P-value for interaction***
Systolic blood pressure (mmHg)					
Waist-to-hip ratio ≤ 0.89 (45)	-1.9 (-3.4, 1.5)	-1.6(-4.0, 2.2)	-0.3 (-2.1, 1.9)	0.93	0.92
Waist-to-hip ratio > 0.89 (47)	-1.9 (-3.7, 1.9)	-2.4 (-4.3, 3.2)	0.5 (-2.2, 3.9)	0.91	
Diastolic blood pressure (mmHg)					
Waist-to-hip ratio ≤ 0.89 (45)	0.6 (-2.8, 3.9)	0.5 (-1.8, 4.2)	0.1 (-4.1, 6.9)	0.98	0.63
Waist-to-hip ratio> 0.89 (47)	-2.9 (-5.2, 4.7)	-0.9 (-3.2, 2.8)	2.0 (-3.2, 75.7)	0.51	
Heart rate (bpm)					
Waist-to-hip ratio ≤ 0.89 (43)	-2.4 (-5.7, 1.0)	1.1 (-2.2, 5.0)	-3.5 (-5.4, 3.0)	0.18	0.77
Waist-to-hip ratio> 0.89 (47)	-0.8 (-4.8, 2.4)	-1.3(-3.3, 3.8)	2.6 (-3.7, 5.8)	0.85	

CI, confidence interval

*Probability value from two-way ANOVA F test statistic

Table 5.5. Improvement in cough* and headache** by age (≤34 years or >34 years) and stove adoption status, n=95

Age > 34	**Adopted stove**	**Cough did not improve (N)**	**Cough improved (N)**	**Total (N)**	**OR# (95% CI)**	**OR## (95% CI)**
Yes	No	16	3	19	0.59 (0.20-6.15)	1.25 (0.24-6.50_
	Yes	17	4	21	0.63 (0.12-5.18)	1.00
No	No	23	2	25	1.28 (0.22-5.58)	1.28 (0.20-8.32)
	Yes	27	3	30	1.00	1.00
Age > 34	**Adopted stove**	**Headache did not improve (N)**	**Headache improved (N)**	**Total (N)**	**OR# (95% CI)**	**OR## (95% CI**
Yes	No	17	2	19	7.44 (0.42-4.60)	6.38 (1.16-34.94)
	Yes	12	9	21	5.25 (0.48-5.56)	1.00
No	No	10	15	25	0.58 (0.61-5.71)	0.58 (0.19-1.71)
	Yes	16	14	30	1.00	1.00

*Probability value for the additive interaction = 0.86

**Probability value for the additive interaction = 0.35

Reference category is age > 34 =no, adopted stove=yes

Reference category is adopted stove=yes in each age stratum

Table 5.6. Improvement in cough* and headache** by age (≤50 years or >50 years) and stove adoption status, n=95

Age > 50	Adopted stove	Cough improved (N)	Cough did not improve (N)	Total (N)	OR# (95% CI)	OR## (95% CI)
Yes	No	1	3	4	0.25 (0.03-8.13)	1.29 (0.09-17.96)
	Yes	3	7	10	0.32 (0.13-14.53)	1.00
No	No	4	36	41	1.00 (0.43-5.98)	0.97 (0.23-4.19
	Yes	4	36	41	1.00	1.00
Age > 50	**Adopted stove**	**Headache improved (N)**	**Headache did not improve (N)**	**Total (N)**	**OR# (95% CI)**	**OR## (95% CI**
Yes	No	0	4	4	0.16*# (0.23-5.39)	8.00 (0.03-19.22)
	Yes	5	5	10	1.28 (0.48-12.72)	1.00
No	No	17	23	40	0.94 (0.65-3.96)	1.06 (0.44-2.58)
	Yes	18	23	41	1.00	1.00

*Probability value for the additive interaction = 0.59

**Probability value for the additive interaction = 0.26

*#Used 0.5 in place of zero when calculating the odds ratio for this stratum

Reference category is age > 50=no, adopted stove=yes

Reference category is adopted stove=yes in each age stratum

Table 5.7. Change in systolic and diastolic blood pressure and heart rate by stove adoption and age, ≤ 34 and >34 years

	Adopted improved stove	**Continued open fire use**			
Health Endpoint (N)	**Estimate of Mean Change (95% CI)**	**Estimate of Mean Change (95% CI)**	**Mean Difference**	**P-value for difference in means**	**P-value for interaction***
Systolic blood pressure (mmHg)					
≤34 years old (47)	-1.1 (-6.7, 4.5)	1.8 (-4.2, 2.3)	2.9 (-5.3, 11.0)	0.49	0.56
>34 years old (36)	-3.0 (-9.6, 3.6)	-6.4 (-13.0, 0.1)	-3.4 (-12.7, 5.9)	0.47	
Diastolic blood pressure (mmHg)					
≤34 years old (47)	-0.2 (-3.9, 3.6)	1.2 (-2.8, 5.2)	1.4 (-4.1, 6.9)	0.61	0.70
>34 years old (36)	-2.8 (-7.2, 1.7)	-1.6 (-6.0, 2.8)	1.1 (-5.1, 7.4)	0.72	
Heart rate					
≤34 years old (48)	-2.2 (-5.5, 1.1)	1.5 (-2.0, 5.0)	3.7 (-2.5, 8.0)	0.13	0.65
>34 years old (35)	-1.2 (-5.1, 2.7)	-0.3 (-4.3, 3.8)	0.9 (-4.7, 6.6)	0.74	

CI, confidence interval

*Probability value from two-way ANOVA F test statistic

Table 5.8. Change in systolic and diastolic blood pressure and heart rate by stove adoption and age, ≤50 and > 50 years

	Adopted improved stove	**Continued open fire use**			
Health Endpoint (N)	**Estimate of Mean Change (95% CI)**	**Estimate of Mean Change (95% CI)**	**Mean Difference**	**P-value for difference in means**	**P-value for interaction***
Systolic blood pressure (mmHg)					
≤50 years old (81)	-1.3 (-65.8, 4.1)	0.2(-2.2, 2.8)	-1.5 (-4.3, 2.0)	0.66	0.39
>50 years old (14)	-4.6 (-9.6, 3.3)	-16.6 (-20.0, 1.1)	12 (-12.9, 1.9)	0.13	
Diastolic blood pressure (mmHg)					
≤50 years old (81)	-0.7 (-3.5, 3.1)	0.5 (-2.8, 3.2)	1.2 (-4.1, 5.9)	0.59	0.81
>50 years old (14)	-3.8 (-7.2, 1.7)	-4.3 (-6.0, 2.8)	0.5 (-4.1, 6.5)	0.93	
Heart rate					
≤50 years old (81)	-1.4 (-4.5, 2.1)	0.7 (-3.0, 4.7)	3.7 (-2.5, 8.0)	0.31	0.92
>50 years old (12)	-2.2 (-5.1, 2.7)	-4.8 (-8.3, 3.6)	0.9 (-4.7, 6.6)	0.62	

CI, confidence interval

*Probability value from two-way ANOVA F test statistic

CHAPTER 6

ASSOCIATION OF CHANGE IN AIR POLLUTION CONCENTRATIONS AND CHANGE IN HEALTH IN A SUBSET OF HOUSEHOLDS (AIM 3)

Introduction

Fine particulate matter ($PM_{2.5}$) and carbon monoxide have been shown in many studies to adversely affect the health of people who are exposed to high concentrations of these pollutants (Brook et al. 2010; Dockery et al. 1994; Pope & Dockery 2006; Borja-Aburto 1998). Chronic exposures to high concentrations of these pollutants are frequently seen among people using inefficient cookstoves to meet heating and cooking needs (Budds et al. 2001; Naeher et al. 2007).

The methods of the previous chapters were limited by the reliance on self-report to determine a participant's stove use status. Because of the observed mixed use of traditional open fires and improved cookstoves among participants, it was difficult to accurately classify each participant as an improved stove adopter or a continued open fire user. The actual measured pollutants in each home can be used to obtain a more accurate depiction of the relationship between exposure to carbon monoxide and $PM_{2.5}$ and the measured health endpoints (blood pressure, heart rate, self-reported cough and headache). The change in 48-hour concentrations of indoor and personal carbon monoxide and indoor $PM_{2.5}$ from baseline to Year 2 was evaluated during Aim 1. The primary aim of this chapter was to evaluate the change in health outcomes in association with the actual change in pollution levels for a subset of the population. This chapter gives a brief synopsis of the background literature, describes the specific statistical methods conducted, and provides results specific to the above aim.

