UNIVERSITY OF CALIFORNIA, SAN DIEGO

SAN DIEGO STATE UNIVERSITY

A Real-Time Intervention to Improve Household Air Quality among Low-Income Families

A dissertation submitted in partial satisfaction of the requirements
for the degree of Doctor in Philosophy

in

Public Health (Health Behavior)

by

Marie Christine Boman-Davis

Committee in charge:

San Diego State University

Professor Melbourne Hovell, Chair
Professor Thomas Novotny
Professor Penelope Quintana

University of California, San Diego

Professor Kenneth Lyons Jones
Professor Lisa Madlensky
Professor Kevin Patrick

2014

The Dissertation of Marie Christine Boman-Davis is approved and it is acceptable in quality and form for publication on microfilm and electronically:

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Chair

University of California, San Diego
San Diego State University
2014

DEDICATION

This dissertation is dedicated to my father and mother, each of whom supported my academic pursuits and celebrated incremental steps in my journey. Before their respective departures, my father reassured me that I was deserving of the opportunity to purse a PhD and my mother expressed how proud she was of both my persistence and achievements. I also dedicate this dissertation to my daughter who, even before she was born, provided me with additional determination to reach my highest goals.

EPIGRAPH

"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."

Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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VITA

Education

Doctor of Philosophy in Public Health (Health Behavior) 2014
University of California San Diego and San Diego State University,
San Diego, CA

Masters of Public Health (Health Promotion) 2007
San Diego State University, San Diego, CA

Bachelor of Science in Health Science (Community Health Education) 2000
San Diego State University, San Diego, CA
Cum Laude & Distinguished Graduate

Current Positions:

Instructor & Onsite Program Lead for the Bachelor of Science 2013-Present
in Public Health School of Health & Human Services, Department
of Community Health, National University, San Diego, CA

Co-Investigator/Research Scientist II, Innovation for Smoke-Free 2014-Present
Homes, Center for Behavioral Epidemiology and Community Health,
San Diego State University Research Foundation, San Diego, CA
(NIH/NHLBI #R01 HL103684)

Adjunct Assistant Faculty (Research), Graduate School of Public Health, 2009-Present
San Diego State University, San Diego, CA

Professional Experience:

Research Associate/Project & Intervention Coordinator, 2011-2013
Center for Behavioral Epidemiology and Community Health,
San Diego State University Research Foundation, San Diego, CA
(NIH/NHLBI #R01 HL103684)

Text Message Study Coordinator, University of California, San Diego, 2010-2011
National Children's Study, San Diego, CA
(NIH/NICHD # HHSN267200700021C)

Research Scientist I/Program Manager, Hookah Use and Secondhand 2009-2010
Smoke & Hookah Tobacco Use: Carcinogenic Metabolites, Center for
Behavioral Epidemiology and Community Health, San Diego State
University Research Foundation, San Diego, CA
(FAMRI # 52364 & ACS #RSG-09-098-01-CNE)

Research Specialist II/Study Coordinator/Study Manager, Hookah Use and Secondhand Smoke, Center for Behavioral Epidemiology and Community Health, San Diego State University Research Foundation, San Diego, CA (FAMRI # 52364)	2006-2009
Grant Writer, Sacramento Chinese Community Service Center Sacramento, CA (Location: San Diego, CA)	2008-2008
Independent Tobacco Control Consultant, San Diego, CA	2004-2007
Prevention Specialist, Communities Against Substance Abuse, El Cajon, CA	2003-2004
Research Assistant II, Trial of Activity for Adolescent Girls, Institute for Behavioral and Community Health, San Diego State University Research Foundation, San Diego, CA, (NIH/NHLBI # R01 1U01HL66856)	2002-2003
Project Director, Young Adult Action Network, Public Health Foundation Enterprises INC, City of Industry, CA (Location: San Diego, CA)	2002-2003
Assistant Project Director, Young Adult Action Network, Public Health Foundation Enterprises INC, City of Industry, CA (Location: San Diego, CA)	2001-2002
Project Coordinator, Youth Media Network, Public Health Foundation Enterprises INC, City of Industry, CA (Location: San Diego, CA)	2000-2001
Marketing Assistant, Coleman College, San Diego, CA	1999-2000
Adult Liaison, California Youth Advocacy Network, Public Health Foundation Enterprises INC, City of Industry, CA (Location: San Diego, CA)	1998-2000
Adult Liaison, Gold Country Tobacco Prevention Coalition, American Lung Association of Sacramento-Emigrant Trails, Sacramento, CA	1997-1998
Project Coordinator, Thumbs Up!, Thumbs Down!, American Lung Association of Sacramento-Emigrant Trails, Sacramento, CA	1995-1998
Independent Tobacco Control Consultant and Volunteer Advocate, Sacramento, CA	1991-1995

Teaching Experience:

Instructor & Onsite Program Lead for the Bachelor of Science in Public Health School of Health & Human Services, Department of Community Health, National University, San Diego, CA — 2013-Present

Undergraduate

- Health Behavior (COH 321)
  - August 2013
- Health Promotion Program Planning & Evaluation (COH 380)
  - November 2013

Graduate

- Public Health Internship (Independent Study) (COH 691)
  - July 2013
- Public Health Program Development (COH 607)
  - January 2014
- Public Health Program Evaluation (COH 609)
  - February 2014
- Public Health Informatics (COH 613)
  - April 2013

Adjunct Faculty, School of Health & Human Services, Department of Community Health, National University, San Diego, CA — 2009-2013

Undergraduate

- Health Promotion Program Planning & Evaluation (COH 380)
  - November 2009
- Health Promotion Strategies & Tactics (COH 430)
  - June 2010, June 2011, Feb 2012
- Drug Use & Abuse (COH 418)
  - April 2011, November 2011, May 2012 (Online)

Graduate

- Theories of Health Behavior (COH 604)
  - January 2013

Publications

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Thesis

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Select Presentations

1. ***Boman-Davis M.,*** and Alvarado O. Health Equity in Affordable Housing: Voluntary Smoke-Free Multi-Unit Housing Policies. Promising Practices To Promote Tobacco-Free Active Living and Healthy Eating in Low Socioeconomic Status Communities, Hyatt Regency Crystal City, Arlington, VA. Panel Presentation. April 29, 2014.

2. Bellettiere J., Berardi, V., ***Boman-Davis, M,*** Hovell, M. (2014). Low Frequency Smoking among Mexicans and Mexican Americans in San Diego, Tijuana, and Guadalajara: A First Look. University of California Global Health Day, University of California Davis, Davis, CA, Poster Presentation. April 26, 2014

3. ***Boman-Davis M.*** A Real-Time Intervention to Improve Household Air Quality among Low-Income Families, National University, Community Health Department, Faculty Focus on Research, San Diego, CA. Mock Dissertation Defense Presentation. April 17, 2014.

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5. ***Boman-Davis, M.*** Weighting Multiple Years to Identify Trends: A Logistic Regression of Public Use Data. Western Users of SAS Software Conference, Las Vegas, NV. Paper Presentation. November 15, 2013.

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8. ***Boman M.,*** Marcelli E. "Family Environment, Social Capital and Smoking among Brazilian Migrants in the Boston Metropolitan Area." Roundtable Presentation, "Innovative Student Research in Public Health", American Public Health Association, Annual Meeting in Philadelphia, PA, November 10, 2009.

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Select Awards

Faculty Scholarship, Western Users of SAS Software Conference	2013-2013
Local Advisory Committee Stipend Comprehensive SDSU/UCSD Cancer Center Partnership	2012-2013
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Local Advisory Committee Stipend Comprehensive SDSU/UCSD Cancer Center Partnership	2010-2011
Bixby Scholarship, San Diego State University	2010-2011
Predoctoral Fellow, Transdisciplinary Training for Predoctoral Behavioral Scientists, SDSU's Ruth L. Kirschstein National Research Service Award Institutional Training Grant, National Institute of General Medical Sciences, National Institutes of Health (NIH/NIGMS #1 T32 GM084896-02)	2008-2011
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ABSTRACT OF THE DISSERTATION

A Real-Time Intervention to Improve Household Air Quality

among Low-Income Families

by

Marie Christine Boman-Davis

Doctor of Philosophy in Public Health (Health Behavior)

University of California, San Diego, 2014

San Diego State University, 2014

Professor Melbourne Hovell, Chair

Fifty years following the first U.S. Surgeon General's Report on Smoking there have been significant decreases in national prevalence of smoking and exposure to secondhand smoke. However, tobacco use and exposure remains a leading cause of preventable morbidity and mortality. Community strategies, such as voluntary and legislative smoke-free policies, have been effective tools for protecting the health of people exposed to smoke in public and private spaces. To date these strategies have been

less successful at protecting children and others in private homes. Biological evidence suggests that more than fifty percent of children are exposed to toxic and hazardous secondhand smoke, primarily at home, with a disproportionate amount of exposure among children in low-income families. The U.S. Department of Health and Human Services has prioritized reduction of children's exposure to secondhand smoke by identifying it as a leading health indicator and creating a specific Healthy People 2020 objective to address this problem. There is no safe level of exposure to secondhand smoke and home-based interventions to protect children from secondhand smoke are needed.

The present n-of-1 clinical trial investigated a real-time intervention to reduce secondhand smoke exposure among young children. A total of 14 families with at least one smoker and one child under the age of five living in the home were recruited. The single case design with repeated measures and group design each provided enough power to detect statistically significant negative differences in cumulative daily geometric mean particle counts and cumulative hours of particle counts above 60µg/m3 in experimental homes using visual analyses, generalized additive models, and multi-levels models with fixed effects. Urine cotinine was positivity and strongly correlated with average log mean particle counts and thus a marker of SHSe. Real-time and delayed real-time feedback resulted in overall and individual home decreases in daily geometric mean fine particle counts thus improving household air quality including probable SHSe reduction.

INTRODUCTION

Rapid response studies (e.g., single-case experimental designs, n-of-1 clinical trials) to test effectiveness of real-time personalized home interventions to reduce infant and child SHSe are needed. The present study was responsive by using hybrid single case experimental and randomized control designs (i.e., n-of-1 clinical trial) to test effects of continuous real-time automated feedback (i.e., lights & sounds) about fine particle (i.e., PM 2.5) levels coupled with delayed real-time feedback (e.g., graphs, advice, praise, motivational interviewing) about particle levels and particle sources as a way to protect children from SHSe.

Primary Aim: To determine household level effects of a personalized real-time lights and sound intervention and delayed real-time graphic feedback and brief coaching intervention on SHSe in the home on daily household fine particle counts.

Hypothesis 1: Real-time feedback coupled with delayed real-time feedback will result in differential within group and between group decreases in daily household fine particle counts as measured by air particle monitoring units.

Secondary Aim: To determine household level effects of intensive data collection measurement on daily household fine particle counts.

Hypothesis 2: Intensive data collection measurement will result in decreases in daily household fine particle counts.

Tertiary Aim: To determine correlation between daily household fine particle counts and reported SHSe, urine cotinine, air nicotine and surface nicotine.

Hypothesis 3: Daily household fine particle counts will be positivity and modestly correlated with reported SHSe, urine cotinine, air nicotine and surface nicotine.

BACKGROUND AND SIGNFICANCE

Secondhand Smoke & Secondhand Smoke Exposure

Secondhand smoke (SHS) is a complex mixture of gases and particles including smoke from a burning tobacco product (e.g., cigarette) known as sidestream smoke and exhaled mainstream smoke.[1, 2] Sidestream smoke contains higher concentrations of numerous toxins than inhaled smoke because it is generated at lower temperatures and under different conditions than mainstream smoke.[1, 2] SHS contains at least 250 chemicals known to be toxic, including more than 50 compounds that are probable or known human carcinogens.[1, 2] Many of the particulates and gas-phase compounds of SHS are US federally recognized[3] and regulated[4] hazardous air pollutants and California state-regulated toxic air contaminants.[5] There is no risk-free level of secondhand smoke.[6] Reliable and valid environmental measures of SHS include passive diffusion monitors (i.e., nicotine dosimeters)[7, 8] and real-time measurement of PM 2.5[9-14] (i.e., fine particles). Urine cotinine is a common measure to assess the validity of self-report SHSe and a can serve as a biomarker for SHSe.[7, 8]

In the United States protecting children from secondhand smoke exposure (SHSe) has been a national priority for more than two decades and is a current objective of Healthy People 2020.[15] Recent national estimates suggest that more than forty percent of non-smoking children experience SHSe.[16] Infants and children are particularly vulnerable to chronic diseases and other morbidities associated with fine particle exposures[17, 18] and from toxic SHSe due in part to rapid lung development.[19] Postnatal SHSe, in the absence of prenatal smoking, is associated with decreased lung function[19-22]

(e.g., frequency of pulmonary neuroendocrine cells, asthma) and altered inflammatory and immune response[23] contributing to disease susceptibility and ill health[24]. SHSe health risks include sudden infant death syndrome (SIDS),[19, 25, 26] respiratory infections[19, 27] (e.g., bronchitis, pneumonia), ear infections,[19, 22, 28] and health conditions that result in hospitalization.[27] Infants and young children are primarily exposed to secondhand smoke in their homes[19] and a disproportionate number of these children are from low-income families.[29] It is estimated that people spend upwards of 90 percent of their time indoors[30] making household environments an important target for childhood SHSe interventions. Recent studies have identified indoor concentrations of fine particles around 60µg/m3 in areas where cigarette smoking is permitted[13, 31] suggestive of a relative concentration for SHSe.

Thirdhand Smoke (THS)

Hazardous and toxic tobacco smoke contamination from SHS accumulates on and in surfaces (e.g., upholstery, dust, hair, clothes) and when volatile contamination (e.g., nicotine) is reemitted it is known as thirdhand smoke (THS).[24, 32-37] Nicotine and other tobacco specific compounds can sorb into surfaces in minutes,[38] and after one day of smoking indoors, can desorb (i.e., off-gas) for weeks to months.[33, 39] THS contamination from regular indoor smoking reaches a steady state of daily desorption after approximately two weeks.[33] Sorbed nicotine, found indoors, can form carcinogenic tobacco-specific nitrosamines (TSNAs) through reaction with ambient nitrous acid (HONO). TSNAs identified included 4-(methylnitrosamino)-1-(3-pyridil)-1-butanone (NNK), 1-(N-methyl-N-nitrosamino)-1-(3-pyridinyl)-4-butanal) (NNA), and nitroso nornicotine (NNN).[32] Recent evidence suggests THS components (i.e., chemicals) are a

potential threat to the health of children[37] that prolonged exposure of children to SHS and THS may result in increased risk of illness and disease as well as neurological and behavioral disorders.[24]

Nicotine surface wipes are a relatively new, unobtrusive, and affordable technology for measuring THS. Recent studies have documented nicotine contamination in dust and surfaces of households and vehicles.[32, 34, 35] Levels of SHSe and THS were 5-7 times higher in households of smokers who smoked outdoors than in households of non-smokers and 3-8 times higher in households of smokers who smoked indoors than in households of smokers who smoked outdoors.[35] Study results demonstrated that smoking outside of the home and away from an infant reduces but does not completely protect a smoker's home from THS and a smoker's infant from SHSe. These results suggest that infants are exposed to THS even when parents do not smoke in the home due to the extended periods of off-gassing of nicotine from contaminated surfaces. These results may also provide insight into the failure of previous clinical trials to obtain cotinine reductions when there were reported reductions or evidence of reduced SHSe in the home.[28]

Interventions to Protect Children from SHSe and THSe

There are no known interventions with explicit intentions to protect children from THSe, however, evidence suggests that after an extended period of time (e.g., months) THS will decrease in the absence additional SHSe.[32, 39] Successful childhood SHSe reduction trials have focused on intensive counseling of parents (e.g., mothers, grandmothers, legal guardians) about smoking in the home and in the presence of children and confirmation of air nicotine reduction was obtained using passive diffusion

monitors.[40] SHSe reduction was demonstrated with self-monitoring and diaries (i.e., reactivity) with additional reductions when followed by brief education.[41] Greater reductions were seen when combined with counseling.[41] A preteen trial demonstrated that delayed cotinine feedback (i.e., two or more weeks) and counseling successfully increased SHSe avoidance.[42] Investigation of real-time measurement of fine particulates in homes has resulted in validation of several instruments that measure personal PM2.5 exposure.[43] In recent years feasibility studies have identified promising practices to change knowledge and reduce fine particles in homes using real-time household air quality measurement and feedback. Time-series and summary graphs of real-time fine particle counts in private homes, provided by cell phone technology[44], assisted in changing knowledge about household air quality[45]. Brief coaching provided with static summaries of active PM 2.5 measurements [13, 46] and dynamic real-time feedback[13] were able to reduce fine particles in homes and provide evidence of reduction in SHSe.

A qualitative pilot study by Kim & Paulos[45] demonstrated that an iPod touch could be attached to a standard Dylos to provide real-time feedback about fine air particle levels in the home and that in absence of information about sources or harm participants were willing to monitor, engage in the technology, and modify particle generating behaviors.

A feasibility study by Wilson and colleagues[46] used a randomized control trial design with the aim of reducing SHS fine particles in private homes of smoking mothers. The study tested a brief motivational interviewing intervention based on static graphic feedback generated from real-time PM 2.5 data collected in the participants' home to reduce SHSe with usual care as the control. Particle data were collected using a fine

particle monitor (Sidepack Personal Aerosol Monitor AM510, TSI Inc, MN, USA) for one twenty-four hour period at baseline and once at the end of the study (nearly one month following the first measurement). Estimates of PM2.5 mass data were collected every minute. Events were graphed and concentrations over 35 µg/m3 were the focus of the intervention because of the likelihood that they represented SHS. Findings suggest that brief motivational interviewing with delayed real-time graphic feedback of one twenty-four hour period produced significant differences in peak PM and time above peak PM, thus indicating a successful reduction in fine particles. However, salivary cotinine measures did not confirm child reduction in SHSe.

A feasibility study by Klepeis and colleagues[13] used a single case research design with the aim of reducing SHS fine particles in private homes of low-income families with at least one smoker. Fine particle count data collection and intervention instrumentation included a customized version of an off-the-shelf air monitoring instrument (i.e., Dylos 1100) calibrated for cigarette smoke (i.e., ≥60 µg/m3) and coupled with a custom add-on module capable real-time auditory and visual feedback to participants about rising particle concentrations in their home. Two monitors were placed in each of three study homes for the entire study period of approximately two weeks. One monitor was placed in a main room (e.g., living room, dining room, kitchen) and one in a bedroom (e.g., pregnant women, child). Particle data were collected every 10 seconds throughout the study which were converted into mass concentration (µg/m3) using tobacco aerosol conversion factors (i.e., coefficients) obtained in the laboratory (University of California, Irvine, USA). Baseline data were recorded for approximately one week. At the end of the baseline period families received one brief coaching session with printed time-series

graphs of particle concentration from the baseline period. Peaks reaching and exceeding 60µg/m3 were discussed as possible evidence of SHSe. Following the coaching session families received approximately one week of real-time intervention consisting of lights, sounds, and dynamic graphic feedback of fine particles on a small computer in the home. Results indicated decreases in SHSe events, and overall satisfaction with the real-time study technology. A recent study suggested comparable data collection between the Dylos 1700 and the sidepack[47] and researchers recommend the use of Dylos 1700 in future studies of SHS and PM 2.5.