Background Literature

Particulate Matter

Fine particulate matter, or $PM_{2.5}$ (particulate matter with a median aerodynamic diameter of < 2.5 μm), originates mostly from combustion sources and is thought to be of greater concern for adverse health effects than PM_{10} because it is within the size fraction that can reach the small airways and the alveoli (Brook et al. 2010). Due to its ability to deposit material deeper in the lungs compared to larger particulate matter fractions, $PM_{2.5}$ is believed to be a more relevant exposure to assess than PM_{10} when evaluating the health effects of biomass fuel combustion (Naeher et al. 2007). In addition to respiratory effects related to the deposition of combustion materials in the lungs, investigators have observed an association between high levels of particulate matter and the occurrence of primary cardiac arrest; however, other studies have not observed an association (Brook et. al, 2010).

The biologic mechanisms linking inhaled particulate matter with adverse cardiovascular health conditions are not well elucidated, but may involve either the direct effect of the pollutants on the cardiovascular system, blood and lung receptors or the indirect effects of the pollutants mediated by pulmonary oxidative stress and inflammatory responses (Brook et al. 2004). Studies have suggested that the possible links between acute and/or chronic exposure to particulate matter and cardiovascular events may be related to increases in heart rate and blood pressure (Donaldson et al. 2001). Other ambient air pollution studies suggest that inhaled particulates may affect the autonomic nervous system through either eliciting a sympathetic stress response or by causing the production of inflammatory cytokines in the lung that are then released into the bloodstream (Magari et al. 2001). This mechanism supports the plausibility that exposure to particulate matter can cause adverse effects to the cardiovascular system (Brook et. al, 2010).

Carbon Monoxide

The combustion of solid fuels in cookstoves generates high carbon monoxide (CO) concentrations in kitchens, which often result in exposures greater than those from large outdoor sources (Zhang et al. 1999). Carbon monoxide results in adverse health via two exposure types: acute CO exposure and chronic CO exposure (Zhang et al. 1999). CO binds to hemoglobin with an affinity 250 times that of oxygen, thereby interfering with the systematic delivery of oxygen to tissues (Brook et. al, 2004). The adverse health effects of exposure to carbon monoxide are due to the prevention of blood oxygenation. Exposure to CO can cause headache, fatigue, dizziness, nausea, decrease cognitive function, heart palpitations, sleep disturbance, and fatal asphyxiation (Kirkpatrick 1987).

Our analysis of the change in pollutant concentrations by stove adoption indicated that there was a large reduction in the pollutants in the study population as a whole, but there was not a significant difference in the reduction of the pollutants (48-hour indoor $PM_{2.5}$ and 48-hour indoor and personal CO) comparing improved stove adopters and continued open fire users. The lack of this relationship with stove adoption is likely due to the mixed use of traditional open fires and improved cookstoves in Year 2, as discussed in previous chapters, and supports the need to examine the actual changes in pollutant concentrations from baseline to Year 2 in relation to a change in cough, headache, blood pressure and heart rate.

Methods

Health measurements:

As detailed in previous chapters, baseline health measurements (blood pressure, heart rate, cough and headache) were conducted in a population of Nicaraguan women prior to receiving an improved cookstove. Approximately 9-12 months later, after cookstoves had been installed, the same health measurements were repeated. Systolic and diastolic blood pressure measurements were taken manually between the hours of 8am and 12pm (to account for known diurnal variations. Three repeat measures were taken within a ten minute period of continued rest and an average of the second and third blood pressure measurements was used for analyses. Heart rate was measured via a portable PulseOx 5500 digital finger pulse oximeter. Three heart rate measurements were recorded and an average of the second and third heart rate measurements was used for analyses. A standardized respiratory symptoms and disease questionnaire, developed and validated by the American Thoracic Society, was translated into Spanish and was verbally administered to ascertain the absence or presence of cough and headache symptoms.

Air pollution measurements:

Air pollution measurements were collected at baseline and Year 2 for a subset of households and the methods for these measurements are discussed in Chapter 4.The concentrations of 48-hour indoor particulate matter ($PM_{2.5}$) and 48-hour indoor and personal CO were measured in each house in a subset of the population (n=33 for 48-hour indoor $PM_{2.5}$, n=41 for indoor 48-hour CO, and n=39 for 48-hour personal CO). Data were continuously collected over an approximate 48-hour period for each household and an average for the measured pollutant was recorded for that 48-hour time period.

Statistical Analyses:

Descriptive statistics (mean, median, standard deviation, minimum, maximum) were calculated for the general demographics of the subset population at baseline. Normality was assessed by evaluation of histograms and normal probability plots and the Shapiro-Wilk test.

Paired t-tests were used to determine whether the subset of participants was representative of the entire study population.

Logistic regression was conducted to examine the association of the change in concentrations of the pollutants and the categorized improvement in the symptoms of cough and headache (as discussed in Chapter 4). Models were created for the changes in the pollutant concentrations based on the interquartile range (IQR) decrease in the 48-hour pollutant concentrations. Increases in 48-hour pollution concentration were removed from the analyses of decrease in IQR, so that a change in IQR could be understood as a decrease in pollutant concentrations, and the effects of a decrease in pollutant concentrations was clearer. The resulting sample sizes were: n=34 for 48-hour indoor CO (7 participants excluded), n=35 for 48-hour personal CO (5 study subjects excluded), and n=30 for 48-hour indoor $PM_{2.5}$ (3 study subjects excluded). Models including increases in pollutant concentrations and models including only households with a decrease in pollutant concentrations were created and were found to not differ significantly, so IQR decrease in the following analyses refers solely to a decrease in pollutant concentrations. Odds ratios and confidence intervals were calculated from the logistic regression models. Linear regression was used to evaluate the association between the decrease in concentrations of the pollutants and the change in heart rate, systolic blood pressure, and diastolic blood pressure from baseline to Year 2. Estimates of mean change and 95% confidence intervals were calculated for systolic blood pressure, diastolic blood pressure, and heart rate by the IQR decrease in concentrations of $PM_{2.5}$ and carbon monoxide.

Plots of the decrease in pollutant concentrations (48-hour indoor and personal carbon monoxide and 48-hour $PM_{2.5}$) and the change in systolic blood pressure, diastolic blood pressure, and heart rate were created to show the distribution of the decrease of pollutant concentrations and the change in the health measurements.

Analysis of confounders:

Smoking was not assessed as a confounder because the study participants, by definition, were all self-reported non-smokers. Baseline health status was also not evaluated as a confounder in this study. Although baseline health status is often considered a confounder, adjusting for it in a model can add bias to results because the change in an outcome measures will depend on measurement error both at baseline and in Year 2 (Rothman et al. 2008).

Results

The demographic characteristics in the subset of participants with available air pollution measurements were similar to the entire study population, as demonstrated in Table 6.1. As previously discussed in Chapter 4, the mean 48-hour indoor carbon monoxide was reduced by 75.4%, the mean 48-hour personal carbon monoxide was reduced by 67.2%, and the mean 48-hour indoor $PM_{2.5}$ was reduced by 79.6% for the study population (Table 6.2). The change in the measured pollutants from baseline to Year 2 was statistically significant for subset of participants. The mean change of 48-hour indoor carbon monoxide was -20.47 ppm (SD=23.96, range of change = -95.82 ppm to 23.8 ppm). The mean change of 48-hour personal carbon monoxide was -1.59 ppm (SD=2.87, range = -13.98 ppm to 5.29 ppm). The mean change of 48-hour indoor $PM_{2.5}$ was -1,412 $\mu g/m^3$ (SD=1,391, range = -4,978 $\mu g/m^3$ to 1547 $\mu g/m^3$). While some study subjects experienced an increase in pollution concentrations, these increased changes were few and were removed from analyses, as described above (in statistical analyses).

A decrease of 48-hour indoor carbon monoxide was not associated with the odds of the improvement in either cough (OR=1.63 per IQR decrease [1.8 ppm], 95% CI=0.44-6.03) or headache (OR=1.01 per IQR decrease [1.8 ppm], 95% CI=0.41-1.83) (Table 6.3). For each IQR decrease in 48-hour personal carbon monoxide, the odds of the improvement was also not associated with the odds of improvement in either cough (OR=0.68 per IQR decrease [26 ppm], 95% CI=0.34-1.35) or headache (OR=0.71 per IQR [26 ppm], 95% CI=2.4-2.09. Similarly, there was also no significant association in the odds of the improvement in cough (OR=0.01 per IQR decrease [2,070 $\mu g/m^3$], 95% CI=<0.001-16.11) or headache (OR=0.42 per IQR decrease [2,070 $\mu g/m^3$], 95%CI=0.15-1.22) for each IQR decrease in 48-hour $PM_{2.5}$ concentrations.