Theoretical Framework

There are a growing number of technology based (e.g., mobile, remote sensing) health behavior interventions based on traditional health behavior theories and models at their core. However, researchers have identified that most introspective theoretical models are inadequate for informing refined engineering, implementing, and evaluating adaptive and dynamic real-time behavioral interventions using innovative technology.[48] The Behavioral Ecological Model (BEM), founded on Principals of Behaviors, posits that contingencies can be engineered to differentially reinforce behaviors for individuals and groups.[13, 49-52] Immediate feedback and other consequences are requisite when shaping new behaviors.[49, 51-54] Individual contingencies can be engineered to punish (e.g., aversive consequences) unhealthy behaviors and reinforce (e.g., reward) preventive health behaviors even in absence of immediate negative health consequences resulting in selection by consequences.[49, 55] In absence of powerful contingencies (e.g., hierarchical & interacting), maintenance of individual health behaviors is especially difficult when health benefits are delayed, morbidity is difficult to detect, and disease onset is delayed.

Thus social (e.g., group, cultural) contingencies can be an important means for individual and group behavior change and maintenance.[49, 52]

Recent empirical evidence suggests positive results using the BEM as the foundation of a SHSe intervention that used brief coaching and dynamic real-time visual as well as auditory feedback of household particles.[13] Results from this feasibility study demonstrate theoretical plausibility that increased frequency of auditory stimuli resulted in increased conditioned punishers (e.g., social criticism) from household members that contributed to SHS reduction behaviors (e.g., ventilation, moving smoking outside). It is also theoretically plausible that decreased frequency of auditory stimuli was associated with an increase in conditioned reinforcement (e.g., social praise) from household members. Delayed real-time feedback (i.e., praise) from research staff for decreasing frequency of peaks above programed thresholds also may have contributed to success.

STUDY DESIGN AND METHODS

Research Design

The study was a hybrid randomized control trial (RCT) and single case research (SCR) with multiple baseline design (i.e., n-of-1clinical trial). This study design was selected because SCR uses repeated measures of within person change over varying phases (i.e., conditions)[56] offered internal validity strengths and random assignment offered external validity strengths of RCT designs when pooled. Following consent, an ABA (i.e., withdraw) and multiple baseline design were used to test reactivity of intensive measurement and education in both groups. The timing of the first baseline condition (A) followed a staggered start date determined by the consent date. The timing of intensive measurement and education condition (B) was initiated after visual analyses of real-time particle count time series data confirmed stable or increasing particle activity.[57] Initiation of the intensive measurement and education condition followed a staggered sequence of at least 72 hours. The intensive measurement condition was a fixed period of seven days and was followed by the second baseline condition (A'). This procedure provided a within group cross person additional control for confounding factors in time. During the second baseline condition enrollment determinations occurred and was followed by paired random assignment of eligible participants. Fourteen qualified and enrolled families were randomly assigned to intervention or control groups and participated in the study for about three months.

Control group participants remained in the second baseline condition until the second intensive measurement condition during the final week of the study. The

experimental group transitioned from the second baseline condition into a real-time and delayed real-time intervention condition with adaptive[57] coaching (C) after visual analyses of real-time time series particle count data confirmed stable or increasing particle activity. This condition also followed a staggered sequence of at least 72 hours. This additional condition resulted in an ABAC design (i.e., modified reversal) and included a multiple baseline design that was employed to control for confounding factors over time.

SCR are common in the field of education and have been used for more than fifty years in the field of psychology[56]. In areas of medicine[57, 58], including tertiary prevention of chronic health conditions (e.g., fibromyalgia)[59], and palliative care[60] SCR also has been effective. Increasing demands for personalized medicine iterative n-of-1 trials can serve both research and clinical practice goals[57] and can help practitioners identify evidence-based personalized medicine and estimates of population treatment effects when reviewed in combination.[59] Repeated n-of-1 clinical trials have been recommended to replace traditional group study designs or randomized clinical trials[61] and are recognized as capable of demonstrating Level 1 treatment effects of evidence based medicine.[62-64] A control group, although not part of repeated n-of-1 clinical trials, has benefits including support for internal validity.

The institutional review boards from San Diego State University and the University of California, San Diego approved this study.

Setting

The study took place in private homes (e.g., multi-unit housing, shared single family homes) of families recruited from San Diego State University Research

Foundation (SDSURF) Women, Infant, and Children (WIC) offices. Families enrolled in WIC qualified for WIC benefits because they have a child up to five years old and gross income at or below 185% of the U.S. Poverty Income Guidelines.

Recruitment Inclusion Criteria

Inclusion criteria for participant recruitment and consent included : 1) at least 18 years old; 2) enrolled in WIC program at the time of recruitment; 3) parent or guardian of at least one child 0-5 years old that lived in the home a minimum of 4 days a week and that had not recently consumed breast milk; 4) had at least one household resident that smoked cigarettes and that lived in the home a minimum of 4 days a week; 5) parent or guardian had no plans to move out of San Diego county in the next 6 months; 6) parent or guardian spoke and read English or Spanish.

Recruitment Procedures

Recruitment occurred through a three step process: 1) WIC screening form; 2) phone screening; and 3) consent visit. WIC screening forms were available in SDSURF WIC offices. These forms consisted of a brief questionnaire and contact information and were encourage through an incentive (entry into a quarterly $100 drawing). Staff from each WIC office encouraged WIC families to complete and return the form. These forms were available in a variety of locations including clipboards, wall displays, and from counseling staff. Completed forms were stored in a locked drop-box in designated areas inside WIC locations and were picked up weekly by trained research assistants (RAs). RAs reviewed forms and identified contacts eligible to complete a phone screen. During the computer assisted phone screen in the preferred language, RAs identified contacts eligible for a consent visit and scheduled appointments accordingly.

Consent Procedures

Consent visits took place in homes of eligible study contacts. RAs conducted the consent visit in a team of two, and the lead RA used a tabletop easel book (i.e., flipbook) to summarize the study in the preferred language and to assist with informed consent. Contacts who agreed to participate were provided two printed consent documents, in the preferred language, that were designed to be at or below Flesch-Kincaid Grade Level 8.5 in English; these were professionally translated and certified in Spanish. The participant retained one copy of the consent form and one signed copy was retained by the lead RA.

Enrollment Eligibility Criteria

Eligibility for enrollment (i.e., randomization) of consented participants occurred after the first intensive measurement condition. In addition to the inclusion criteria, eligibility for enrollment included at least two of the following: a) parent or guardian report of SHSe of target child during the interview; b) parent or guardian report of partial or non-existent home smoking ban during the interview; c) RA observation of tobacco use in the home (e.g., observed smoking, tobacco paraphernalia); d) particle monitor readings that suggested the presence of SHS in the home.

Random Assignment

Eligible participants were randomly assigned in pairs (i.e., equal group random assignment) to the intervention or control using a computer-generated random number scheme. Paired random assignment was used to control for confounding factors in time and to ensure equal numbers in each group. When data are pooled with additional homes (e.g., N = 300), randomization should control for unknown and known confounding factors.

Baseline Conditions (A & A')

The first baseline condition (A) for both groups included the following: one floor plan sketch; one urine sample from the target child; two nicotine surface wipes; one continuous passive nicotine diffusion monitor; and two continuous real-time air particle monitoring units that communicated with the study netbook. The second baseline condition (A') for both groups included only one continuous passive nicotine diffusion monitor; and two continuous real-time air particle monitoring units that communicated with the study netbook.

Intensive Measurement Conditions (B & B')

The one week intensive measurement and brief education condition (B) for both groups included the following: daily air diaries; three urine samples collected approximately 48 hours apart from the target child; one continuous passive nicotine diffusion monitor; two continuous real-time air particle monitoring units that communicated with the study netbook; one interview lasting approximately 45 minutes; and concluded with brief education and materials (e.g., brochures) about the dangers of SHS, SHSe, THS and the benefits of smoke-free homes and cars. The intensive measurement condition (B') for both groups included everything in (B) except brief education and materials.

Intervention Condition (C)

The real-time and delayed real-time intervention with brief coaching condition (C) for the experimental group began after the following conditions were met: 1) at least 1 week of baseline data following the week of intensive measurement; 2) fine particle counts resulted in peaks above threshold and stable or increasing; 3) at least 72 hours

after another experimental home initiation. Up to four short meetings (i.e., brief coaching sessions) were conducted in the homes of intervention participants. During the first meeting RAs would initiate real-time lights & sounds and conduct brief coaching, using techniques including motivational interviewing, for study participants to identify strategies and set goals associated with preventing SHSe and keeping the lights green. Meetings included the following: time-series graphs of particle levels in the homes (i.e., delayed real-time feedback); brief adaptive coaching and motivational interviewing about decreasing or eliminating sources of fine particles with the primary focus on SHSe in the home and near the target child and discussion about continuous real-time lights and sound feedback about fine particle levels in the home. Graphs provided to participants displayed particle data collected in the home the week prior to the visit that provided information useful for goal setting and praise. Coaching topics typically included moving smoking outside, putting up no-smoking signs, and creating or enforcing a complete home smoking ban. In addition to delayed real-time feedback and brief adaptive coaching participants received continuous real-time feedback from air monitoring units.

Two fixed threshold were used for real-time feedback. When fine particle counts (Dylos 1700, Dylos Products, Inc., Riverside, CA, USA) in the home remained below the custom calibration of 60µg/m3[13] the LCD monitor light was green and silent (i.e., no sound). Each time fine particle counts near the monitor reached or exceeded 60µg/m3 the LCD monitor light was yellow/orange and an auditory alert played for under five seconds. Each time fine particles counts detected by the monitor doubled or exceeded the first threshold the LCD monitor light turned red and a higher hertz version of the auditory

alert played for under five seconds. When fine particles counts in the home returned below 60µg/m3 the LCD monitor light was green and remained silent (i.e., no sound). As a result of the custom calibration each monitor had unique particle counts associated with 60 µg/m3 for each monitor.

Study Conditions and Participation Timeline, Contacts and Study Conclusion

Planned data collection and intervention timing are depicted in Table 1. Unplanned calls and additional visits to troubleshoot and repair real-time technology occurred throughout the study in both groups. However, these visits are not depicted in the table. Also not depicted in the table is the delivery of fine particle level summary graphs and brief education that was provided to all study participants after their participation concluded (e.g., days to weeks). Additionally, control group participants were provided SHSe reduction prompts (e.g., no-smoking signs) previously available only to the intervention group.

Theoretical Principles of Intervention Group Target Behavior

The custom air particle monitor provided automated feedback immediately following a detected increase fine particle counts (e.g., tobacco smoking event). This design followed principles of behavior that indicate that immediate feedback is more reinforcing or punishing compared to delayed. The monitors were programmed to provide two brief auditory stimuli (i.e., sounds) when SHS related fine particles increased beyond two fixed thresholds. Each upward stimulus was intended to serve as positive punishment that, theoretically, would prompt behaviors that decrease fine particles associated with secondhand smoke (e.g., move smoking outside). When particle levels decreased below the lower threshold the light would turn green which was intended to

provide positive consequence for behaviors associated with achieving low levels of fine particles. It was hypothesized that increasing frequency of auditory stimuli would be associated with increases in conditioned punishers (e.g., social criticism) from household members. It was also hypothesized that decreasing frequency of auditory stimuli will be associated with increases in conditioned reinforcements (e.g., social praise) from household members. Interventions also included praise from RAs for decreasing frequency and duration of peaks above programed thresholds.

Compensation for Participation

Participants were provided cash gifts for completing study measures. On the day written consent was obtained, participants received a $10 cash gift after they answered a few questions about the home (e.g., year built) and RA's completed a floor plan sketch. At the conclusion of each intensive measurement week participants received a cash gift of $15 for returning at least one air diary, $20 for providing at least one urine sample from the target child, and either $25 for completing the pre-test interview or $30 for completing the post-test interview. Participants that completed requested measures were provided as much as $135 over the course of approximately three months.

Primary and Secondary Outcome Measures

The primary outcome measure was daily fine particle counts based on the netbook data. This study used all available data by computing geometric means of fine particle counts per day without imputing missing values or excluding days with less than 100% of fine particle count data. Secondary outcome measures included parent report of SHSe, urine cotinine, air nicotine and surface nicotine.

Data Collection

Floor Plan Sketch: After a completed consent, participants guided research assistants through their homes to complete a hand drawn floor plan sketch and answer a few questions about the home. The primary purpose of the sketch was to record and measure placement of the air monitors and netbook. The secondary purpose was to understand air flow in the home and obtain information about the primary smoking room and the room where the child slept.

Nicotine Surface Wipes: In the primary smoking room two nicotine surface wipes and one field blank wipe were collected to measure third hand smoke on the first day of the study and the last day of the study. One wipe was taken around adult level (approximately 1.5 meter) and one at child level (less than 1 meter). The surface nicotine samples were taken with a cotton wipe freshly prepared with 0.1% ascorbic acid and covered a 10 x 10 cm area. Wipes were placed in amber vials to preserve the nicotine and frozen for storage. Surface nicotine analyses were conducted at the SDSU Chemistry lab using liquid chromatography-tandem mass spectrometry. The method is sensitive to 0.1 micrograms of nicotine per wipe. This measure has been demonstrated to be both reliable and valid.[65]

Observational Survey: While in the home on the first and last day of the study, RAs observed the home to capture information related to tobacco paraphernalia and home smoking bans. RAs independently recorded information immediately after leaving the home. Upon data entry any discrepancies were addressed by a third party independent observer. Research assistants recorded observational measures after leaving the home following interviews visits. The observational measures were used to assess eligibility

determination and environmental changes related to tobacco use or home bans. Measures included no-smoking signs, tobacco use and tobacco paraphernalia (e.g., ashtrays).

Passive Nicotine Diffusion Monitor: A single nicotine dosimeter was hung during each condition of the study in the main smoking room to collect air phase nicotine (i.e. evidence of SHS) in the home. Dosimeters are small polystyrene cassettes (37mm diameter) that operate by passive diffusion of nicotine to chemically treated filters. The Teflon-coated glass-fiber filters (Emfab TX 40HI20WW, Pallflex Corp., Putnam, CT) are saturated with an aqueous solution of 4% sodium bisulfate and 5% ethanol and dried. After exposure, the collected nicotine and bisulfate are desorbed in water, the pH adjusted with 10 N sodium hydroxide, and the neutral nicotine molecule concentrated into 250 micro-L of heptane by liquid/liquid extraction. An aliquot of the heptane solution is injected into a gas chromatograph with nitrogen-selective detection for quantification of the nicotine level. The detection limit of the dosimeter is 0.01 micro-g, and the coefficient of variability is 0.11. The dosimeter measure has been shown to be both reliable and valid.[66] Results are presented as concentration of nicotine in relation to the number of hours in use in participants' homes. Analyses were conducted by Dr. Chatfield in the Chemistry Lab at San Diego State University. Previous research has shown that reported measures of SHSe are valid based on associations ($r > .50$) with nicotine dosimeter assays[7, 8]

Real-time Continuous Air Monitoring and Netbook: RAs placed two air particle monitors and one netbook computer each participant home for the duration of the study. One monitor was placed in the room where the youngest child (i.e., target child) slept at night and the other was be placed in the primary smoking room. The netbook was placed

in a location that would allow for optimal communication with both monitors. The monitors continuously measured fine air particles and raw particle counts were sent to the netbook and to a secure webserver. Data were available in real-time as web based time-series graphs for review by RAs and other study staff.

Air Diaries (Self-Administered): Participants were asked to record daily particle generating and ventilation activities in their home during the same weeks they are collecting urine. Typical data collected included cooking, cleaning, ventilation, and smoking activities.

Urine Collection from Target Child: Participants were asked to collect a total of seven urine samples from the youngest child in their home throughout the course of the study. One urine sample on the first day of the study and three urine samples during each week of intensive measurement each collected approximately 48 hours apart. Urine samples were collected by one of three methods. The first method used pads placed inside a plastic diaper liner. The second method used a toilet training chair. The third method used a urine cup. Research assistants provided study participants urine collection supplies and instructions and made arrangements to pick-up the samples. Children's urine samples were collected by parents and processed by research assistants trained according to SDSU biosafety protocols. Samples were analyzed only for cotinine in Dr. Chatfield's lab in the SDSU Chemistry Department, using isotope-dilution liquid chromatography-tandem mass spectrometry, with a limit of detection <0.05 ng/ml, and a split-sample reliability of ~99%.[67] Previous research has shown that reported measures of SHSe are valid based on associations ($r > .50$) with cotinine assays[7, 8]

Interview (Interviewer Administered): During the second and last study visits

participants were interviewed about smoking, smoking rules, and exposure to smoke. Interviews were completed using a computer-assisted protocol, and RAs also audio recorded each interview with permission of the participant.

Statistical Analysis Decisions and Data Analysis Strategy

Primary Hypothesis and Sample Size Calculations

The null hypothesis is that real-time feedback coupled with delayed real-time feedback will not result in differential within group and between group decreases in daily household fine particle counts as measured by the air particle monitoring unit. SAS version 9.3 was used to determine sample size needed to detect within group and between group differences in daily particle counts. As the first study of this kind, there was no identified empirical evidence of intraclass correlation or effect size for daily fine particle counts using a custom Dylos 1700 monitor (Dylos Products, Inc., Riverside, CA, USA) with an add-on device for data recording and intervention capability (OWL, EME Systems, Berkeley, CA) [13]; therefore theoretically plausible values were selected. Sample size calculation for within group difference was determined using the estimate of 112 days of repeated measures per home, power (.80) for a 2 tailed test (.05), intraclass correlation (.05), effect size (.95), resulting in one home for control and treatment group. Since each home served as their own control only one (n=1) home would be needed to detect within group differences. Sample size calculation for between group differences was determined using the estimate of 112 days of repeated measures per home, power (.80) for a 2 tailed test (.05), intraclass correlation (.05), effect size (.80), resulting in 2 homes for the control and 2 homes for the treatment group. Since each home served as their own control only two (n=2) homes would be needed to detect within group

differences. Repeated pairs were needed for multiple baseline and n-of-1 clinical trial format. A sample of ten homes with equal group[68] random assignment to intervention and control group was determined to be financially and logistically possible. To account for unknown attrition rates two additional pair of homes were recruited for a total sample of fourteen homes (n=14).

Study Aims and Analyses

The aims of this study were: 1) To determine household level effects of a personalized real-time and delayed real-time intervention on SHSe in the home; 2) To determine change in daily household fine particle counts following an intensive measurement condition; 3) To determine the correlation between daily household fine particle counts and reported SHSe, urine cotinine, air nicotine and surface nicotine.