When examining the effect of the change in pollution concentrations on systolic and diastolic blood pressure (Table 6.4), we observed that there were no significant differences in the change in blood pressure or heart rate for each IQR decrease in 48-hour indoor carbon monoxide, 48-hour personal carbon monoxide, and 48-hour indoor $PM_{2.5}$ concentrations. When the decreases in the pollutant concentrations were plotted with the change in blood pressure and heart rate (Figures 6.1-6.9), the plots support the conclusion that the decrease in pollutant concentrations was not associated with the change in blood pressure or heart rate.

Attempts to further categorize the decreases in pollutants (in two groups and into tertiles) led to unstable models. Only two participants reported an improvement in cough and nine participants reported an improvement in headache, leading to stability issues with the models.

Discussion

The cookstove intervention implemented in this study achieved large reductions in the pollutant concentrations in our study population, though the levels were still very high in Year 2. Similar high post-intervention exposure concentrations have been observed in other studies (Chengappa et al. 2007; Masera et al. 2007; Alabak et al. 2007; McCracken et al. 2007). It is possible that our pollution concentrations were still quite high due to improper use of the stove or improper functioning of the stove. We observed the deterioration of many stoves in Year 2, as well as improper maintenance of the stoves. This has also been discussed in previous studies. One study observed a 7% increase in stove emissions, which researchers stated could have been due in part to stove deterioration and improper stove maintenance (Albalak et al. 2001).

Our study did not find a statistically significant association between the improvement in self-reported cough and headache and the decrease in any of the measured pollutants (48-hour indoor CO, 48-hour personal CO and 48-hour indoor $PM_{2.5}$). Because $PM_{2.5}$ is a known lung irritant and cause for various adverse respiratory health outcomes, an improvement in self-reported cough per IQR decrease in $PM_{2.5}$ concentration would have been expected. Physiologically, one would also expect that the symptom of self-reported headache would improve with a decrease in both personal and indoor carbon monoxide concentrations because carbon monoxide is known to cause headaches in acute exposures (Kirkpatrick 1987). The small sample size for these measurements likely influenced the results in our study. Very few participants reported an improvement in cough or headache (n=2 and n=9, respectively) in the subset of those with air pollution measurements, so there was limited ability to detect an improvement in self-reported cough or headache per IQR decrease.

In our study there were no significant associations between the change in blood pressure and heart rate and the decreases of the measured pollutants (48-hour indoor CO, 48-hour personal CO and 48-hour indoor $PM_{2.5}$). As discussed above, it is possible that this observed lack of a significant association was due to the small sample. Additionally, while most of the participants experienced a reduction in indoor and personal carbon monoxide and indoor $PM_{2.5}$, the changes in blood pressure and heart rate were both positive and negative, and were not larger with larger decreases in pollutant concentrations (see figures 6.1-6.9). Biologically, a decrease in blood pressure would be expected with a decrease in $PM_{2.5}$ concentrations because particulate matter has been shown to cause systemic inflammation and oxidative stress at levels similar to what was observed in our study (Barregard et al. 2006).

Limitations:

As discussed in Chapter 4, there are several sources of measurement error for the health endpoints. Of particular note, the measurement of blood pressure was conducted manually. The Korotkoff sounds were determined by the team member’s judgment of what consisted of the correct sounds for systolic and diastolic blood pressure and it was difficult to hear while taking blood pressure measurements at many of the households. Blood pressure measurements recorded for a participant may not have been accurate due to this interference. This potential measurement error was likely non-differential and an underestimation of the effect of the improved stove on blood pressure. The measurements of blood pressure, heart rate, and the symptoms of cough and headache were also one-time measurements of health and may not have been reflective of the participant’s actual health status. Factors such as an infection or stress may have affected the participant’s health measurements on that day, could have resulted in non-differential misclassification of any of measured health endpoints, resulting in an underestimate of the effect of decreasing pollution concentrations on health.

There are also several potential sources of measurement error for the air pollution measurements. An important limitation is that there was only one 48-hour measurement for each household for baseline and Year 2. As such, the measurements of one 48-hour period at baseline and Year 2 for $PM_{2.5}$ and CO may not be reflective of typical pollutant concentrations in the household. For example, participants may have changed their habits during the measurement period. The participants could have been more apt to stay away from the stove or cooked less frequently during the measurement period. If our measured pollutants concentrations were lower than typical exposures, it would bias the association of the exposure with the change in health outcomes if participants avoided exposure during the 48-hour measurement period. This could have led to a non-differential bias and an underestimation of the effect of decreased air pollutant concentrations on the measured health outcomes. Measurements are also likely influenced by daily variation, which could lead to an additional measurement error and a misclassification of exposure; this is expected to be non-differential and may underestimate the effect of $PM_{2.5}$ concentrations on the health outcomes. For example, it is possible that our particle monitors were also measuring other sources of $PM_{2.5}$. Burning trash is a common practice in El Fortin, so it is possible that some of the $PM_{2.5}$ our monitors measured is from this type of outside source. If this occurred, it could partially explain why reductions in pollution concentrations was not markedly different by stove use group and remained generally high for the study population. Because our monitors were not calibrated at the study site, monitor readings could have also been affected by ambient conditions such as temperature, wind, or humidity. An incorrectly calibrated monitor could have biased the results, though it is uncertain in which direction (depends on whether the monitor was reading lower or higher than actual).

Another limitation is the use of a mean in exposure concentrations for the 48-hour timeframe in our study. The use of a mean measure of pollutant concentrations does not provide detailed information on the peaks of exposure. High peaks in exposure have been described in the literature, are associated with adverse health outcomes, and could be more harmful to health (Ezzati et al. 2002). It is possible that an effect of air pollutant concentrations on the health measures may have been different had we also looked at the peaks in exposure, as opposed to solely reporting the mean 48-hour pollutant concentrations. It is also possible, as mentioned in previous chapters, that while the pollutant concentrations were significantly reduced by up to 80%, this reduction was still not low enough to result in significant changes in health outcomes. Despite the reductions achieved, levels of pollutants were still much higher than the recommended levels. The Year 2 mean concentration of indoor carbon monoxide for our study population was 6.68 ppm. The World Health Organizations (WHO) 24-hour limit for CO was 5.68 ppm (WHO, 2010). The Year 2 mean concentration of indoor $PM_{2.5}$ was 361 $\mu g/m^3$, and the WHO 24-hour limit for ambient PM2.5 exposure is 25 $\mu g/m^3$ (WHO, 2005). There could be a threshold for changing health outcomes that we did not achieve in our pollution reductions that could have prevented improvements in health outcomes.

The results of the study may have also been limited by the chosen time period of pollutant measurements in relation to health outcomes. Historical air pollution exposures may be more relevant for some health outcomes than current air pollution exposures. Historical air pollution exposures may be more informative for chronic conditions leading to the prevalence of our measured symptoms, such as asthma (Schei et al. 2004). The use of current air pollution exposure data may be more informative of exacerbations of health conditions or acute responses. We may not have observed significant changes in health in response to a reduction in pollution because the critical time period for reversing adverse health occurred before the study was conducted.

An additional limitation is the small sample size of participants with both baseline and Year 2 pollutant measurements. This is particularly noticeable in the analysis of the improvement in cough by the change in pollutant concentrations. In this subset, only two participants reported having an improvement in cough. It is possible that important information on the change in cough was lost in the use of a subset of the study population. It is also possible that some women may have had an adverse health symptom, such as cough, due to an irreversible condition. This could have prevented improvement in the health measurement form occurring.

Strengths:

A strength of the study is that we were able to obtain both kitchen and personal pollution measurements. If we were to have relied solely on pollutant concentrations in the kitchen, it would be difficult to determine what the participants' actual exposure was during the 48-hour time period, because they could leave the kitchen and thus have less exposure than was measured in the kitchen. Having both personal and kitchen measurements gives a more accurate picture of exposure than either piece alone.

As discussed in Chapter 4, an additional strength of the study is that we were able to obtain information on blood pressure and heart rate as well as self-reported symptoms. We were also able to obtain health measurements at two time points, baseline and Year 2, which gives some indication of temporality as compared to many biomass fuel studies that are cross-sectional in nature.

Summary:

The results our cookstove intervention study indicate that the improved cookstove was effective at significantly reducing the levels of indoor air pollution. Large reductions in indoor $PM_{2.5}$ and indoor and personal carbon monoxide were achieved from baseline to Year 2. In general, non-significant changes in the health measures were observed. The change in indoor and personal carbon monoxide and indoor $PM_{2.5}$ concentrations were not associated with an improvement in self-reported cough or headache, or a change in blood pressure or heart rate, though sample sizes were quite small.

The levels of pollutants in homes using improved cookstoves were still very high and this may have limited the change in health outcomes observed in this study. It is possible that more significant changes in health outcomes would have been observed with even greater reductions in indoor air pollution by the improved cookstoves.

Table 6.1. Personal characteristic for the entire study population and the subset population (participants with air pollution measurements) at baseline

	Entire study population			Subset population			
Personal characteristics	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**P-value***
Age (years)	97	34.5	15.4	41	33.7	15.6	0.88
Weight (lbs)	97	143.2	36.2	41	137.3	35.1	0.71
Height (in)	97	59.8	2.5	41	59.6	2.7	0.98
Waist circumference (in)	94	41.5	5.2	41	40.7	5.3	0.92
BMI (kg/m^2)	97	28.2	6.9	41	27.1	6.7	0.89
Systolic blood pressure (mmHg)	83	120.0	20.1	41	117.6	18.3	0.83
Diastolic blood pressure (mmHg)	83	75.4	11.1	41	73.8	10.4	0.88
Heart rate (bpm)	83	76.0	11.0	41	77.2	11.2	0.90

*Paired t-test probability value

Table 6.2. Measured pollutant concentrations for the study population at baseline and Year 2

Pollutant	**N**	**Mean**	**SD**	**Min**	**Max**	**IQR**	**P-value***
48-hour carbon monoxide, personal (ppm)	35						
Baseline		2.35	2.50	0.09	14.08	1.88	
Year 2		0.77	1.11	0.01	6.55	1.08	
Change		-1.59	2.87	-13.98	5.29	1.81	0.001
48-hour carbon monoxide, indoor (ppm)	34						
Baseline		27.14	24.16	0.40	112.20	26.00	
Year 2		6.68	10.35	0.01	42.61	7.53	
Change		-20.47	23.96	-95.82	27.02	23.80	<0.0001
48-hour $PM_{2.5}$, indoor ($\mu g/m^3$)	30						
Baseline		1,773	1,581	154	5,246	2,070	
Year 2		361	478	22	2,207	290	
Average Change		-1,412	1,391	-4,978	130	1547	<0.0001

SD, standard deviation; IQR, interquartile range; PM, particulate matter; ppm, parts per million

*Probability value for the paired t-test of difference between baseline and Year 2 pollutant concentrations

Table 6.3. Odds ratios and 95% confidence intervals for improvement in headache and cough per IQR decrease in pollution

Pollutant (IQR decrease)	**Symptom improved (N)**	**Symptom did not improve (N)**	**Odds Ratio per IQR decrease**	**95% CI**
Improvement in Cough:				
48-hr Personal CO (26 ppm)	2	25	0.71	0.24-2.09
48-hr Indoor CO (1.8 ppm)	2	27	1.63	0.44-6.03
48-hr Indoor $PM_{2.5}$ (2,070 $\mu g/m^3$)	2	24	0.01	<0.01-16.11
Improvement in Headache:				
48-hr Personal CO (26 ppm)	9	18	0.68	0.34-1.35
48-hr Indoor CO (1.8 ppm)	9	20	1.01	0.41-1.83
48-hr Indoor $PM_{2.5}$ (2,070 $\mu g/m^3$)	9	17	0.42	0.15-1.22

IQR, interquartile range; CO, carbon monoxide; PM, particulate matter; ppm, parts per million

Table 6.4. Estimates of mean change for systolic and diastolic blood pressure and heart rate per IQR decrease in pollution.

Pollutant (IQR decrease)	**N**	**Estimate of mean change (mmHg)**	**95% CI**
Systolic Blood Pressure:			
48-hr Personal CO (26 ppm)	25	-0.5	(-3.7, 2.0)
48-hr Indoor CO (1.8 ppm)	27	0.1	(-0.2, 0.4)
48-hr Indoor $PM_{2.5}$ (2,070 μg/m^3)	25	0.3	(-3.7, 4.1)
Diastolic Blood Pressure:			
48-hr Personal CO (26 ppm)	25	-0.2	(-2.0, 1.4)
48-hr Indoor CO (1.8 ppm)	27	0.2	(-0.1, 0.3)
48-hr Indoor $PM_{2.5}$ (2,070 μg/m^3)	25	0.7	(-1.7, 3.1)
Pollutant (IQR)	**N**	**Estimate of mean change (beats/minute)**	**95% CI**
Heart Rate:			
48-hr Personal CO (26 ppm)	25	0.6	(-0.8, 2.4)
48-hr Indoor CO (1.8 ppm)	27	0.1	(-0.2, 0.3)
48-hr Indoor $PM_{2.5}$ (2,070 μg/m^3)	25	1.6	(-0.9, 4.1)

IQR, interquartile range; CO, carbon monoxide; PM, particulate matter; ppm, parts per million

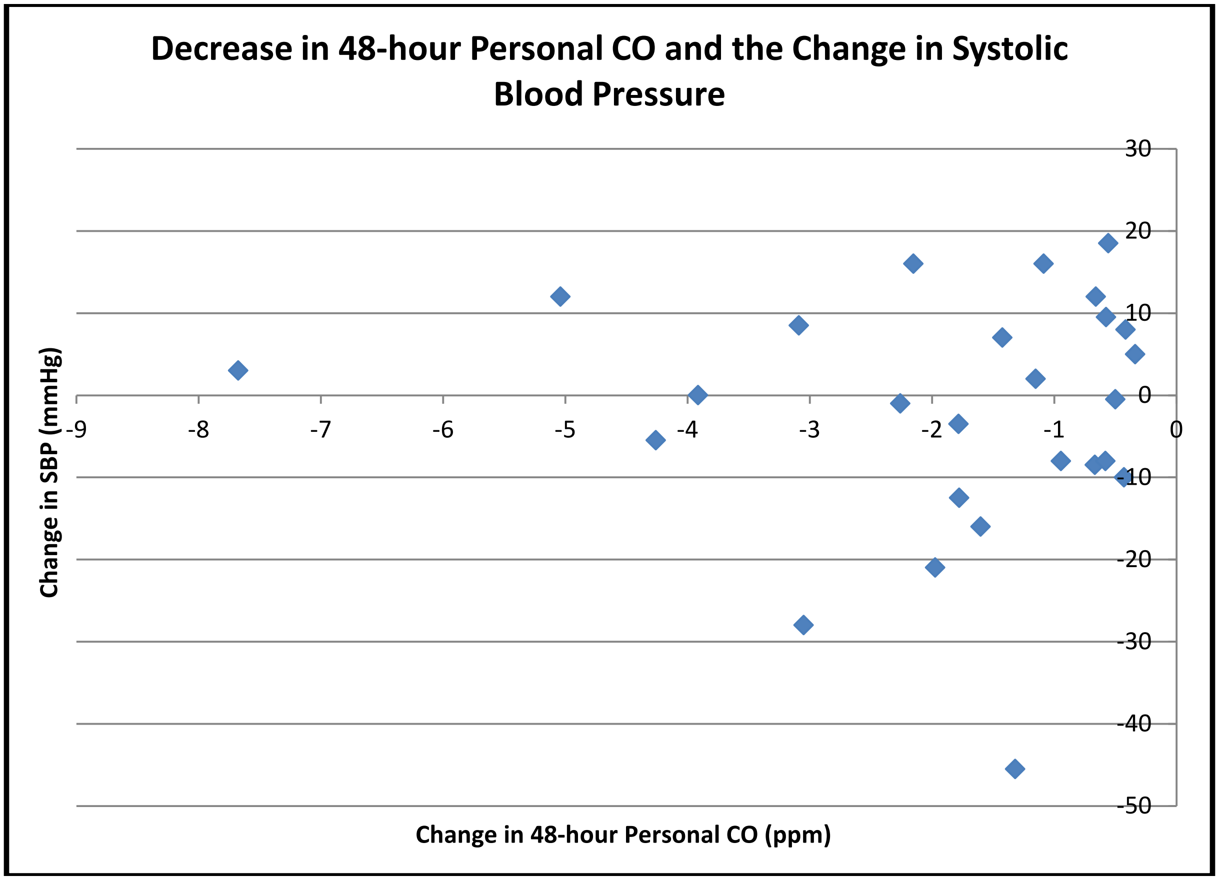

Figure 6.1. Decrease in 48-hour personal carbon monoxide and the change in systolic blood pressure (n=27)