The primary and secondary outcomes were first analyzed using visual inspection of time-series plots and statistical analyses of geometric mean daily particle counts by condition. Statistical analyses then included: a) nonparametric regression using either condition or time as the splines and for identification of data structure using generalized additive modeling (GAM); and b) mixed linear modeling (i.e., multi-level modeling) to test within-group and between group effects of study conditions with either condition or time as a fixed effect and group (i.e., experimental or control) as a random effect. The tertiary aim was analyzed by validation correlations (i.e., a validation matrix) of arithmetic mean of daily particle counts and the following: a) reported home smoking bans; b) reported child SHSe; c) child urine cotinine; d) passive diffusion air nicotine; and e) nicotine surface wipes.

Descriptive statistics and bivariate analyses were conducted on socio-

demographic (e.g., age, sex, education) and household characteristics (e.g., home smoking ban, number of rooms). Bivariate analyses were used to assess if random assignment was successful at balancing the groups. Particle count data obtained from netbooks were cleaned and concatenated in R (GNU S). Bivariate analyses, geometric mean and log mean calculations of daily particle counts were conducted using SPSS Version 21. Visual analyses, generalized additive modeling, and multi-level modeling were conducted using SAS Version 9.3. Validation correlations were constructed using STATA Version 11.0.

RESULTS

Population

Pre-test measures indicated that the majority (69.2%) of participants reported smoking cigarettes every day, having a complete home smoking ban (57.1%), and being primarily responsible for home smoking rules (53.8%). Most (85.7%) were female, between the ages of 25-34 (69.2%), and had some college or vocational education (35.7%). At post-test there was a statically significant ($p=0.004$) change in reported smoking status in the experimental group (see Tables 2a, b).

Primary Aim Analyses

All Homes Together Across Time by Group: Experimental group GAM and MLM results showed significant negative group differences in daily particle counts (-614.47 ± 127.96, $p<.0001$) and cumulative hours of particle counts above 60µg/m3 (-0.29 ± 0.08, $p<.0001$) in child room monitors. There were also statistically significant negative differences (-406.33 ± 90.19, $p<.0001$) in daily particle counts and cumulative hours of particle counts above 60µg/m3 (-0.20 ± 0.04, $p<.0001$) in the main room monitors (see Tables 3, 3a). Control group GAM results showed a statistically significant positive group difference in daily particle counts (257.02 ± 102.54, $p=0.0124$) for the child room monitors (see Tables 3a, b). Experimental and control homes GAM results had a Gaussian distribution and therefore MLM was used for all subsequent analyses.

Individual Homes Across Time by Monitor and Group: In the experimental homes, visual analyses and MLM demonstrated statistically significant decreases ($\geq -6.82 \pm 2.49$, $p\leq0.0194$) in particle counts in five (71.4%) child room monitors and statistically significant decreases ($\geq -5.86 \pm 1.61$, $p\leq0.0058$) in five (71.4%) main room monitors

across time (see Figures 1-7 and Table 4). In the control homes, visual analyses and MLM demonstrated statistically significant increases (≥0.70 ± 5.98, p≤0.0003) in particle counts in four (57.1%) child room monitors and statistically significant increases (≥8.48 ± 3.23, p≤0.0099) in particle counts in two (28.6%) main room monitors across time (see Figures 8-14 and Table 5).

Conditions A (First Baseline) versus C (Intervention) by Home and by Monitor: Visual analyses demonstrated changes in daily particle counts in Phase C (i.e., Intervention) for the majority of child room and main room monitors (see Figures 15-21). Experimental home MLM analyses confirmed that daily particle counts in Condition A were statistically significantly higher (≥1378.36 ± 266.30, p≤.0001) than in Condition C for three (42.9%) child room monitors and statistically significantly higher (≥1668.55 ± 595.87, p≤0.0075) for three (42.9%) main room monitors (see Tables 6a, b). MLM also confirmed that Condition A had statistically significantly higher number of cumulative hours of particle counts above 60µg/m3 (2.36 ± 1.02, p=0.0263) in the child room monitor in one home (14.3%) and statistically significantly higher number of cumulative hours of particle counts above 60µg/m3 (≥0.04 ± 0.10, p=0.0003) in the main room monitors in four homes (57.1%) (tables not shown).

Conditions A' (Second Baseline) versus C (Intervention) by Home and by Monitor: Condition A' was designed to serve as a washout period following intensive measurement therefore data were included from the day of the participant interview and brief education intervention. MLM showed that daily particle counts in Condition A' were statistically significantly higher (≥1141.13 ± 351.71, p≤0.0015) than in Condition C for two (28.6%) child room monitors and statistically significantly higher (≥728.33 ±

148.39, p≤.0001) for five (71.4%) main room monitors (see Tables 6a, b). MLM also confirmed that Condition A' had statistically significantly higher number of cumulative hours particle counts above 60µg/m3 (≥0.53 ± 0.22, p=0.0197) in child room monitors in three homes (42.9%) and statistically significantly higher number of cumulative hours of particle counts above 60µg/m3 (≥0.34 ± 0.90, p=0.0003) in main room monitors in three homes (42.9%) (tables not shown).

Secondary Aim Analyses

Experimental group MLM analyses revealed a statistically significant positive difference (1585.23 ± 455.30, p=0.0007) in the child room monitor for one home (14.3%) (see Tables 6a, b). Control group MLM analyses revealed statistically significant positive differences (≥1424.12 ± 364.32, p=0.0002) in child room monitors for three homes (42.9%) (see Tables 7a, b).

Tertiary Aim Analyses

The correlation coefficients of child urine cotinine with the arithmetic mean of log transformed daily particle counts, using all available main room monitor data, was strongly positive (r=0.64) and statistically significant (p=0.015) (see Table 8).

DISCUSSION

There is no safe level of exposure to SHS, and children in low-income families are disproportionality affected by this environmental contaminant. This study is the first n-of-1 clinical trial to use real-time and delayed real-time feedback of fine particle measurements to reduce SHSe in low-income private homes of cigarette smokers with children under the age of five years. Experimental group results demonstrated that a personalized real-time and delayed real-time intervention based on these measurements resulted in statistically significant overall declines in geometric mean daily particle counts and cumulative hours that particle counts were above 60µg/m3 for each monitor record. In the absence of the intervention (i.e., lights and sound feedback) no significant improvements in daily geometric mean particle counts were recorded in the child room or main room monitors. Results suggest that the intervention success was not due to chance but also that intensive measurement and education did not result in long-term improvements. Averaged log mean particle counts were positivity and strongly associated with urine cotinine values.

Strengths and Weaknesses

Strengths: Intensive measurement and brief education about SHS resulted in statistically significant short-term reductions in fine particles. Real-time and delayed real-time feedback about fine particle counts and personalized brief coaching resulted in statistically significant reductions in fine particles beyond improvements made with only intensive measurement and brief education. Associations between child urine cotinine and average log transformed particle counts were strongly and positively correlated.

Conducting the study in private homes affirms external validity because it was implemented in the context of real-life situations, including several associated confounders. This study expands on the feasibility study by Wilson and colleagues[46] by using real-time measurement of fine particles throughout the study and for initiation of the intervention period and throughout brief coaching sessions (instead of only at pre and post-test). The study also expands on the feasibility study by Klepeis and colleagues[13] by adding a control group, by having additional weeks of intervention, and by using real-time measurement of fine particles throughout the intervention. However, this study did not provide real-time visual feedback to participants.

Weaknesses: The Dylos 1700 was not designed to differentiate between SHSe fine particles and other sources of fine particles; however, a recent controlled experiment suggested that with additional analyses SHS can be detected.[69] The lack of specificity and sensitivity may have resulted in false positive alerts (i.e., signals and lights not associated with SHSe). Another limitation was the use a calendar week (i.e., systematic scheduling) for intensive measurement conditions. Ideally and theoretically all condition changes should be made contingent on baseline trends and levels and not on time alone. Finally, over extended periods of time sound signals theoretically may become less powerful as a result of adaptation, however, there is no empirical evidence for this adaptation.

Implications

Real-time monitoring, feedback, and intervention can reduce SHSe of children and improve household air quality among low-income families. Intensive measurement and education does not appear sufficient to make long-term changes to behavior in absence of feedback which provides evidence to support the theoretical framework that

posits that feedback is requisite for behavior change. Health promotion specialists, behavioral interventionists, and medical practitioners can use these technologies to provide adaptive and targeted remote interventions to improve the health of children and vulnerable populations (e.g., asthmatics). Policy makers (e.g., multi-unit housing owners) can use the technology to adopt, implement, and enforce smoke-free housing policies, thus protecting current residents from SHSe and future residents from possible THSe.

Future Directions

Adaptive goals based on moving thresholds (e.g., percentiles based on previous data) may be employed to automatically shape behavior and should be tested to determine the effect beyond using a fixed threshold. This would allow for more precise feedback and tailored interventions that might lead to greater decrease in smoking on the home and possibly longer maintenance. Social contingencies were likely to be important in these low-income settings; however, these were not assessed in this study. An examination of the quality and content of praise and criticism regarding smoking behaviors could be analyzed to explain variances between homes. Household characteristics such as the number of smoking residents, number of children, health of children, and number of bedrooms could also be investigated to determine if these crowding characteristics supported or impeded SHSe reduction behaviors.

TABLES AND FIGURES

Table 1. Control Group and Experimental Group Study Conditions and Participation Timeline[a]													
Control Group Conditions & Duration	1 Day	(A) ≤ 4 Weeks	(B) 1 Week			(A') ≤ 13 Weeks					(A + B') 1 Week		
Home Visits	1		2	3 & 4	5						6	7 & 8	9
Floor Plan Sketch	X												
Nicotine Surface Wipes	X												X
Observational Survey	X												X
Passive Nicotine Diffusion Monitor	X	XXXX	X			XXXXXXXXXXXXX					X		
Real-time Continuous Air Monitoring Unit	X	XXXX	X			XXXXXXXXXXXXX					X		
Air Diaries (Self-Administered)			X								X		
Urine Collection from Target Child				X								X	
Interview (Interviewer Administered)					X[b]								X
Brief Education					X[b]								X
Experimental Group Conditions & Duration	1 Day	(A) ≤ 4 Weeks	(B) 1 Week			(A') ≤ 4 Weeks	(C) ≤ 9 Weeks				(A + B' + C') 1 Week		
Time-Series Graphs from Air Monitoring							XXXXXXXXX						
Real-time Lights & Sound							XXXXXXXXX				X		
Brief Coaching & Motivational Interviewing							XXXXXXXXX						

[a]Timeline represents typical participation [b]Effects of the interviewer administered interview and brief education were anticipated to result in a washout period therefore this day was included in the Phase A' data analyses.

Table 2a. Characteristics of Study Participants by Group at Pre-test (N=14)

Variable	Population Pre-test *N* (%) (N=7)	Experimental Group Pre-test *n* (%) (N=7)	Control Group Pre-test *n* (%) (N=7)
Parent/Guardian Smoking Status			
Not at All	1 (7.7)	0 (0.0)	1 (14.3)
Some Days	3 (23.1)	1 (16.7)	2 (28.6)
Every Day	9 (69.2)	5 (83.3)	4 (44.4)
Complete Home Smoking Ban[i]			
Yes	8 (57.1)	5 (71.4)	3 (42.9)
No	6 (42.9)	2 (28.6)	4 (57.1)
Responsible for Smoking Rules			
Self	7 (53.8)	5 (71.4)	2 (33.3)
Partner/Spouse	5 (38.5)	2 (28.6)	3 (50.0)
Parent(s)	1 (7.7)	0 (0.0)	1 (7.7)
Parent/Guardian Gender			
Male	2 (14.3)	0 (0.00)	2 (28.6)
Female	12 (85.7)	7 (100)	5 (71.4)
Parent/Guardian Age, years			
18-24	1 (7.7)	0 (0.0)	1 (14.3)
25-34	9 (69.2)	5 (83.3)	4 (57.1)
35-44	2 (15.4)	1 (16.7)	1 (14.3)
Over 44	1 (7.7)	0 (0.0)	1 (14.3)
Parent/Guardian Education			
No high school diploma	2 (14.3)	2 (28.6)	0 (0.0)
High school diploma/equivalent	4 (28.6)	1 (14.3)	3 (42.9)
Some college/Vocational	5 (35.7)	2 (28.6)	3 (42.9)
College degree	3 (21.4)	2 (28.6)	1 (14.3)

[i]Complete ban determined using four questions about home smoking rules

Table 2b. Bivariate Analyses of Study Participants by Group Pre-test versus Post-test

Variable	Experimental Group		P Value	Control Group		P Value
	n (%) (N=7)	*n* (%) (N=7)		*n* (%) (N=7)	*n* (%) (N=7)	
	Pre-test	Post-test		Pre-test	Post-test	
Parent/Guardian Smoking Status			0.004			0.076
Not at All	0 (0.0)	0 (0.0)		1 (14.3)	0 (0.0)	
Some Days	1 (16.7)	2 (33.3)		2 (28.6)	2 (25.0)	
Every Day	5 (83.3)	4 (66.7)		4 (57.1)	4 (75.0)	
Complete Home Smoking Ban[i]			0.172			0.175
Yes	5 (71.4)	7 (100)		3 (42.9)	1 (16.7)	
No	2 (28.6)	0 (0.0)		4 (57.1)	5 (83.3)	
Responsible for Smoking Rules			0.689			0.695
Self	5 (71.4)	6 (85.7)		2 (33.3)	4 (66.7)	
Partner/Spouse	2 (28.6)	0 (0.0)		3 (50.0)	1 (16.7)	
Parent(s)	0 (0.0)	1 (14.3)		1 (16.7)	1 (16.7)	

[i]Complete ban determined using four questions about home smoking rules

Table 3a. Estimated Change in Daily Geometric Mean Particle Counts across Conditions by Group and Air Particle Monitoring Unit with All Available Data used in Generalized Additive Model

Condition(s)	Homes (N)	Monitor	N Obs	Parameter Estimate (SE)	Min	Max	t Value	Pr > |t|	
Experimental	**7**	**CHD**	**744**	**-614.47 (127.96)**	**32.11**	**48204.21**	**-4.80**	**<.0001**	*****
Experimental	**7**	**MNR**	**780**	**-406.33 (90.19)**	**36.83**	**42072.06**	**-4.51**	**<.0001**	*****
Control	**7**	**CHD**	**698**	**257.02 (102.54)**	**135.40**	**24540.77**	**2.51**	**0.0124**	*****
Control	7	MNR	741	39.96 (82.38)	183.00	19457.16	0.47	0.6364	

Note: MNR = Main Room Monitor, CHD = Child Room Monitor
*Significance ≤0.05

Table 3b. Estimated Change in Hours of Particle Counts Above 60µg/m3 across Conditions by Group and Air Particle Monitoring Unit with All Available Data used in Generalized Additive Model

Condition(s)	Homes (N)	Monitor	N Obs	Parameter Estimate (SE)	Min	Max	t Value	Pr > |t|	
Experimental	**7**	**CHD**	**280**	**-0.2941 (0.0776)**	**0.00**	**9.41**	**-3.79**	**<.0001**	*****
Experimental	**7**	**MNR**	**434**	**-0.1971 (0.0402)**	**0.00**	**5.83**	**-4.91**	**<.0001**	*****
Control	7	CHD	368	0.0702 (0.06389)	0.00	9.88	1.10	0.2725	
Control	7	MNR	519	-0.0448 (0.0392)	0.00	10.01	-1.17	0.2541	

Note: MNR = Main Room Monitor, CHD = Child Room Monitor
*Significance ≤0.05

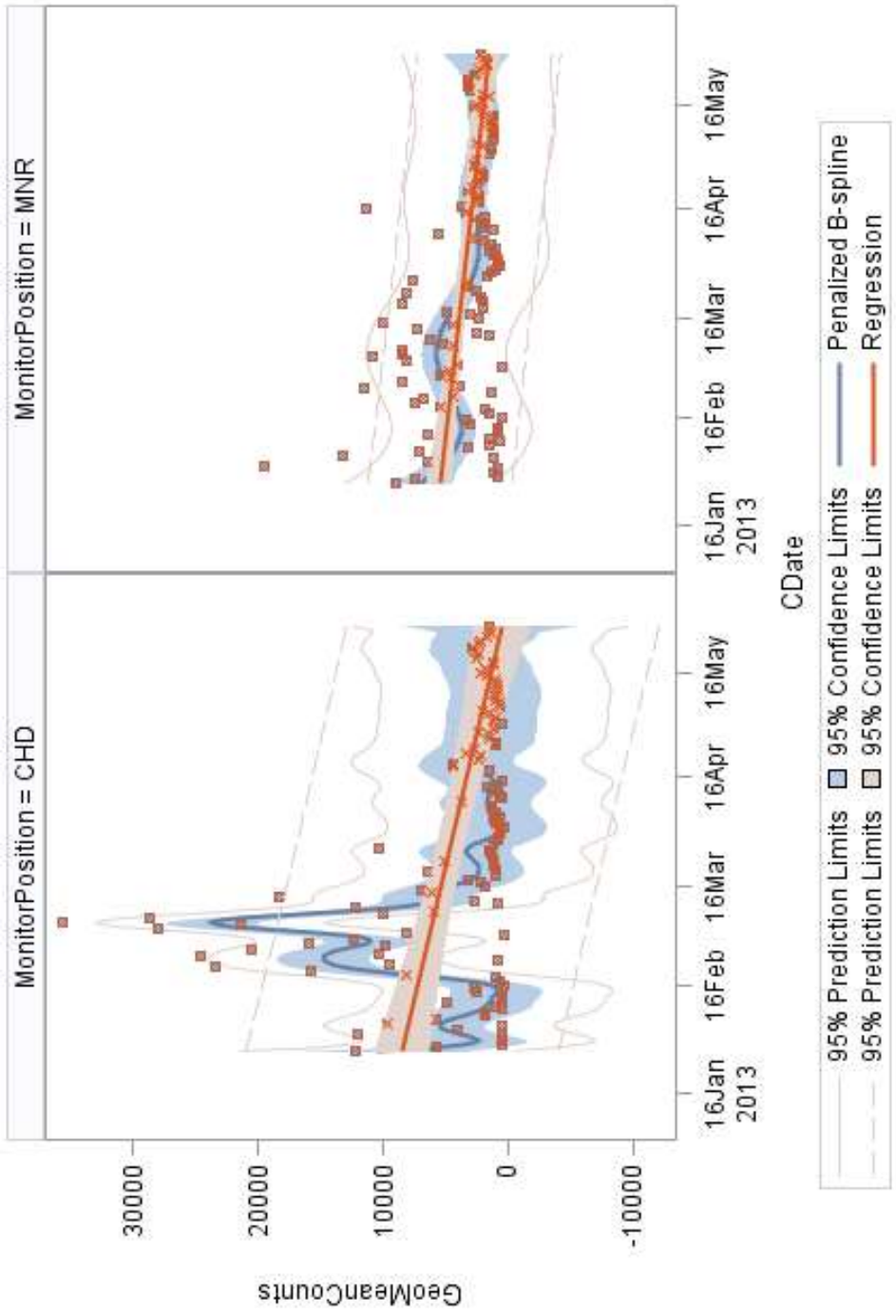

Figure 1. Experimental Home 1 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

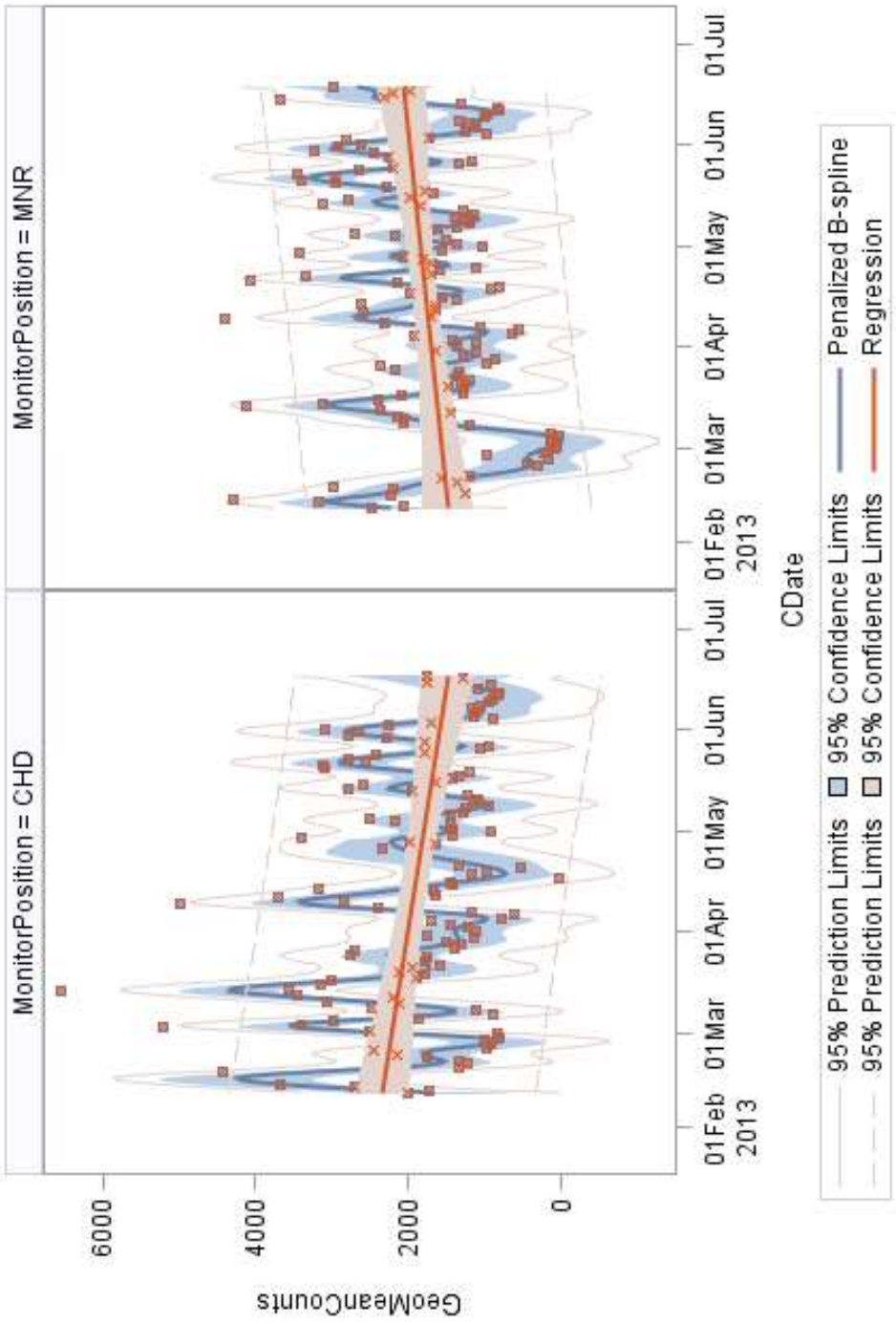

Figure 2. Experimental Home 2 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

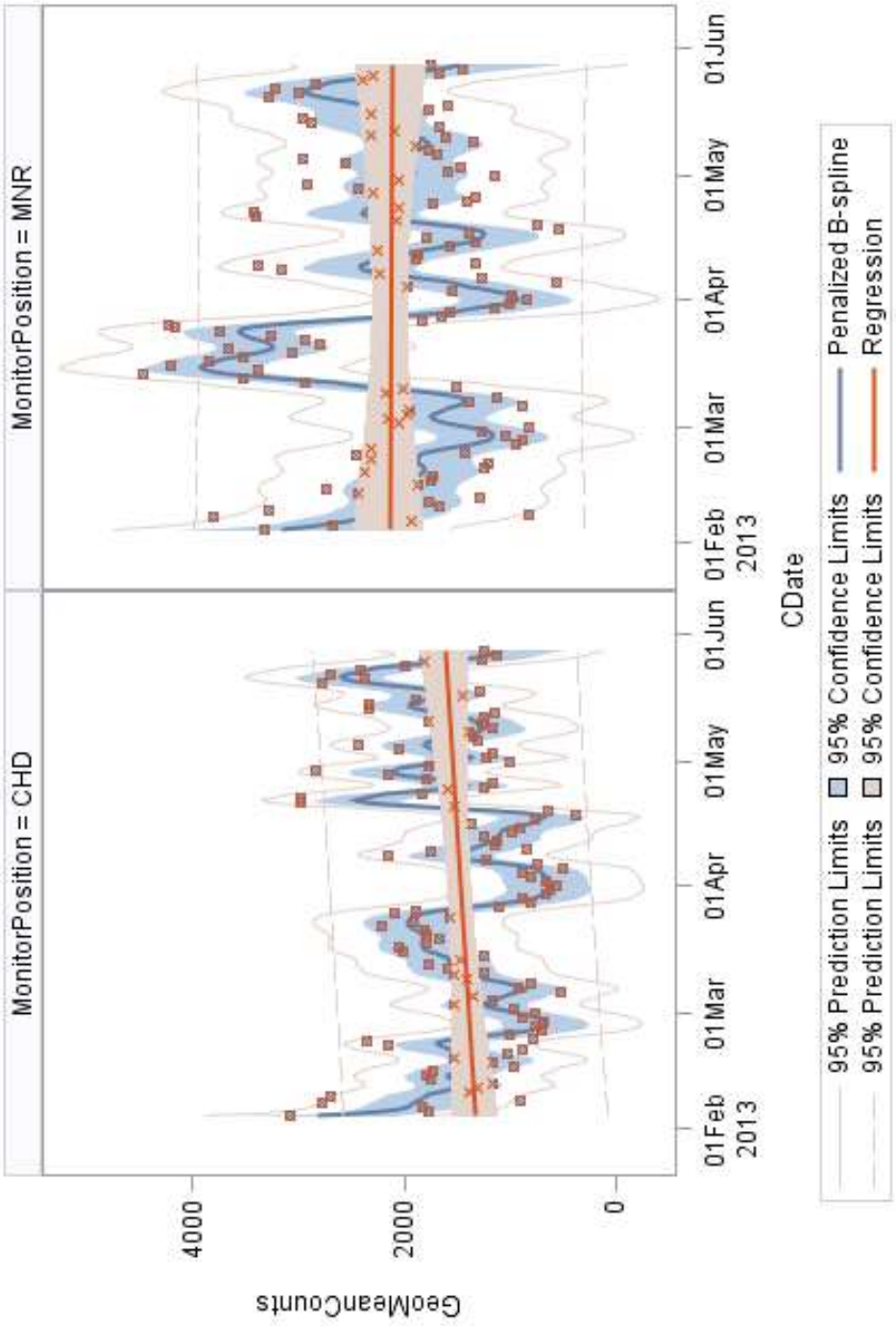

Figure 3. Experimental Home 3 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

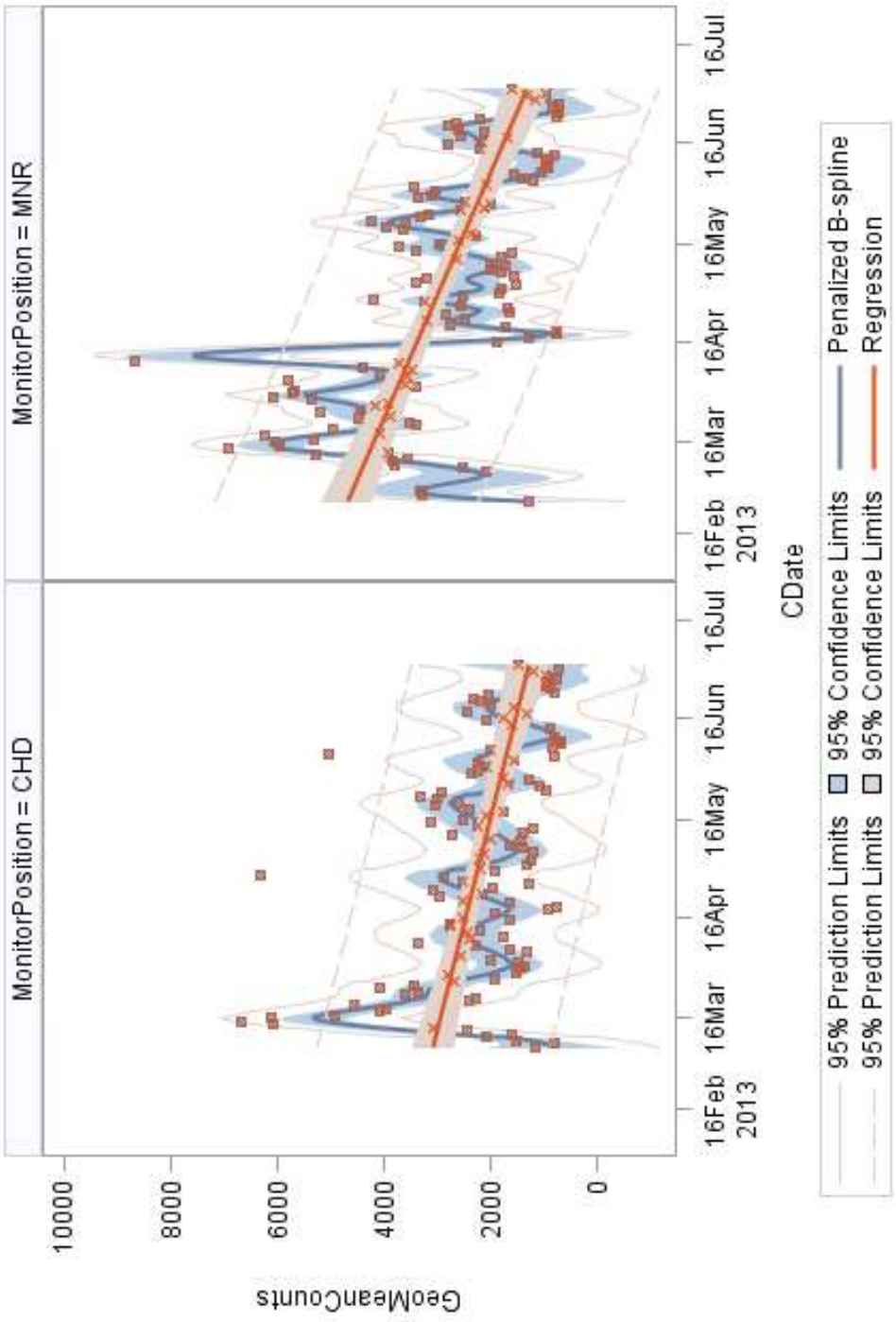

Figure 4. Experimental Home 4 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

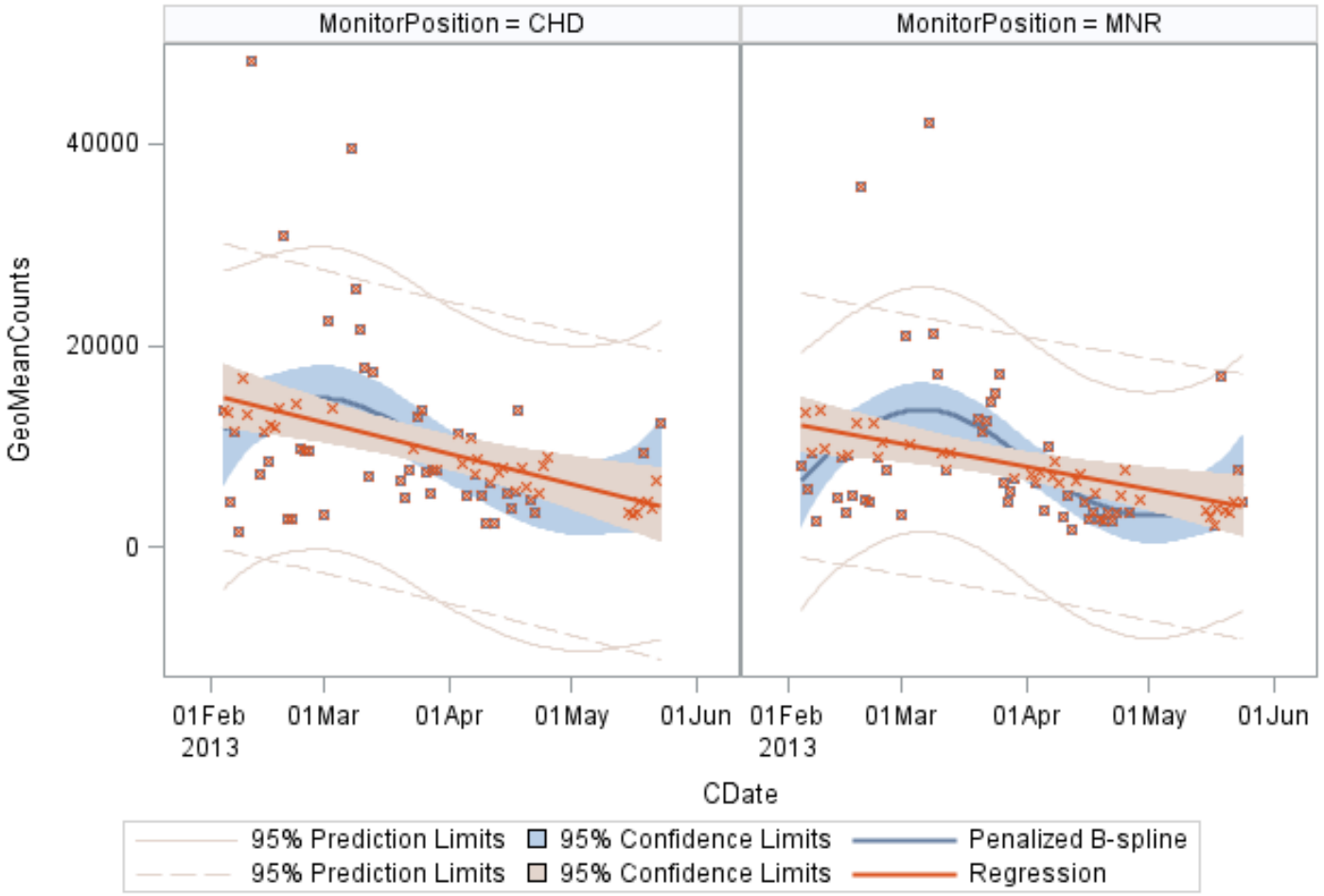

Figure 5. Experimental Home 5 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

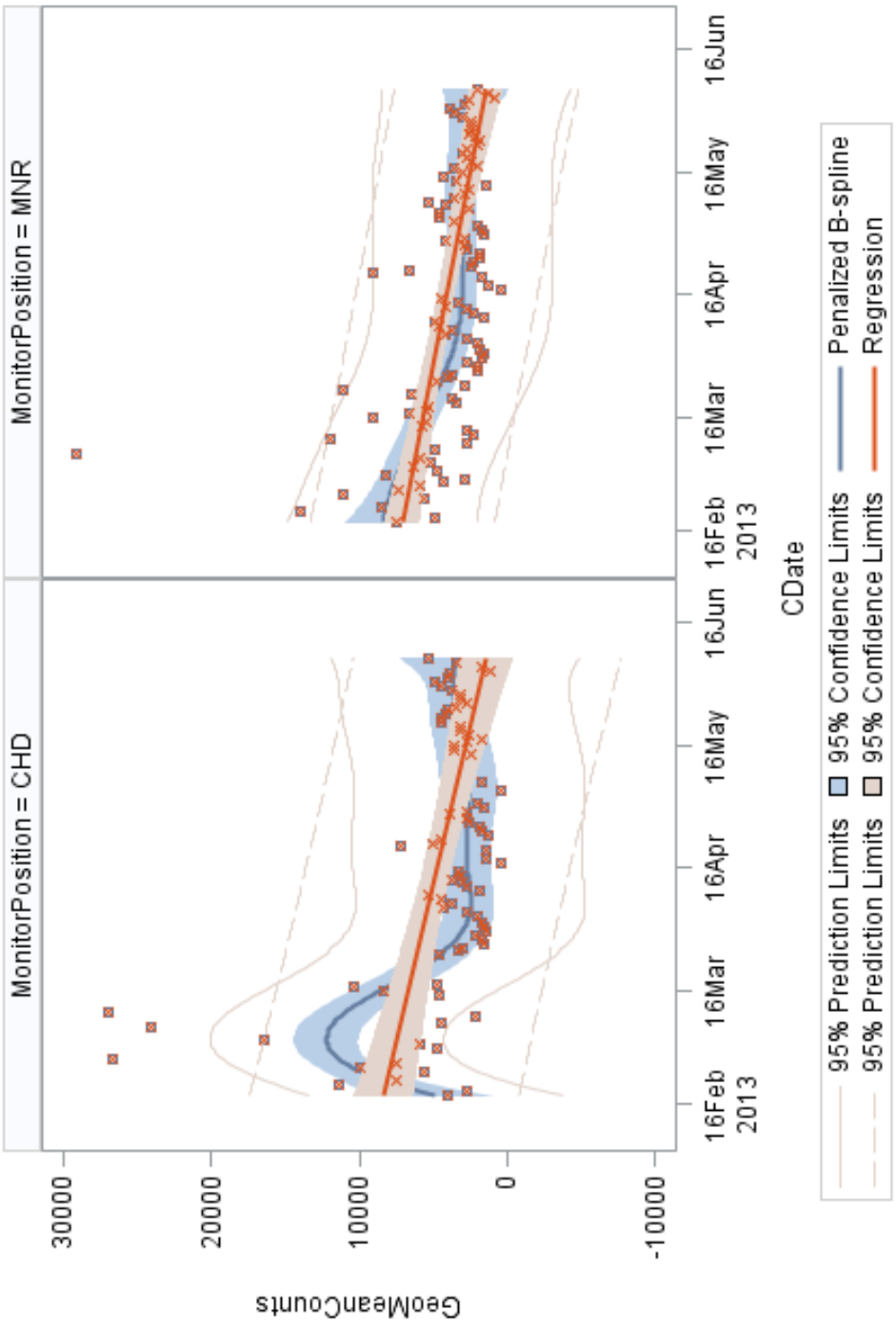

Figure 6. Experimental Home 6 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