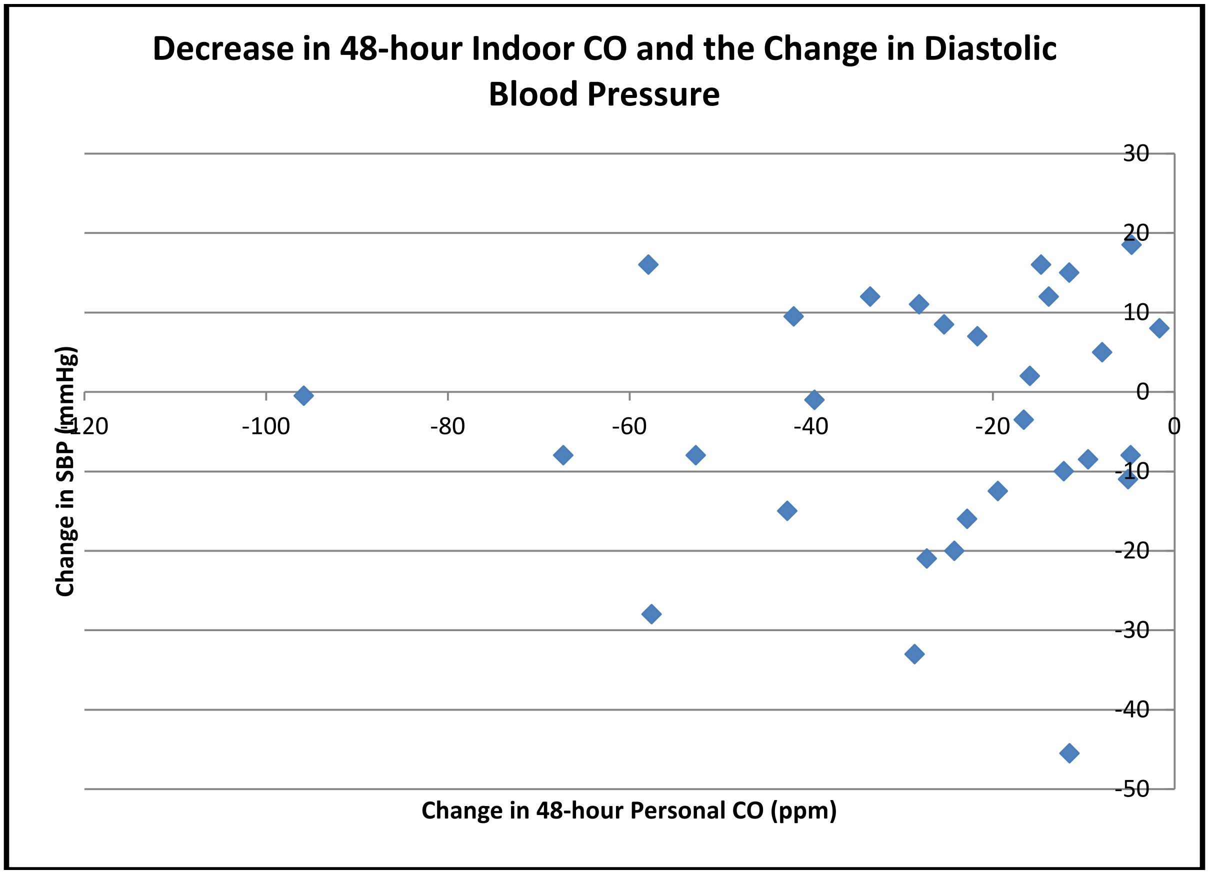

Figure 6.2. Decrease in 48-hour indoor carbon monoxide and the change in systolic blood pressure (n=25)

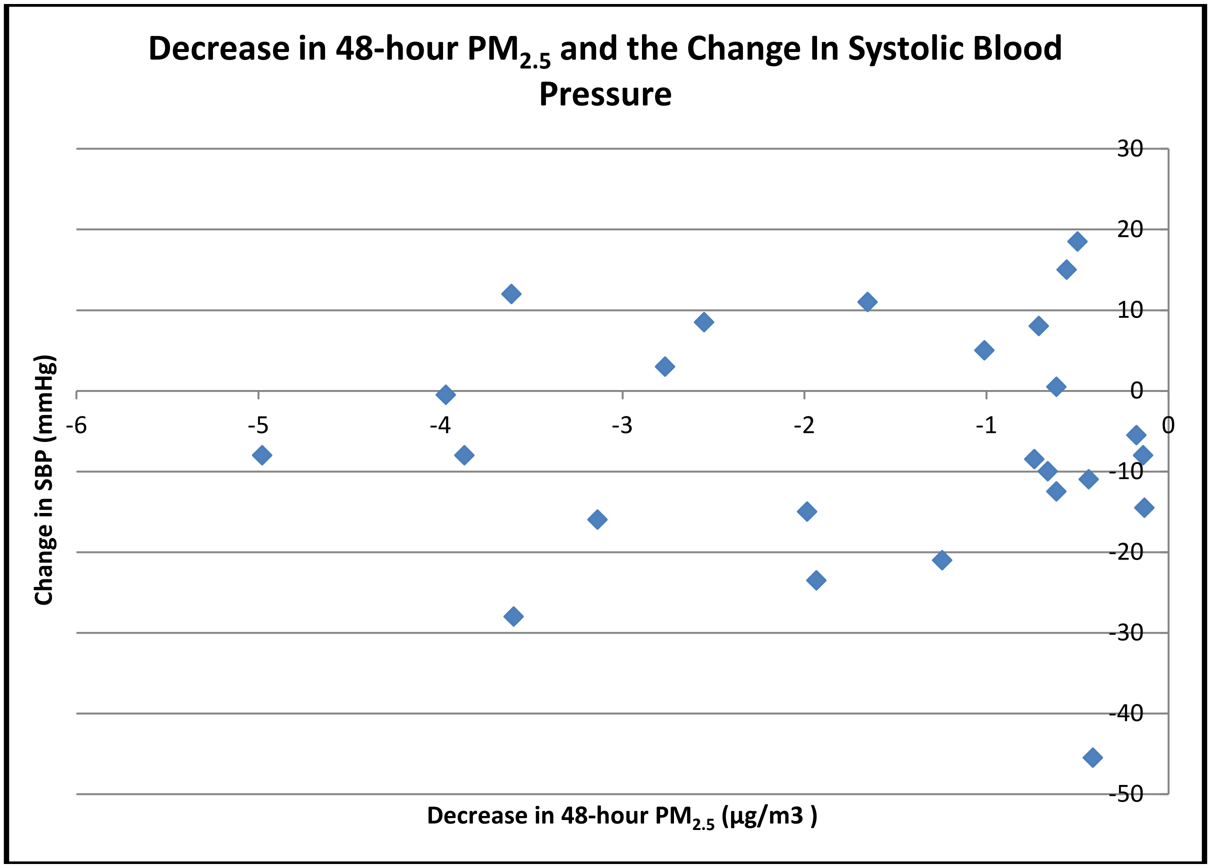

Figure 6.3. Decrease in 48-hour $PM_{2.5}$ and the Change in Systolic Blood Pressure (n=25)