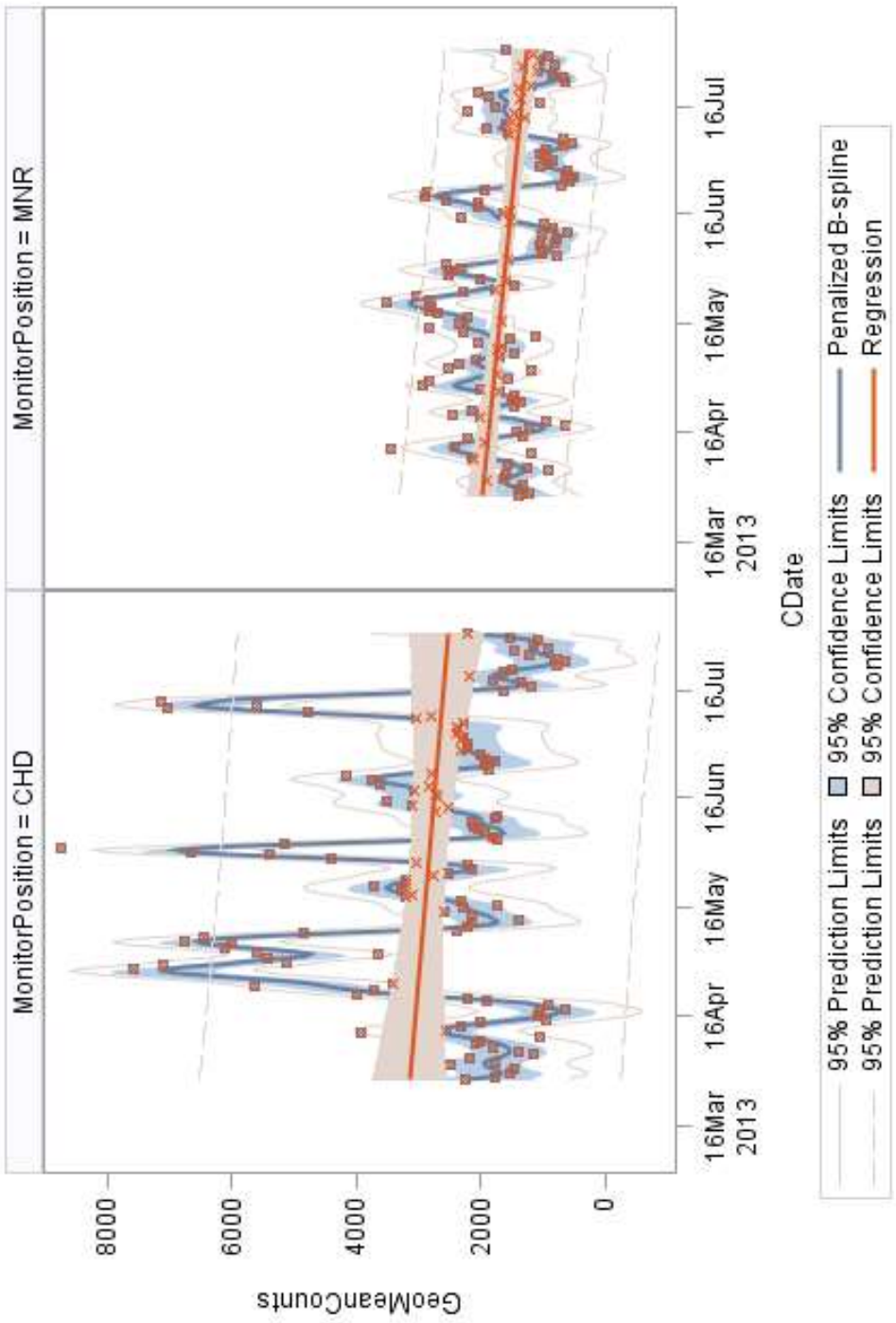

Figure 7. Experimental Home 7 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

Table 4. Estimated Change in Experimental Home Daily Geometric Mean Particle Counts across Time by Air Particle Monitoring Unit and by Home with All Available Data used in Multi-Level Mixed Model Analyses

	Child Room Monitor			**Main Room Monitor**		
	Estimate (SE)	*P* value		Estimate (SE)	*P* value	
Experimental Home 1	**-66.20 (16.00)**	**<.0001**	*****	**-32.03 (7.28)**	**<.0001**	*****
Experimental Home 2	**-6.82 (2.49)**	**0.0070**	*****	**4.76 (2.26)**	**0.0373**	*****
Experimental Home 3	2.58 (1.79)	0.1523	*	-0.18 (2.63)	0.9464	
Experimental Home 4	**-15.08 (2.97)**	**<.0001**	*****	**-26.89 (3.18)**	**<.0001**	*****
Experimental Home 5	**-99.69 (27.70)**	**0.0006**	*****	**-73.83 (23.29)**	**0.0022**	*****
Experimental Home 6	**-53.44 (9.69)**	**<.0001**	*****	**-63.81 (15.36)**	**<.0001**	*****
Experimental Home 7	-4.85 (4.22)	0.2527	*****	**-5.86 (1.61)**	**0.0004**	*****