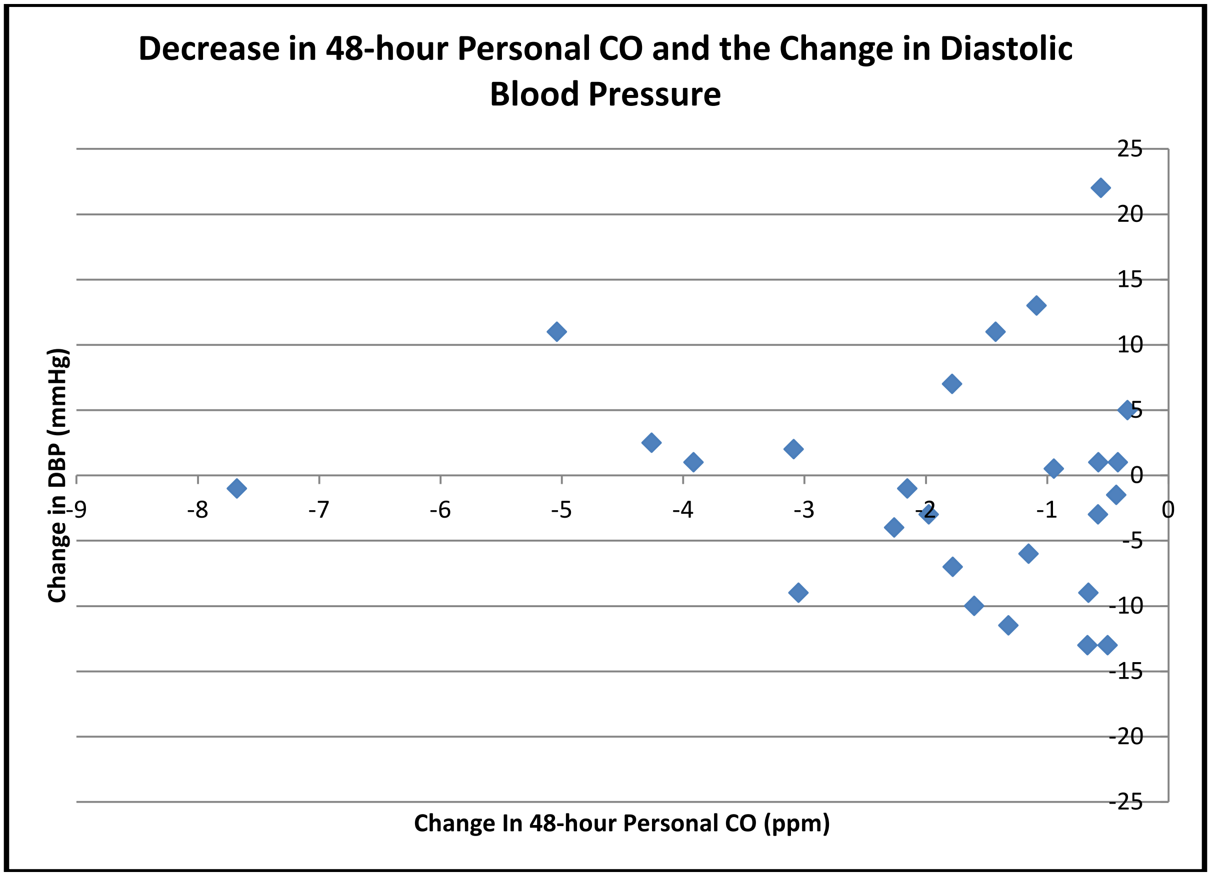

Figure 6.4. Decrease in 48-hour personal carbon monoxide and the change in diastolic blood pressure (n=27)

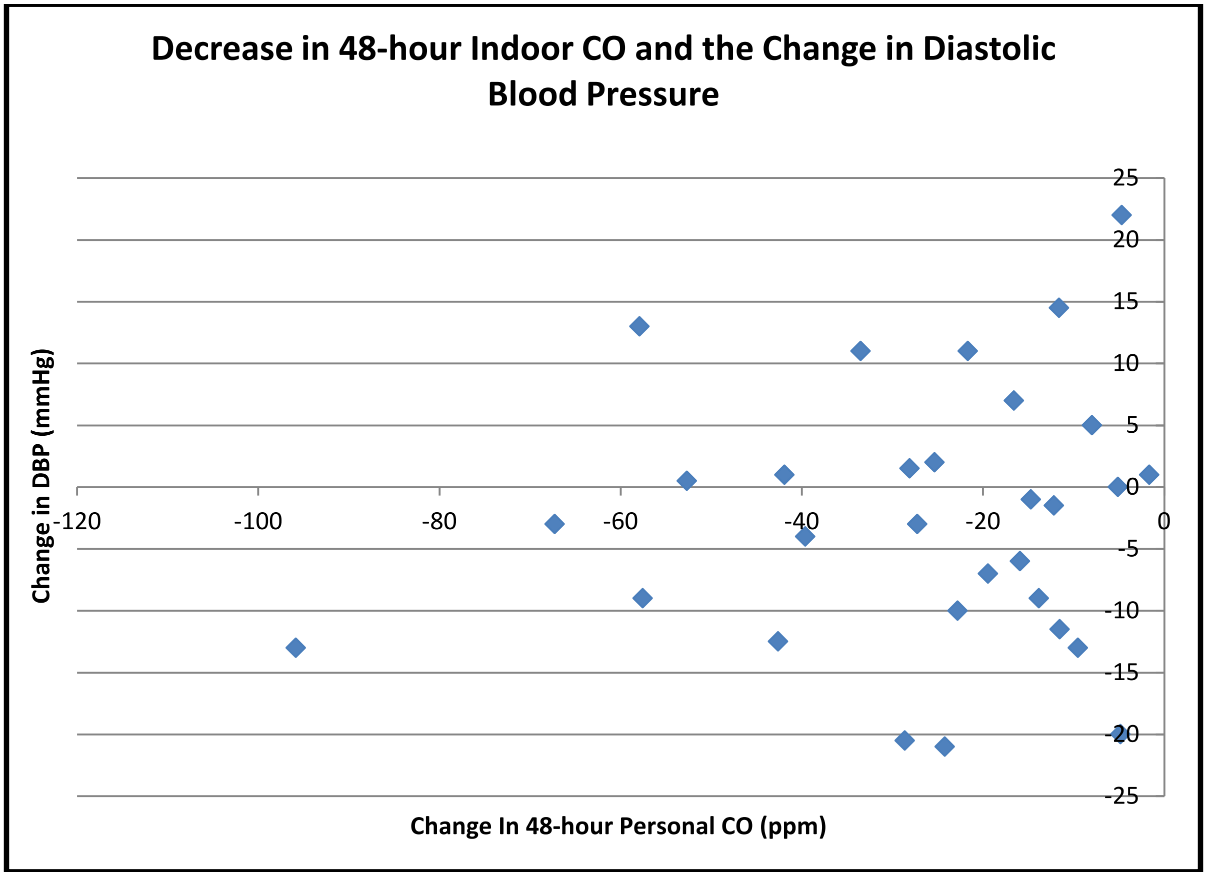

Figure 6.5. Decrease in 48-hour indoor carbon monoxide and the change in diastolic blood pressure (n=25)

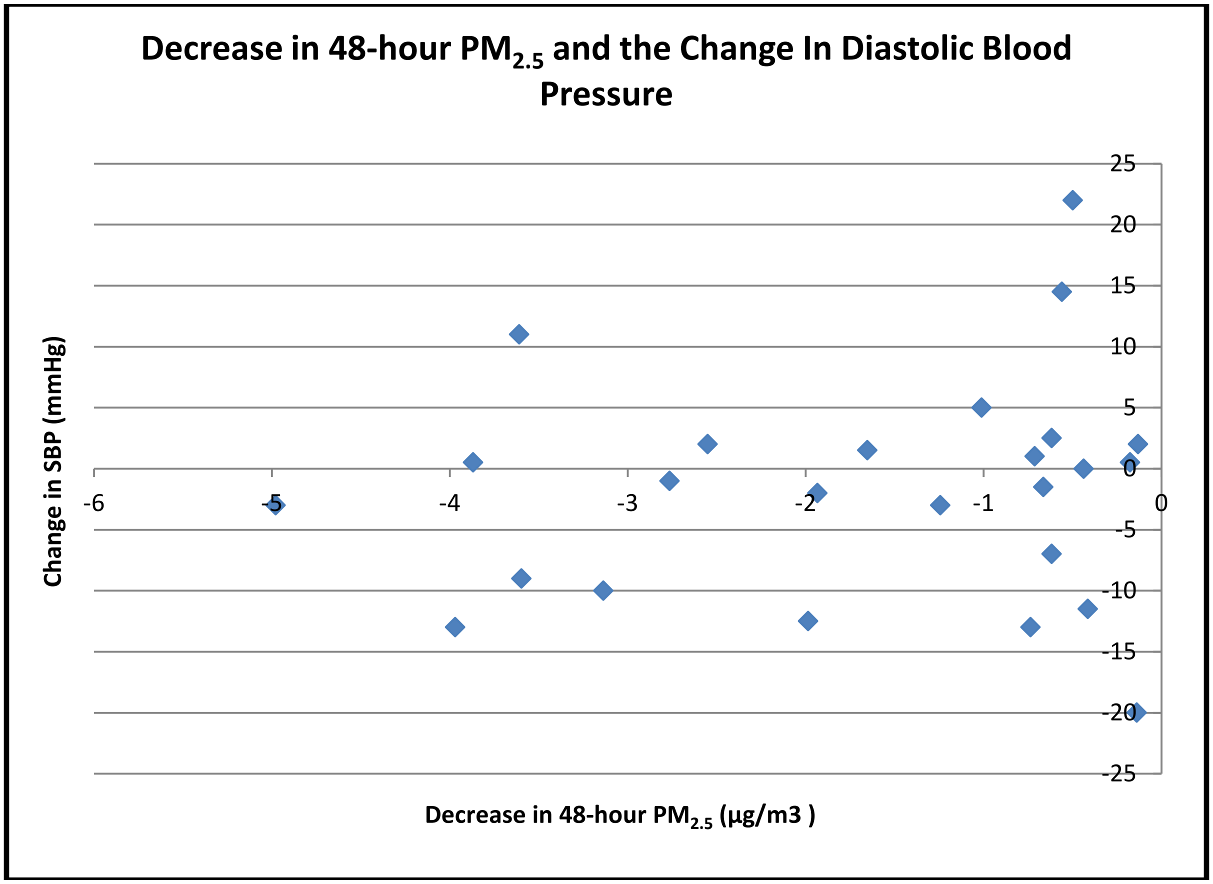

Figure 6.6. Decrease in 48-hour $PM_{2.5}$ and the Change in Diastolic Blood Pressure (n=25)