*Significance ≤0.05

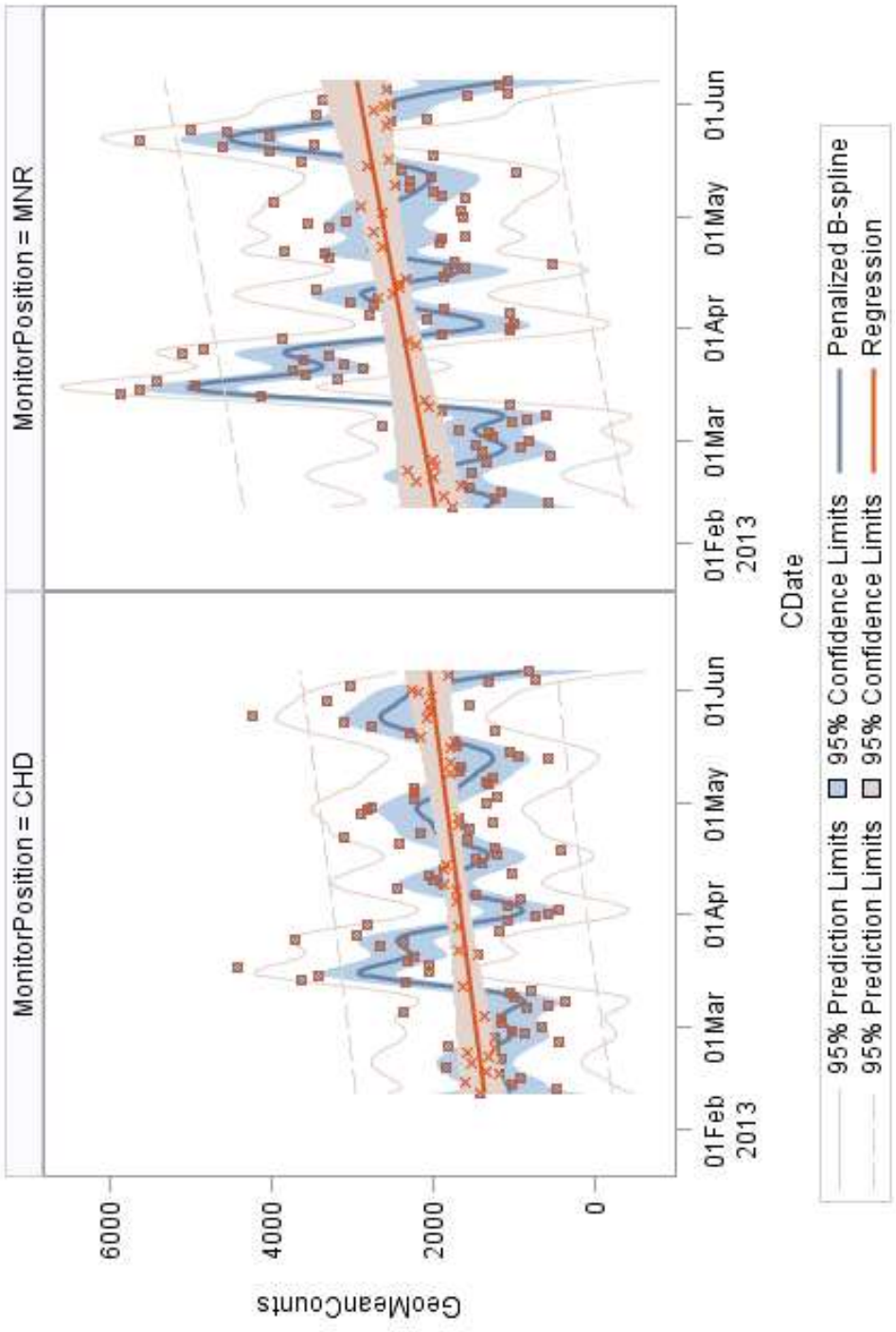

Figure 8. Control Home 8 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

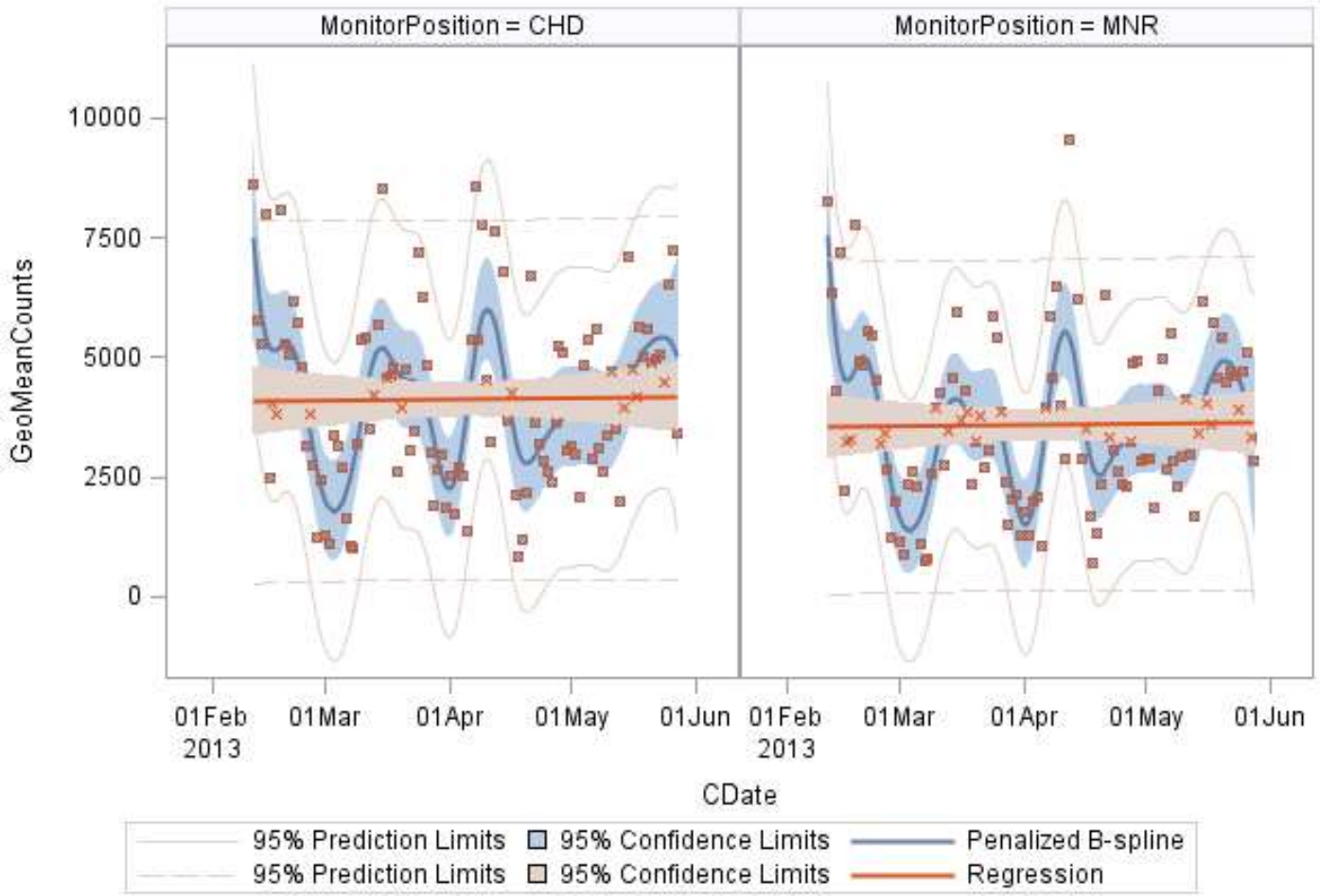

Figure 9. Control Home 9 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

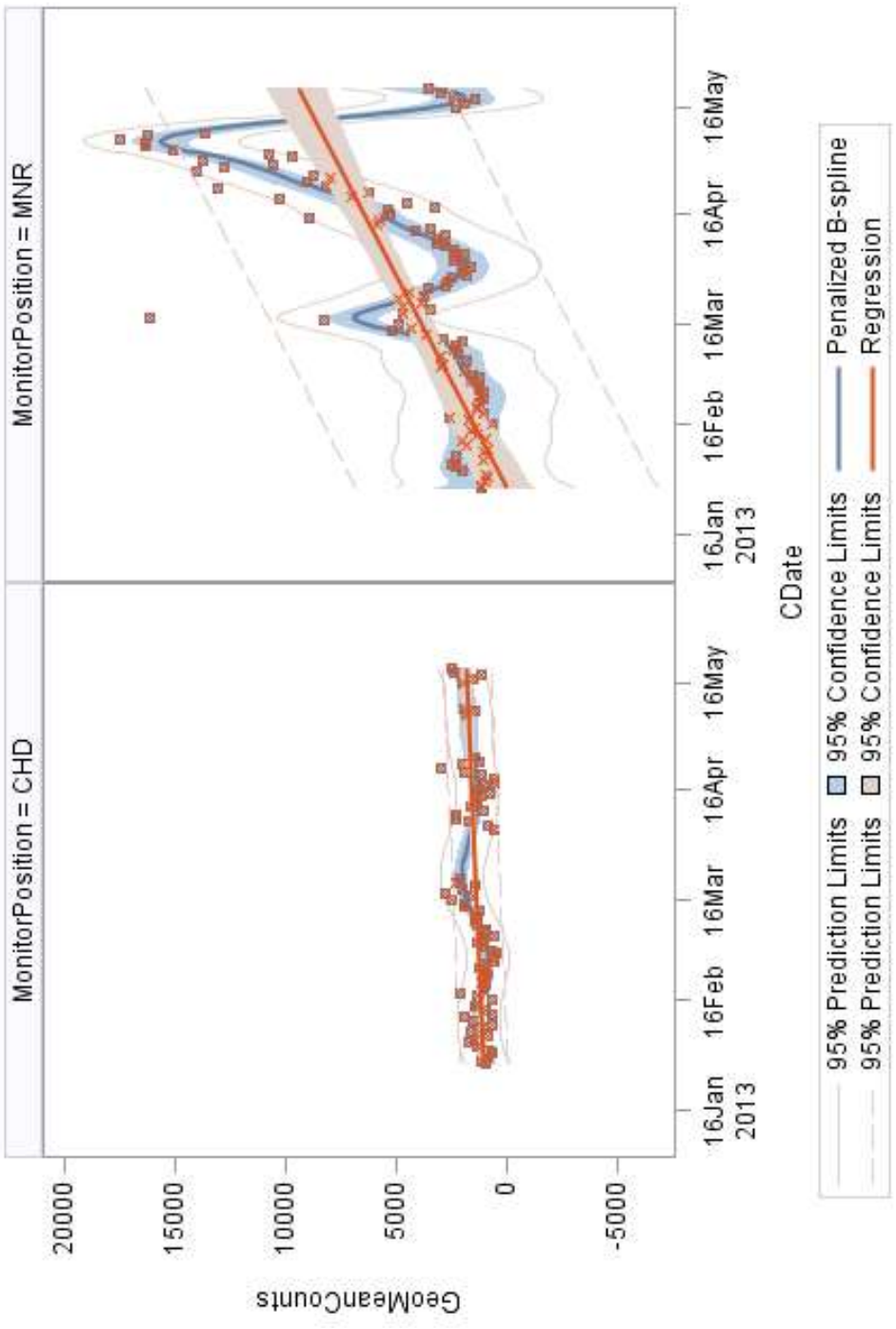

Figure 10. Control Home 10 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

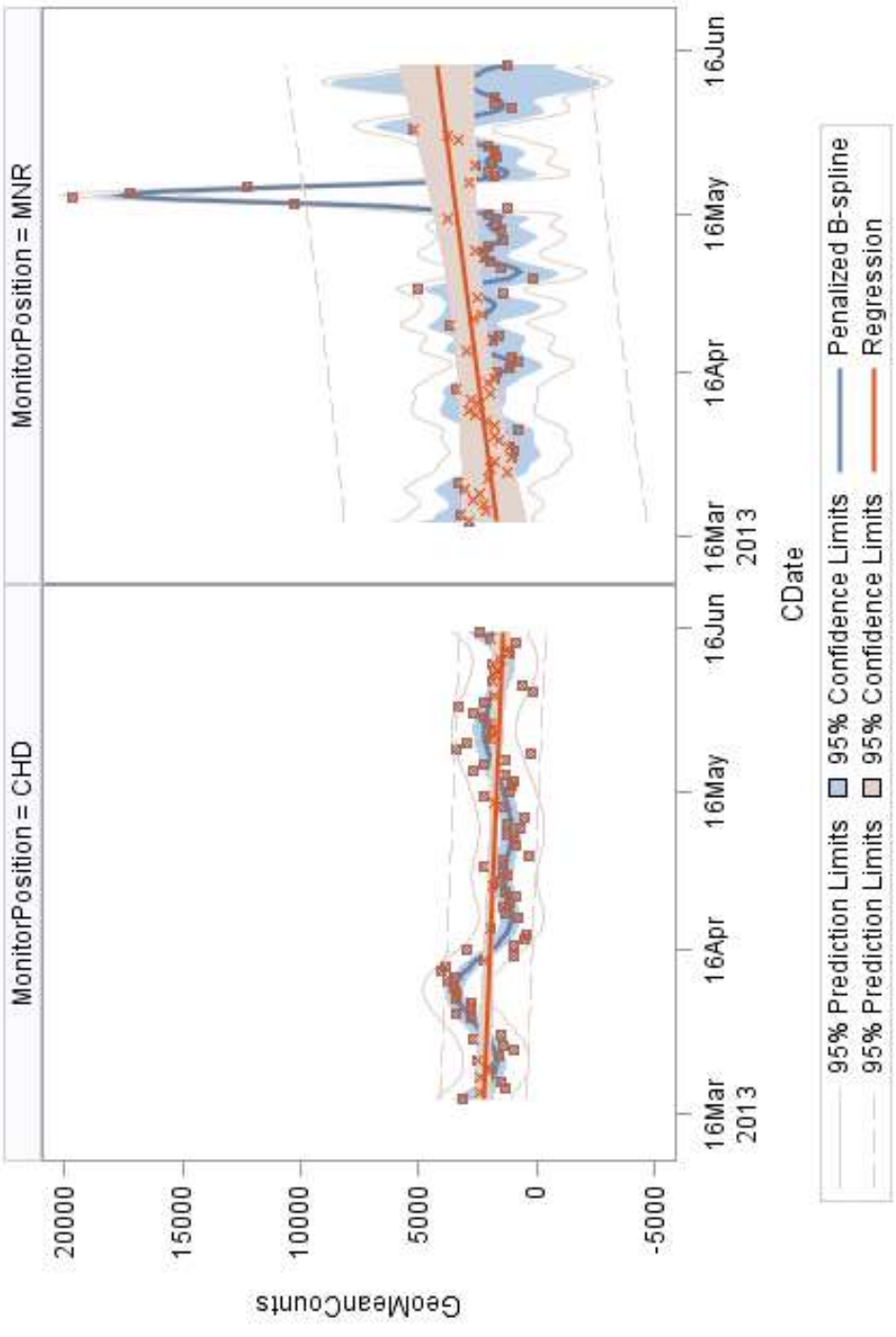

Figure 11. Control Home 11 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

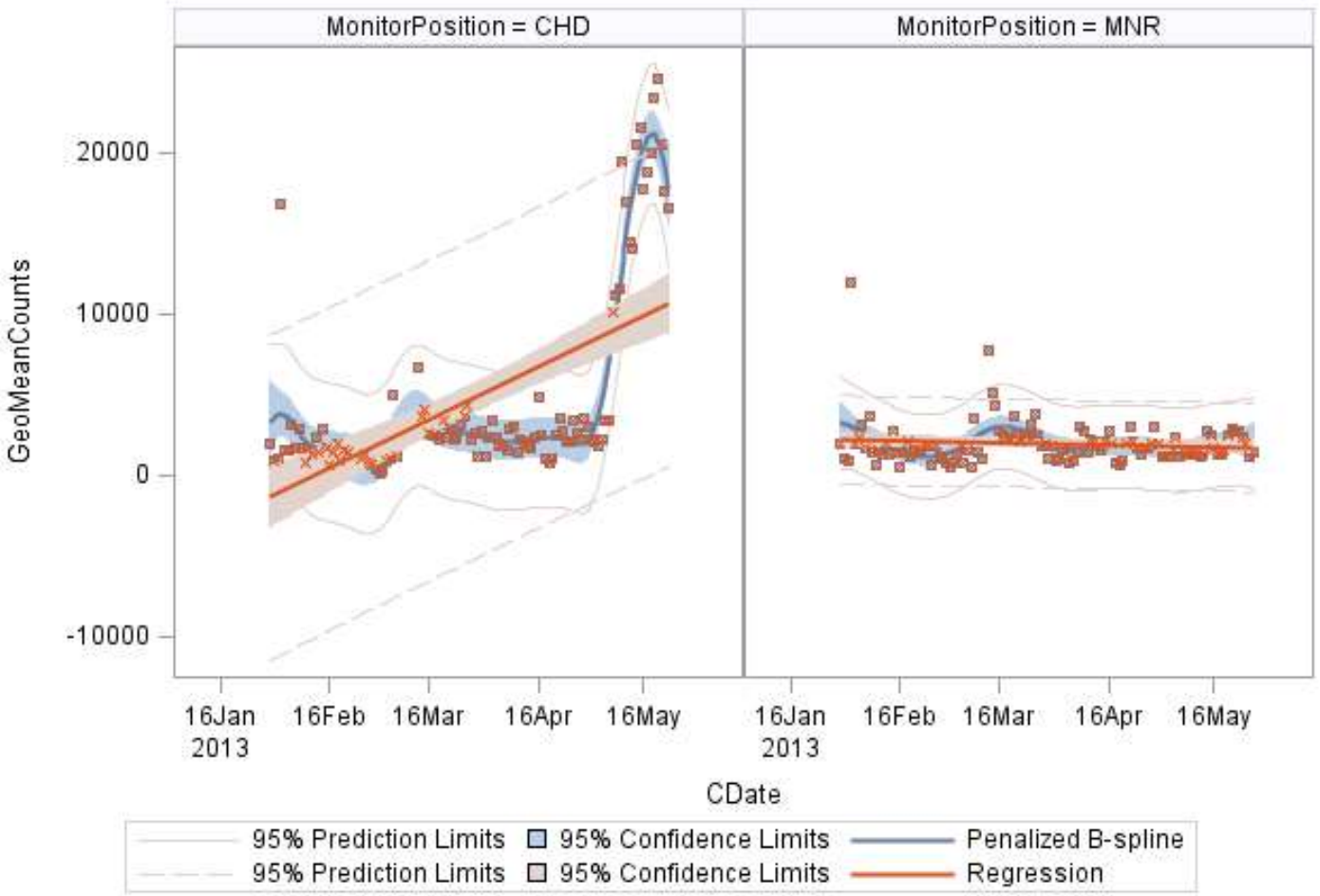

Figure 12. Control Home 12 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

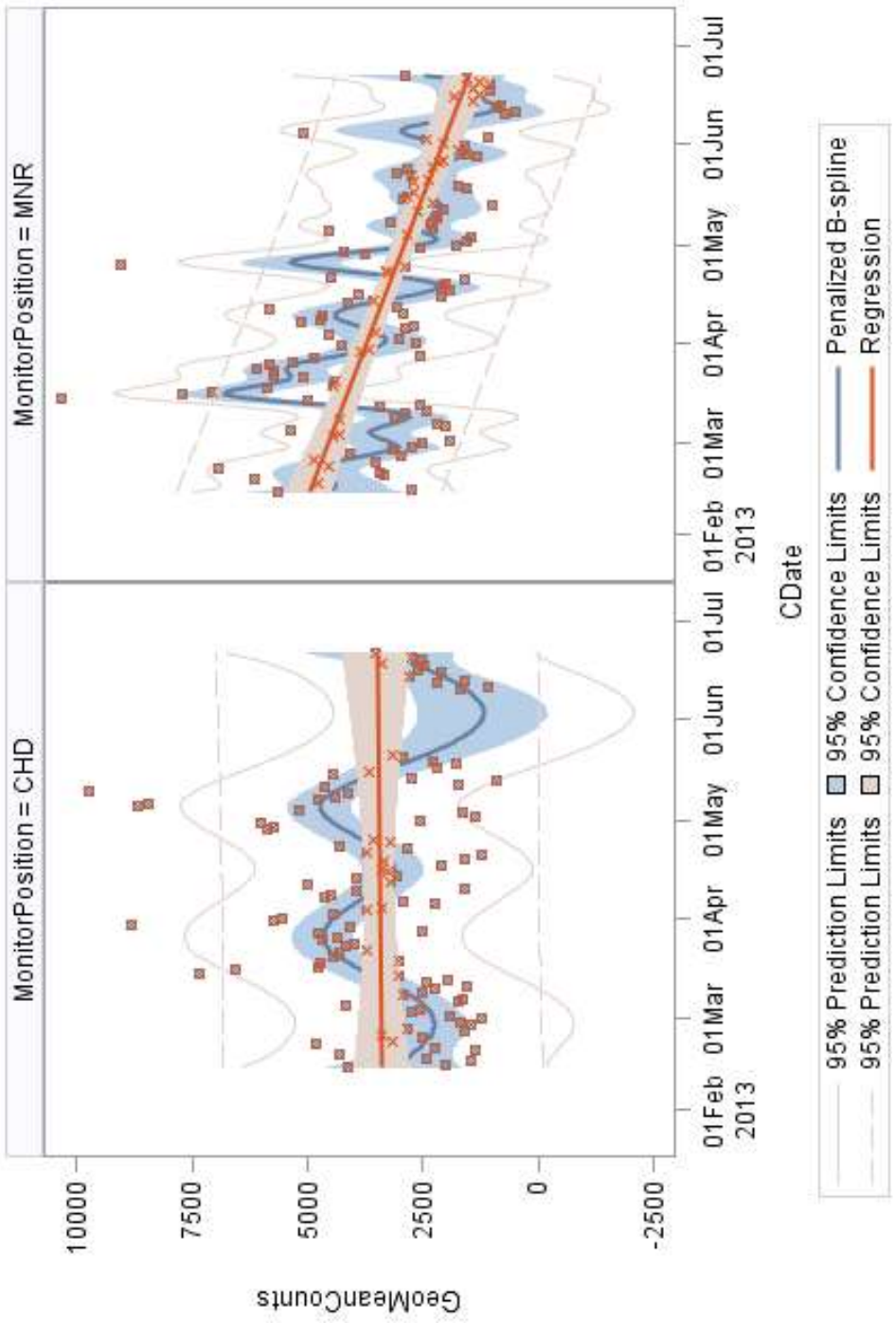

Figure 13. Control Home 13 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

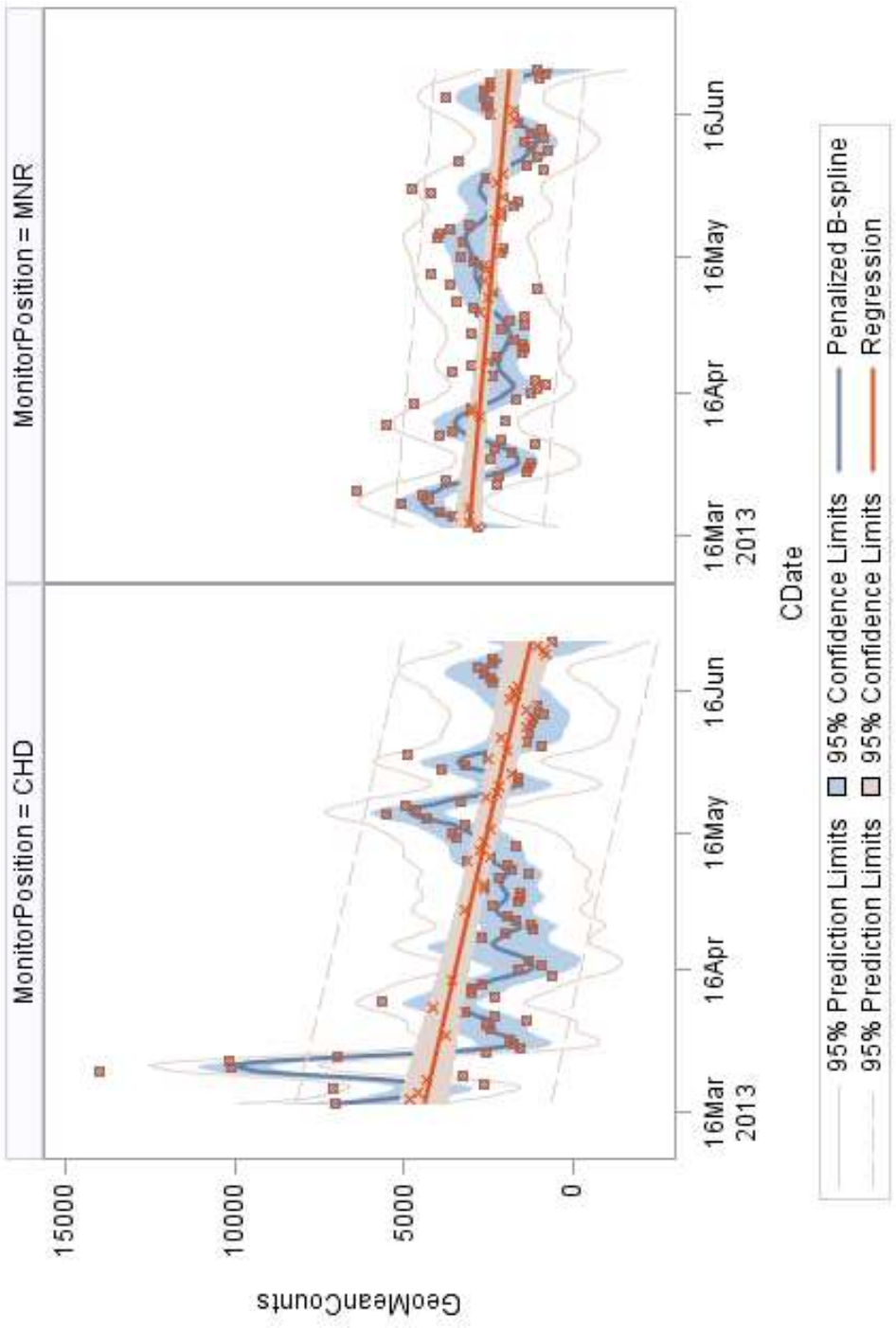

Figure 14. Control Home 14 – Daily Geometric Mean Particle Counts (GeoMeanCounts) Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

Table 5. Control Home Daily Geometric Mean Particle Counts across Time by Air Particle Monitoring Unit and by Home with All Available Data used in Multi-Level Mixed Model

	Child Room Monitor			**Main Room Monitor**		
	Estimate (SE)	P value		Estimate (SE)	P value	
Control Home 1	**6.00 (2.19)**	**0.0070**	*****	**8.48 (3.23)**	**0.0099**	*****
Control Home 2	**0.70 (5.98)**	**0.0003**	*****	0.76 (5.43)	0.8888	
Control Home 3	**6.90 (1.87)**	**0.0004**	*	**84.58 (10.41)**	**<.0001**	*****
Control Home 4	**-9.26 (3.79)**	**0.0168**	*****	28.68 (15.30)	0.0653	
Control Home 5	**105.92 (14.48)**	**<.0001**	*****	-3.85 (3.70)	0.3002	
Control Home 6	0.93 (4.72)	0.8846		**-27.03 (3.54)**	**<.0001**	*****
Control Home 7	**-31.33 (6.31)**	**<.0001**	*****	**-12.33 (3.75)**	**0.0014**	*****

*Significance ≤0.05

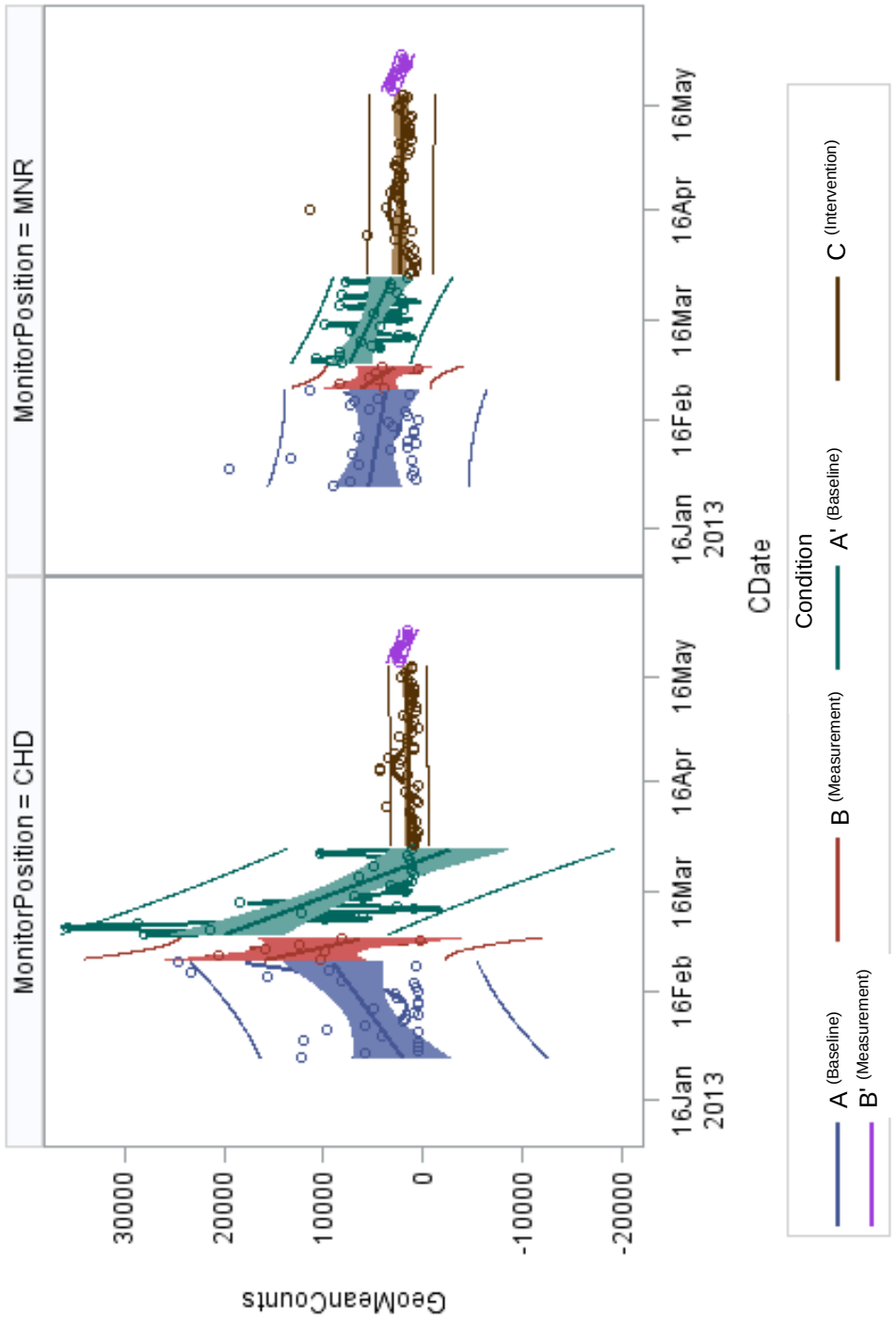

Figure 15. Experimental Home 1 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