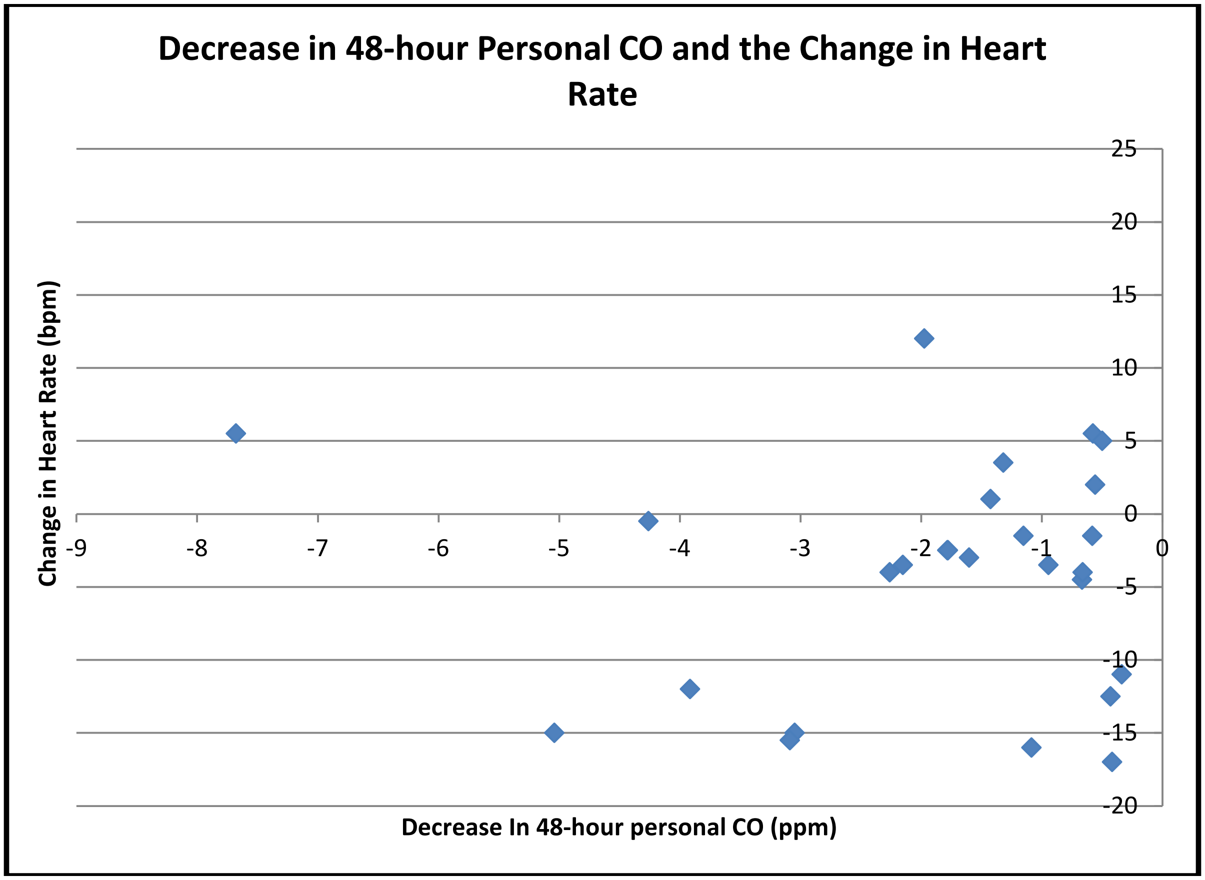

Figure 6.7. Decrease in 48-hour personal carbon monoxide and the change in heart rate (n=27)

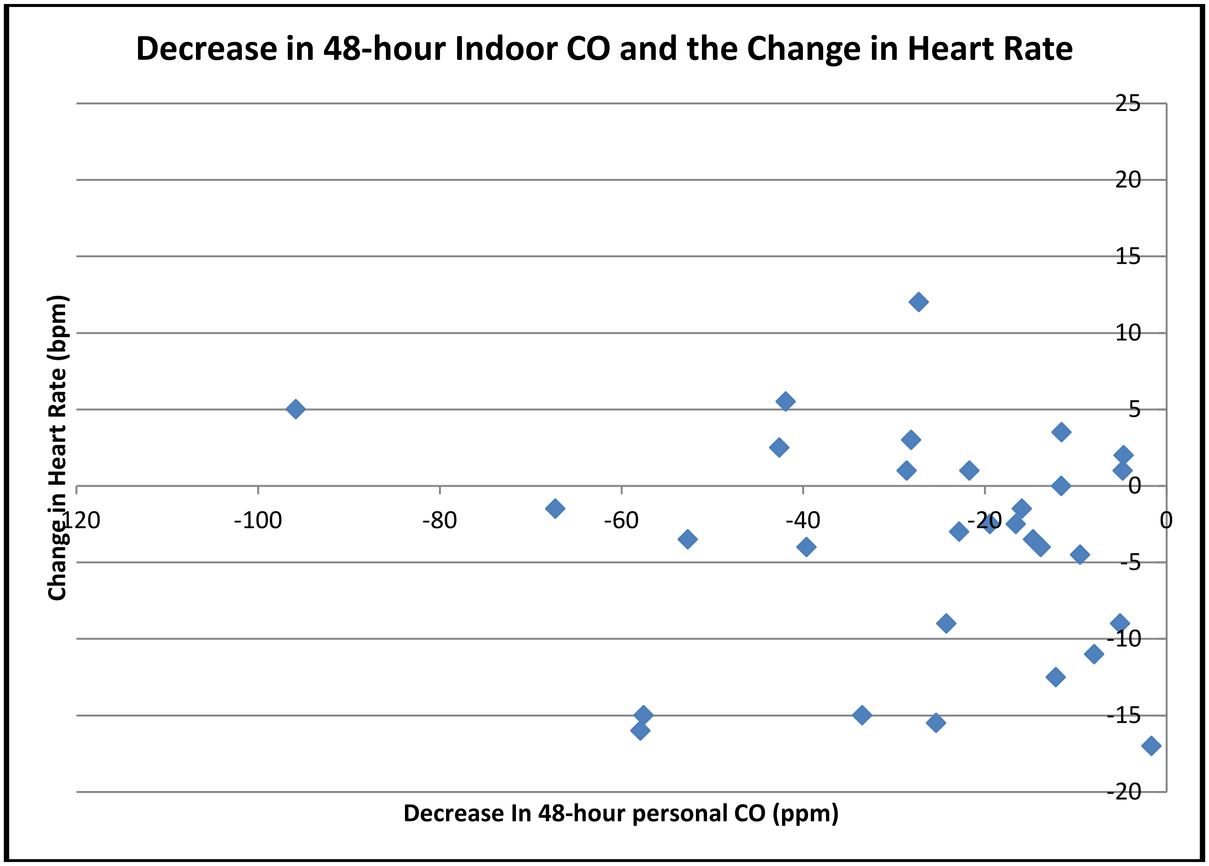

Figure 6.8. Decrease in 48-hour indoor carbon monoxide and change in heart rate (n=25)