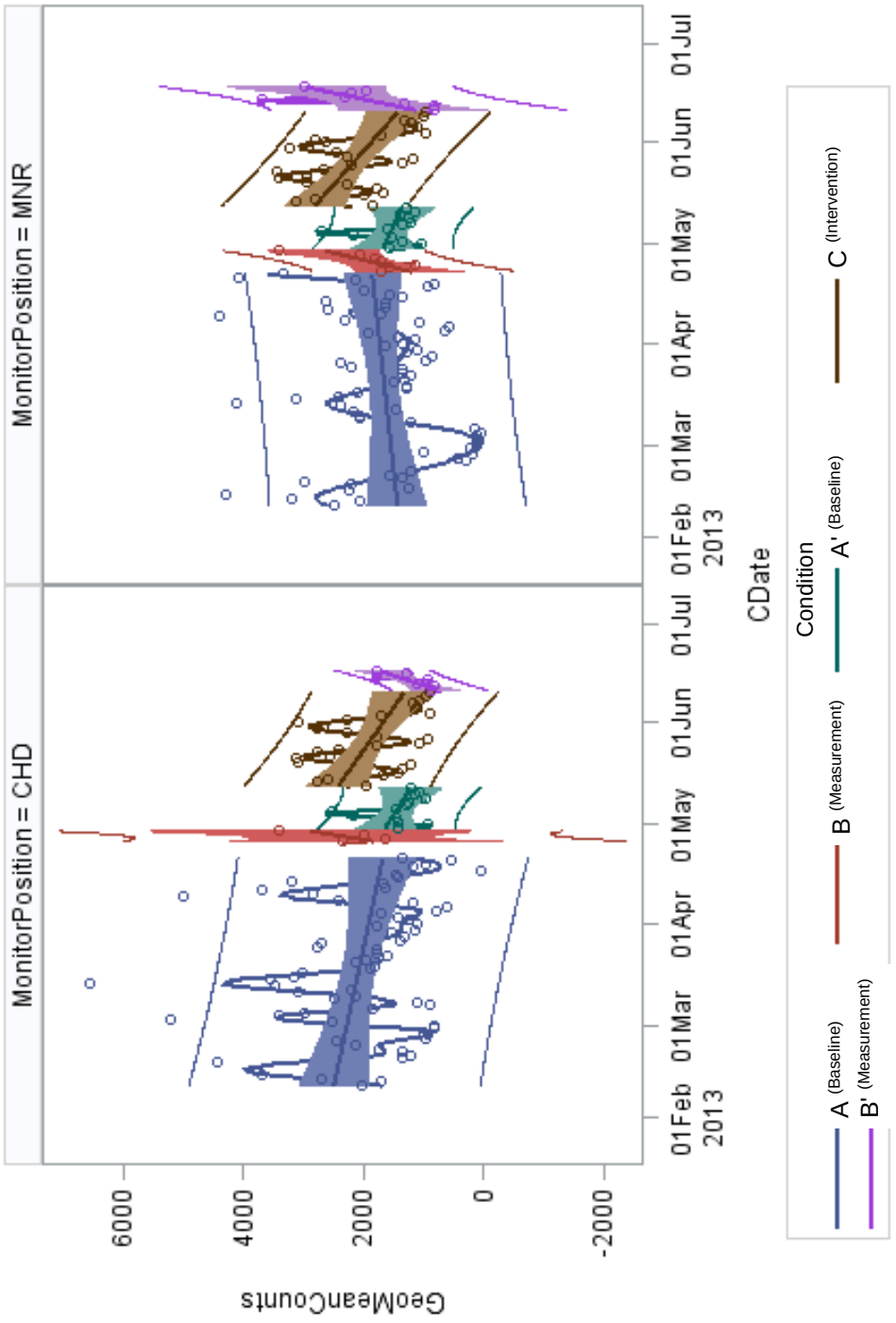

Figure 16. Experimental Home 2 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

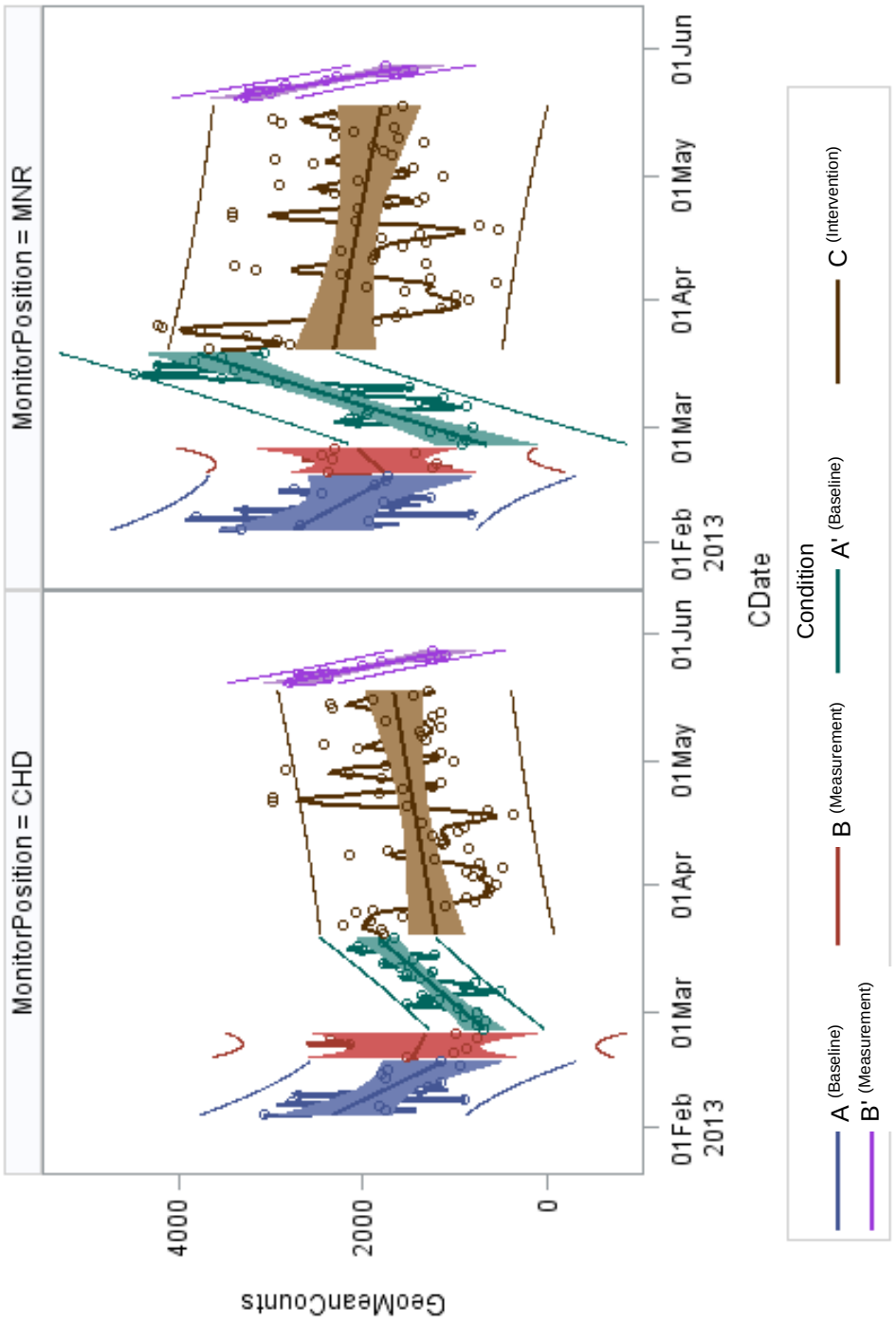

Figure 17. Experimental Home 3 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

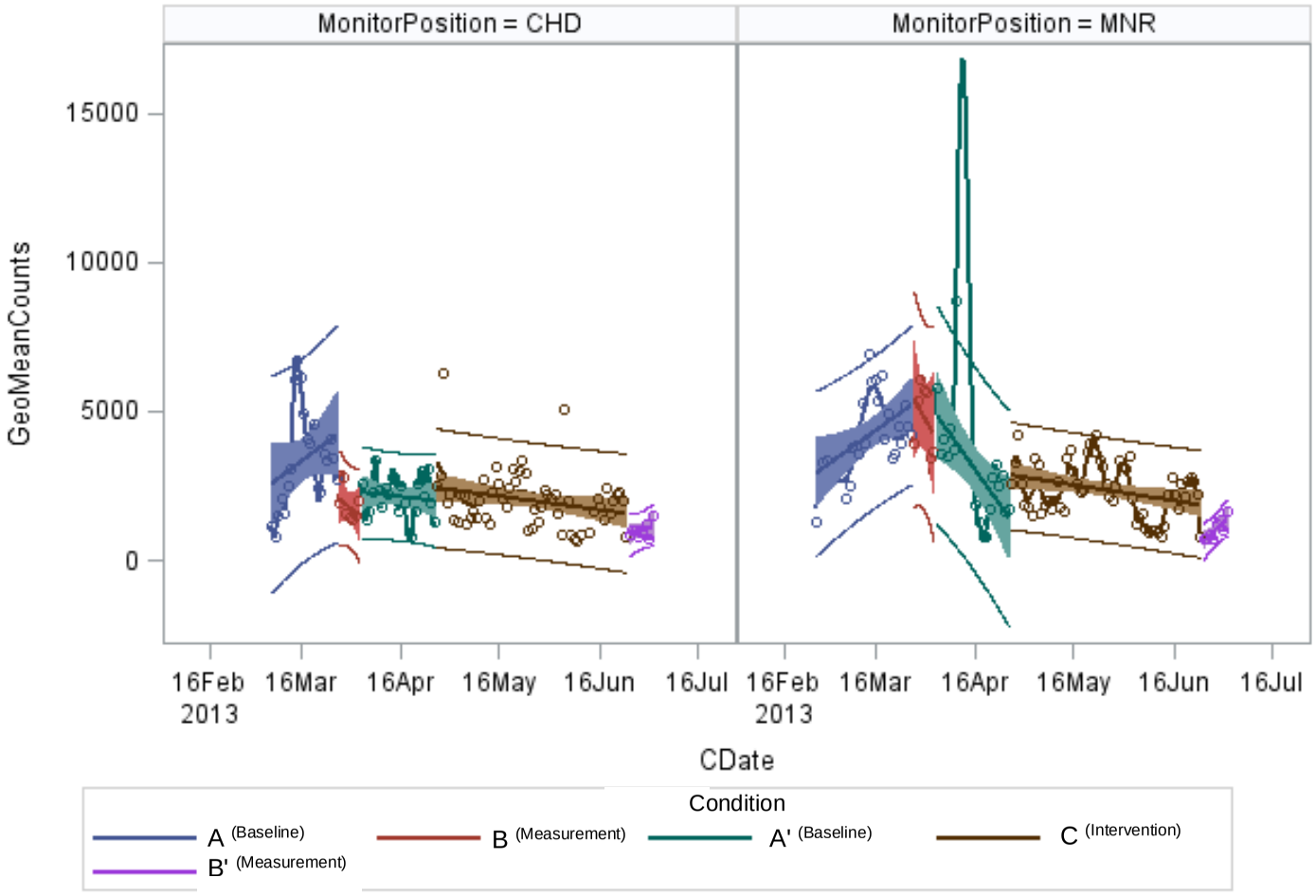

Figure 18. Experimental Home 4 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

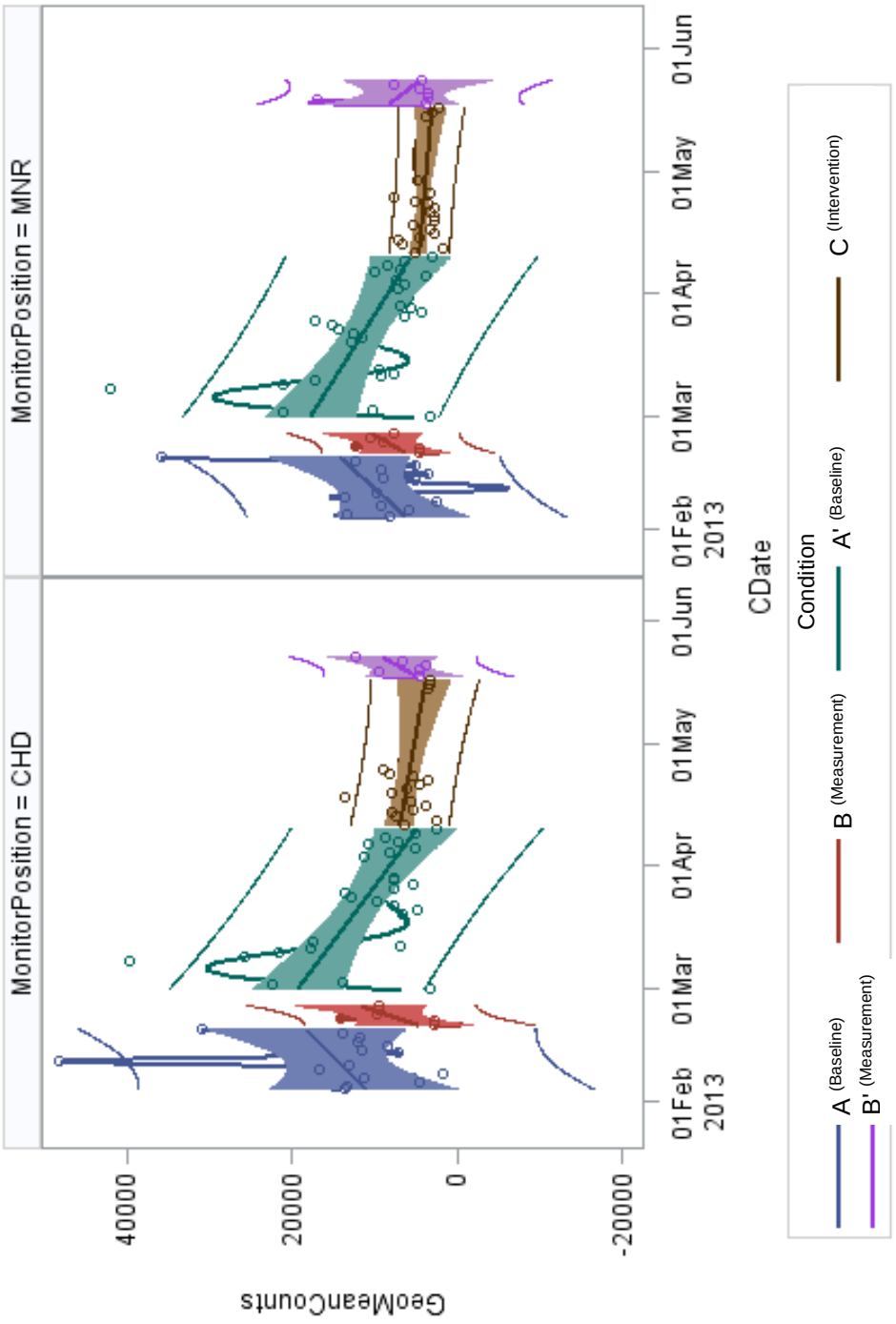

Figure 19, Experimental Home 5 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

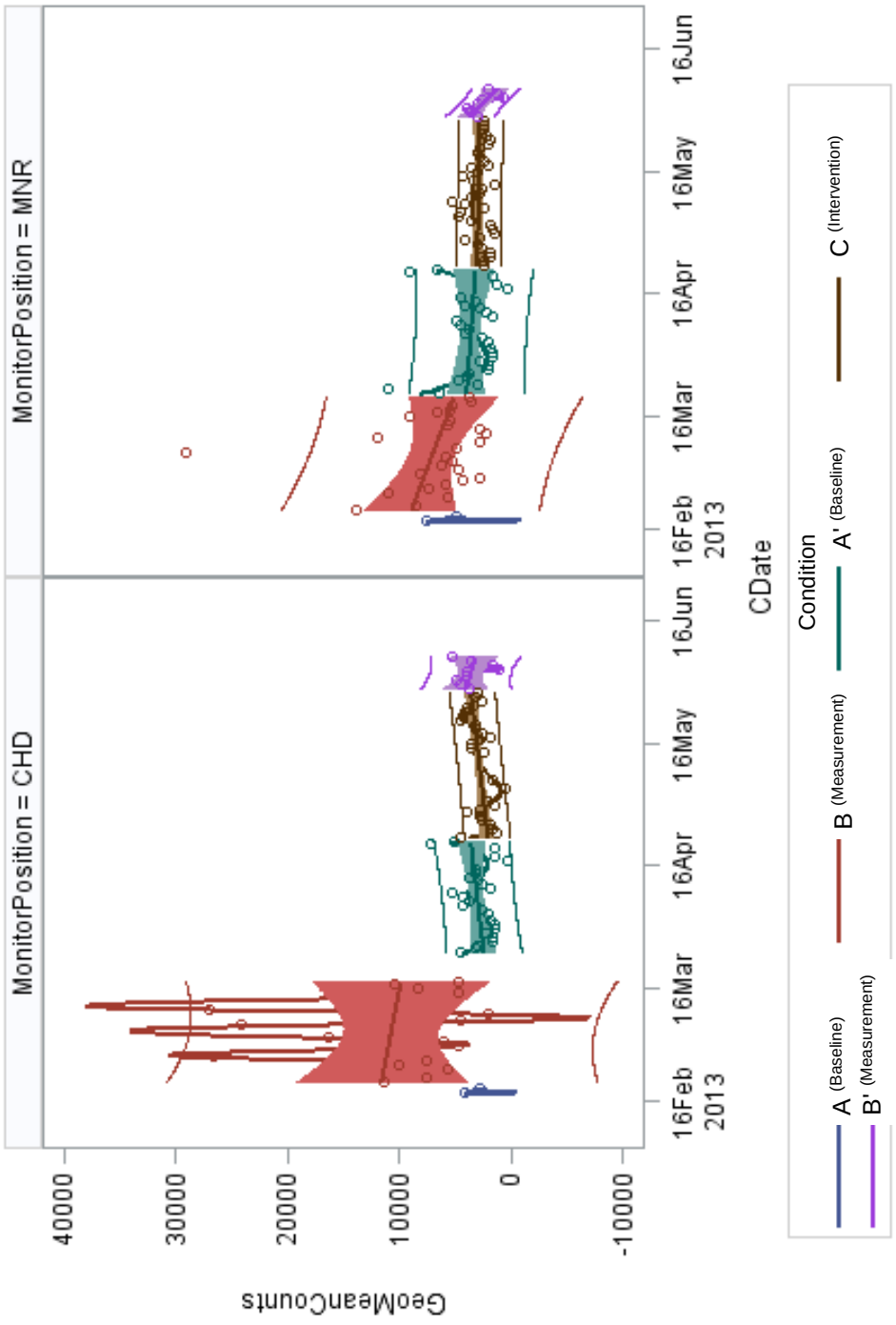

Figure 20. Experimental Home 6 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit
Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