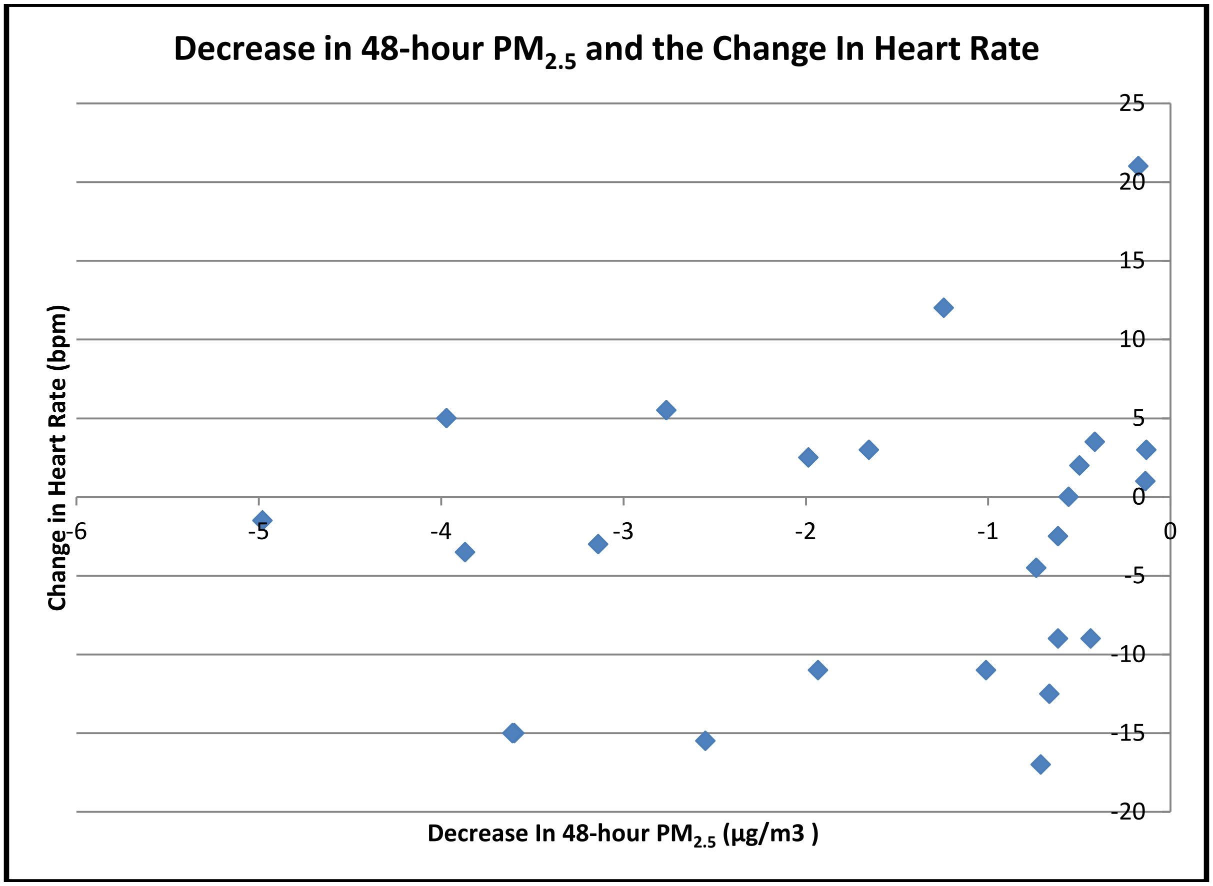

Figure 6.9. Decrease in 48-hour $PM_{2.5}$ and the change in heart rate (n=25)

CHAPTER 7

CONCLUSIONS

In our study, we observed large reductions in indoor $PM_{2.5}$ and indoor and personal carbon monoxide for the study population as a whole and regardless of stove adoption status. Reductions in pollutant concentrations ranged from 74% to 85%. We observed no significant difference in pollutant reductions among participants who reported only improved stove use compared to participants who reported continued open fire use. The assessment of stove adoption status was an important component of this study. In our study, 53.7% women reported completely adopting the improved stove, though it is unclear what percentage of improved stove adopters were truly using solely the improved stove and it is also unclear what the stove use is among the study subjects who were classified as continued open fire users.

The results of our study, when looking at the association of stove adoption status and the improvement in health measures (blood pressure, heart rate, and self-reported cough and headache), were largely non-significant. There were improvements in these measures, but stove adoption status did not appear to play a role in these changes. There were also large reductions in indoor $PM_{2.5}$ and indoor and personal carbon monoxide for the study population, but we observed no difference in pollutant reductions among participants who adopted the improved stove compared to participants who reported continued open fire use. These results suggest that improved stove interventions can have a significant impact on reducing indoor air pollutants, regardless of whether a participant chooses to fully adopt the improved stove. While many improved stove studies experience difficulties with complete stove adoption, our results provide valuable evidence that large reductions in pollutants are still achievable with incomplete adoption.

While many of the changes in health measures were largely non-significant when evaluated by stove adoption status, our study found some interesting trends in the results. There was a substantial decrease in the prevalence of self-reported headache in the entire study population; this decrease was also larger among stove adopters with a waist-to-hip ratio greater than 0.89. There were also small decreases in blood pressure and heart rate among study participants, regardless of stove adoption status. Blood pressure and heart rate decreased more for improved stove adopters than continued open fire users among younger participants, regardless of how age was categorized (cutoff of 34 years or 50 years). Among older study participants, blood pressure, heart rate, and self-reported headache improved for both improved stove adopters and continued open fire users. Our results indicate that it could be useful to focus on identifying ways to encourage older participants to completely adopt an improved stove, as they may be more likely to experience an increase in various health outcomes, particularly headache.

When looking at the effects of obesity, we also observed an interesting trend. Non-obese study participants generally had a larger decrease in blood pressure and heart rate among improved stove adopters than continued open fire users. In the literature, the opposite trend has been reported. Cardiovascular effects from ambient air pollution have been greater among obese individuals than those that are not obese (Dubowsky et al. 2006; Kannan et al. 2010). Studies have suggested that obesity can promote inflammation in individuals and make them more susceptible to developing adverse cardiovascular health (Libby et al. 2002). Previously published results of our study population demonstrated that there were increases in systolic blood pressure associated with indoor carbon monoxide and $PM_{2.5}$ among obese women (Clark et al. 2011; Clark et al. 2012). Our study used stove adoption instead of actual pollution measurements to investigate the potential effect modification of obesity. Because our classification of stove adoption included mixed stove use (participants may have used both the improved cookstove and traditional open fire), it may have led to a less distinguishable difference between improved stove adopters and continued open fire users because each stove use group experienced large decreases in actual exposure.

An important limitation of cookstove intervention studies is that the studies commonly experience low adoption rates of the improved cookstoves (Troncoso et al. 2007). Women often continue to use their traditional stoves in concurrence with the improved stove to meet cooking demands (Ruiz-Mercado et al. 2011; Pine et al. 2011). Women may also continue to use their traditional stove due to cultural preferences, a lack of familiarity with the new technology of the improved stove, or a problem with the maintenance of the stove (Troncoso et al. 2007; Ruiz-Mercado et al. 2011). In our study, we noted problems with the maintenance of the improved cookstoves and the general longevity of the stove's materials. Many women in our study also preferred their traditional open fires for a variety of reasons and some viewed the improved cookstove as an additional stove to meet larger cooking demands. However, as shown in other studies, even if many women in a community where a cookstove intervention has taken place have not completely stopped using their open fires, they are still receiving substantial benefits from access to clean wood burning cookstoves in the community (Troncoso et al 2007). So while we had an issue with mixed stove use, perhaps a reason for a lack of difference among stove use groups was because both groups were experiencing similar benefits from decrease exposure to pollutants in the home.

While there were limitations to our study, it our results add to the sparse literature of the impact of the adoption of an improved stove on health. Our study supports other work that has observed large reductions in indoor air pollution concentrations with the adoption of an improved stove, and also supports the literature that improved cookstove interventions are capable of improving adverse health outcomes, including cardiovascular health, as demonstrated by the observed changes in heart rate and blood pressure. The majority of the limitations of the study discussed in previous chapters likely led to an underestimation of effect, providing the change in health outcome occurred. This potentially adds strength to the small but not statistically significant changes in health outcomes observed in our study.

Additionally, our study is one of the few longitudinal cookstove studies. While we only have one year of comparison, the study still provides a better indication of temporality than a cross-sectional study. Because our study was conducted during the same season at baseline and Year 2, the changes in health outcomes likely reflect actual responses to the cookstove intervention, rather than a difference in season.

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