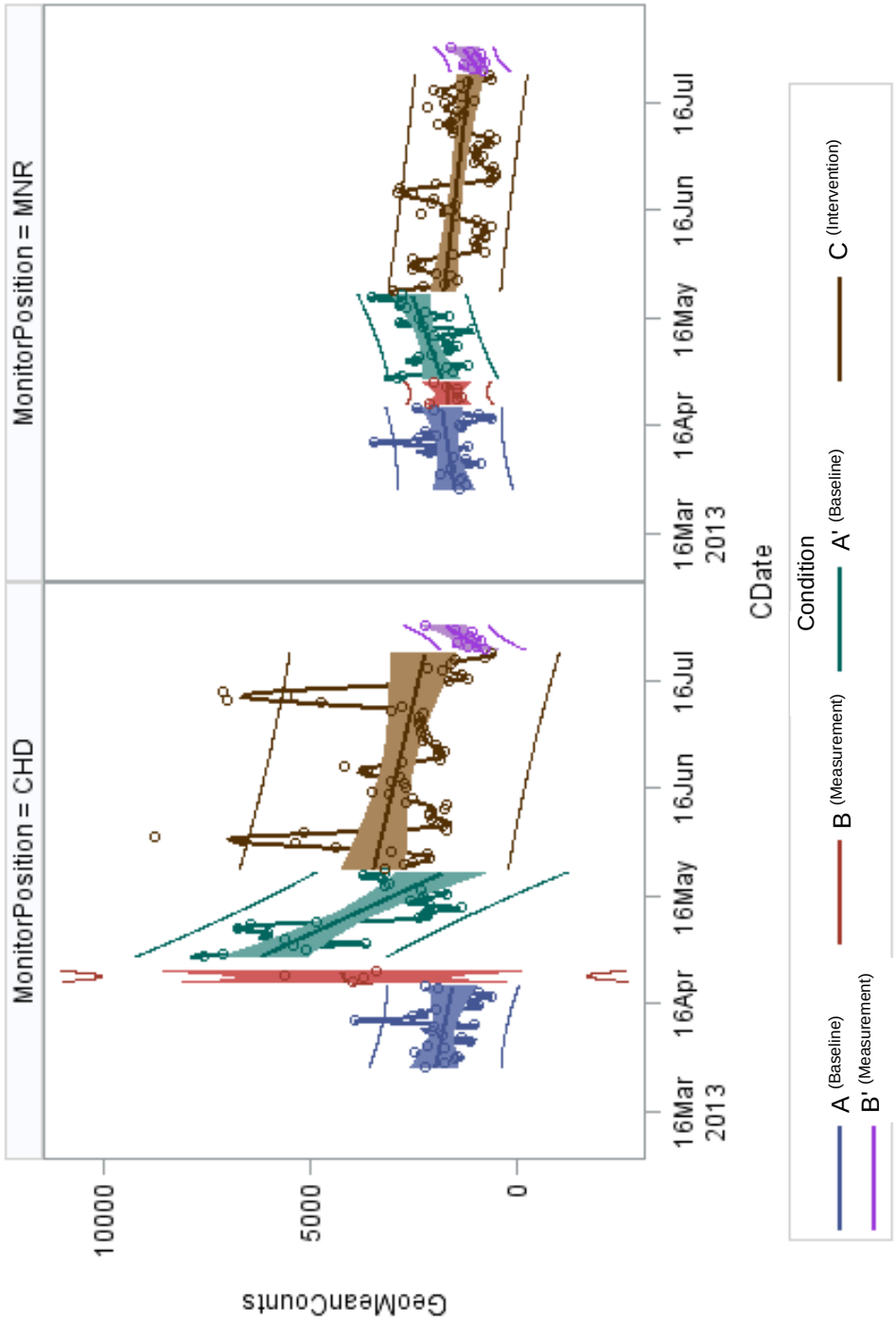

Figure 21. Experimental Home 7 – Daily Geometric Mean Particle Counts (GeoMeanCounts) by Condition Across Time (CDate) for each Air Particle Monitoring Unit Note: MontiorPosition CHD = Child's Room, MonitorPosition MNR = Main Smoking Room

Table 6a. Experimental Home Daily Geometric Mean Particle Counts Descriptive Data across Conditions by Air Particle Monitoring Unit with All Available Data used in Multi-Level Mixed Model Analyses

		Child Room Monitor[a]				Main Room Monitor[a]		
		Mean (SE)	Min	Max		Mean (SE)	Min	Max
Experimental Home 1	A	5453.68 (1106.50)	409.76	24568.64	A	4617.16 (532.08)	524.53	19483.82
	B	11086 (2331.00)	362.67	20555.55	B	4526.53 (1064.15)	556.19	8472.22
	A’	8572.66 (1171.01)	920.40	35615.23	A’	5145.89 (563.10)	1484.57	10812.56
	C	1435.33 (828.03)	406.19	4347.57	C	2180.91 (394.25)	696.49	11341.47
	B’	2107.45 (1851.53)	1344.59	2912.81	B’	2532.75 (394.25)	1633.77	3240.04
Experimental Home 2	A	2060.77 (122.33)	32.11	6544.17	A	1644.36 (112.39)	36.83	4396.56
	B	2345.50 (500.66)	1643.08	3402.67	B	1915.34 (350.31)	1131.67	3416.62
	A’	1412.01 (277.72)	939.22	2520.31	A’	1509.54 (257.05)	1029.05	2713.83
	C	1881.76 (185.94)	885.43	3133.17	C	2123.23 (172.11)	973.03	3449.43
	B’	1218.60 (378.46)	819.13	1773.60	B’	2016.58 (327.68)	824.68	3679.08
Experimental Home 3	A	1733.44 (161.15)	891.54	3072.75	A	2221.05 (245.18)	826.82	3806.97
	B	1389.63 (229.90)	774.01	2353.68	B	1905.01 (376.74)	1206.01	2454.60
	A’	1250.40 (125.73)	511.52	2055.56	A’	2219.78 (191.29)	813.74	4477.13
	C	1426.65 (77.84)	372.87	2986.09	C	2054.50 (118.43)	528.12	4222.23
	B’	1967.35 (200.99)	1112.94	2780.78	B’	2434.38 (305.80)	1449.14	3280.51
Experimental Home 4	A	3388.73 (227.65)	807.00	6688.87	A	4240.89 (246.52)	1289.83	6933.12
	B	1803.50 (394.30)	1392.69	2804.28	B	4833.95 (456.46)	3421.69	6085.45
	A’	2135.75 (217.53)	768.34	3366.84	A’	3050.79 (284.65)	766.06	8700.14
	C	2010.37 (138.18)	678.90	6314.46	C	2358.91 (157.23)	786.79	4245.84
	B’	1008.42 (368.94)	733.56	1505.96	B’	1027.75 (426.98)	727.67	1630.41
Experimental Home 5	A	14537 (1957.18)	1604.25	48204.21	A	10137 (1687.37)	2501.36	35758.79
	B	8063.05 (3094.57)	2719.51	14144.30	B	8064.21 (2577.50)	4453.73	12379.15
	A’	11509 (1458.80)	2432.52	39633.74	A’	10989 (1193.15)	3044.06	42072.06
	C	5933.72 (1786.65)	2388.35	13673.39	C	4072.64 (1411.75)	1777.42	7623.49
	B’	6840.30 (3094.57)	3802.72	12317.96	B’	6338.35 (2386.30)	3517.96	16934.67
Experimental Home 6	A	3388.91 (2716.63)	2717.38	4060.45	A	6219.66 (2165.67)	4939.33	7499.99
	B	10667 (931.80)	2092.11	27029.00	B	6967.86 (589.42)	2228.61	29111.21
	A’	2928.96 (753.46)	389.46	7207.06	A’	3601.86 (568.73)	389.66	11070.19
	C	2821.21 (726.05)	452.00	4481.83	C	2813.47 (503.51)	1468.47	5330.47
	B’	3602.82 (1280.63)	1110.49	5286.61	B’	2492.92 (1082.83)	762.90	3870.31
Experimental Home 7	A	1764.50 (301.59)	633.81	3905.13	A	1650.03 (127.85)	633.74	3455.41
	B	4183.69 (738.74)	3406.72	5631.62	B	1658.57 (236.74)	1354.28	2136.44
	A’	4010.55 (295.50)	1375.95	7567.02	A’	2171.33 (125.27)	1114.00	3495.73
	C	2869.42 (190.74)	645.82	8744.06	C	1443.00 (79.55)	505.40	3014.52
	B’	1289.89 (522.37)	790.62	2216.50	B’	1096.07 (221.45)	795.73	1607.76

[a]Calculated using least-squares means regression adjusted for condition and individual homes

Table 6b. Estimated Difference in Experimental Home Daily Geometric Mean Particle Counts between Conditions by Air Particle Monitoring Unit with All Available Data used in Multi-Level Mixed Model Analyses

	Child Room Monitor Adjusted Difference[b] (SE)		*P* value		Main Room Monitor Adjusted Difference[b] (SE)		*P* value	
	Cond.	Mean (SE)			Cond.	Mean (SE)		
Experimental Home 1	**A vs B**	-5632.15 (2474.21)	0.0247	*	**A vs B**	90.63 (1189.76)	0.9394	
	A vs A'	-3118.98 (1611.09)	0.0553		**A vs A'**	-528.73 (774.71)	0.4963	
	A vs C	4018.35 (1382.02)	0.0044	*	**A vs C**	2436.26 (662.22)	0.0004	*
	A' vs C	1700.07 (1145.98)	0.1449		**A' vs C**	2964.99 (687.39)	<.0001	*
Experimental Home 2	**A vs B**	-284.74 (515.39)	0.5819		**A vs B**	-270.98 (367.89)	0.4628	
	A vs A'	648.75 (303.47)	0.0346	*	**A vs A'**	134.82 (280.55)	0.6317	
	A vs C	179.01 (222.57)	0.4229		**A vs C**	-478.87 (205.56)	0.0215	*
	A' vs C	-469.75 (334.22)	0.1626		**A' vs C**	-613.69 (309.35)	0.0496	*
Experimental Home 3	**A vs B**	343.81 (279.12)	0.2207		**A vs B**	316.04 (424.67)	0.4584	
	A vs A'	483.04 (204.39)	0.0199	*	**A vs A'**	1.2765 (310.98)	0.9967	
	A vs C	306.78 (178.96)	0.0894		**A vs C**	166.55 (272.29)	0.5420	
	A' vs C	-176.26 (147.87)	0.2359		**A' vs C**	165.28 (224.99)	0.4642	
Experimental Home 4	**A vs B**	1585.23 (455.30)	0.0007	**	**A vs B**	-593.06 (518.78)	0.2554	
	A vs A'	1252.97 (314.97)	0.0001	*	**A vs A'**	1190.10 (376.56)	0.0020	*
	A vs C	1378.36 (266.30)	<.0001		**A vs C**	1881.98 (292.39)	<.0001	*
	A' vs C	125.38 (257.70)	0.6275		**A' vs C**	691.89 (325.19)	0.0356	*
Experimental Home 5	**A vs B**	6474.17 (3661.55)	0.0816		**A vs B**	2072.39 (3080.70)	0.5034	
	A vs A'	3028.51 (2441.03)	0.2191		**A vs A'**	-851.91 (2066.60)	0.6814	
	A vs C	8603.50 (2650.04)	0.0018	*	**A vs C**	6063.96 (2200.06)	0.0074	*
	A' vs C	5574.99 (2306.56)	0.0184	*	**A' vs C**	6915.87 (1848.42)	0.0004	*
Experimental Home 6	**A vs B**	-7277.81 (2871.99)	0.0133	*	**A vs B**	138.30 (956.31)	0.7895	
	A vs A'	459.96 (2819.18)	0.8708		**A vs A'**	-76.20 (469.72)	0.8719	
	A vs C	567.70 (2811.98)	0.8405		**A vs C**	1668.55 (595.87)	0.0075	*
	A' vs C	107.47 (1046.35)	0.9183		**A' vs C**	1744.75 (586.28)	0.0047	*
Experimental Home 7	**A vs B**	-2419.20 (797.93)	0.0030	*	**A vs B**	-8.54 (269.05)	0.9747	
	A vs A'	-2246.06 (422.22)	<.0001	*	**A vs A'**	-521.30 (178.99)	0.0043	
	A vs C	-1104.92 (356.84)	0.0025	*	**A vs C**	207.03 (150.58)	0.1717	*
	A' vs C	1141.13 (351.71)	0.0015	*	**A' vs C**	728.33 (148.39)	<.0001	*

[b]Difference in least square mean values between phases adjusted for phase and individual homes
*Significance ≤0.05

Table 7a. Control Home Daily Geometric Mean Particle Counts Descriptive Data across Conditions by Air Particle Monitoring Unit with All Available Data used in Multi-Level Mixed Model Analyses

		Child Room Monitor[a]				Main Room Monitor[a]		
		Mean (SE)	Min	Max		Mean (SE)	Min	Max
Control Home 1	A	1578.48 (97.85)	377.97	4418.99	A	2287.55 (145.27)	536.48	5893.45
	B	1964.21 (302.64)	1231.10	3106.16	B	2673.28 (449.42)	1742.15	3859.27
	A’	1953.83 (1744.10)	580.47	4245.81	A’	2884.0 1 (200.99)	4663.92	970.82
	B’	1744.10 (302.64)	746.66	3025.87	B’	2007.04 (420.39)	1089.94	3371.14
Control Home 2	A	5442.67 (462.91)	2466.42	8601.93	A	5075.14 (421.92)	2227.41	8256.52
	B	2282.00 (654.70)	1079.98	3805.87	B	1952.78 (596.69)	891.63	3398.98
	A’	3911.19 (198.69)	832.93	8550.27	A’	3363.19 (181.09)	686.48	9535.85
	B’	5260.20 (612.41)	3410.88	7221.84	B’	4338.51 (526.23)	2838.05	5400.40
Control Home 3	A	1123.92 (135.32)	610.82	1858.88	A	1441.71 (962.55)	810.64	2474.21
	B	1214.64 (210.89)	643.46	2108.21	B	1429.98 (1500.03)	667.40	2567.53
	A’	1353.55 (76.64)	438.38	2959.64	A’	5587.17 (452.28)	987.79	17474.42
	B’	1902.27 (249.53)	1125.49	2495.54	B’	2415.12 (1620.22)	1381.40	3550.05
Control Home 4	A	2487.71 (153.04)	933.13	4044.01	A	2088.07 (573.79)	746.56	3360.61
	B	1063.60 (330.61)	444.90	1928.91	B	1630.56 (1405.50)	758.54	2940.38
	A’	1579.69 (122.09)	135.40	3421.07	A’	3681.64 (523.80)	183.00	19640.16
	B’	1495.40 (330.61)	830.08	2402.80	B’	1262.62 (3142.79)	1262.62	1262.62
Control Home 5	A	2698.14 (1455.47)	784.89	16793.59	A	2447.58 (353.06)	688.64	11957.46
	B	1565.12 (2301.30)	636.56	2895.52	B	1529.17 (558.23)	496.18	2733.07
	A’	4887.54 (622.50)	146.23	24540.77	A’	1872.02 (144.94)	450.46	7748.33
	B’	18196 (3254.53)	16567.73	20487.25	B’	2149.63 (516.82)	1167.12	2834.53
Control Home 6	A	2698.14 (1455.47)	1209.62	7352.51	A	4275.51 (251.91)	1932.18	10338.27
	B	1565.12 (2301.30)	2528.22	4789.04	B	5158.66 (519.32)	2548.41	6095.93
	A’	4887.54 (622.50)	889.00	9757.69	A’	2835.43 (176.83)	477.89	9068.78
	B’	18196 (3254.53)	1617.13	3535.19	B’	1457.12 (464.49)	791.99	2882.23
Control Home 7	A	5076.05 (419.50)	1570.43	13974.28	A	3070.68 (262.69)	1223.51	6371.70
	B	3127.41 (672.69)	1343.56	5646.78	B	2999.49 (421.25)	1101.62	5538.84
	A’	2271.28 (220.75)	637.45	5513.45	A’	2298.26 (134.17)	720.58	4744.01
	B’	1679.19 (629.25)	604.23	2792.89	B’	2014.76 (421.25)	806.23	3749.92

[a]Calculated using least-squares means regression adjusted for condition and individual homes

Table 7b. Estimated Difference in Experimental Home Daily Geometric Mean Particle Counts between Conditions by Air Particle Monitoring Unit with All Available Data used in Multi-Level Mixed Model Analyses

	Child Room Monitor Adjusted Difference[b] (SE)		*P* value		Main Room Monitor Adjusted Difference[b] (SE)		*P* value	
	Phases	Mean (SE)			Phases	Mean (SE)		
Control	A vs B	-385.74 (318.05)	0.2278		A vs B	-385.74 (472.31)	0.4158	
Home 1	**A vs A'**	**-375.35 (166.99)**	**0.0266**	*	**A vs A'**	-596.45 (247.99)	**0.0178**	*
Control	A vs B	-90.72 (250.57)	0.7183		A vs B	11.73 (1782.30)	0.9948	
Home 2	**A vs A'**	-229.63 (155.52)	0.1438		A vs A'	-4145.46 (1063.51)	**0.0002**	*
Control	A vs B	**3160.66 (801.84)**	**0.0001**	*	**A vs B**	-385.74 (318.05)	0.2278	
Home 3	**A vs A'**	**1531.47 (503.78)**	**0.0030**	*	**A vs A'**	-375.35 (166.99)	**0.0266**	*
Control	A vs B	**1424.12 (364.32)**	**0.0002**	*	**A vs B**	457.52 (1518.11)	0.7641	
Home 4	**A vs A'**	**911.02 (195.77)**	**<.0001**	*	**A vs A'**	-1593.57 (776.92)	**0.0441**	*
Control	A vs B	1133.02 (2722.93)	0.6782		A vs B	918.41 (575.56)	0.1671	
Home 5	A vs A'	-2189.40 (1538.00)	0.1697		A vs A'	575.56 (381.65)	0.1343	
Control	A vs B	-1121.89 (656.56)	0.0905		A vs B	-883.15 (577.19)	0.1287	
Home 6	**A vs A'**	**-827.14 (362.26)**	**0.0245**	*	**A vs A'**	**1440.09 (307.77)**	**<.0001**	*
Control	A vs B	**1948.64 (792.77)**	**0.0158**	*	**A vs B**	71.20 (496.45)	0.8863	
Home 7	**A vs A'**	**2804.77 (474.04)**	**<.0001**	*	**A vs A'**	**775.42 (294.98)**	**0.0100**	*

[b]Difference in least square mean values between phases adjusted for condition and individual homes
*Significance ≤0.05

Table 8. Validation Correlations between Average Daily Mean Log Particle Counts and Environmental and Biological Measures of SHS and THS

	Main Room Monitor		*P* value	
	N	R		
Complete Ban [a,1]	26	-0.1575	0.591	
Number of Cigarettes[b,1]	26	-0.2057	0.481	
Urine Cotinine [b,1]	**35**	**0.6336**	**0.015**	*****
Air Nicotine [b,1]	39	0.4455	0.110	
Child Level Nicotine Wipe [b,1]	9	-0.3108	0.845	
Adult Level Nicotine Wipe [b,1]	10	-0.4330	0.604	

[a]Dichotomous, [b]Continuous
[1]One Week Measurement(s)
*Significance ≤0.05

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