Cache Valley Resident Exposure to PM2.5

Kristina Krepinski
Utah State University

CACHE VALLEY RESIDENT EXPOSURE TO $PM_{2.5}$

by

Kristina Krepinski

**Thesis submitted in partial fulfillment
of the requirements for the degree**

of

UNIVERSITY HONORS

in

**Biology (Human Emphasis)
in the Department of Biology**

Approved:

Capstone Mentor Dr. Michael Lefevre	**Committee Member** Dr. Randal Martin
Departmental Honors Advisor Dr. Heidi Wengreen	**Director of USU Honors Program** Dr. Kristine Miller

**UTAH STATE UNIVERSITY
Logan, UT**

Summer 2017

ABSTRACT

Air pollution poses one of the largest environmental risks to human health, and greatly contributes to increased mortality within populations. Of the different types of pollutants, fine particulate matter ($PM_{2.5}$) has the most adverse health effects. Long-term exposure to $PM_{2.5}$ is known to have serious health outcomes; however, evidence has indicated that even short-term exposure to moderate concentrations of $PM_{2.5}$ is detrimental to human health. While $PM_{2.5}$ does contribute to various respiratory conditions by affecting lung function, it also significantly affects the cardiovascular system. Elevated $PM_{2.5}$ exposure increases risk for cardiovascular disease, congestive heart failure, and cardiac arrhythmias. To assess risk for these conditions, $PM_{2.5}$ exposure levels must be accurately measured. This is most commonly done through centrally located air monitoring stations that are dispersed throughout the U.S. In Utah, these stations are managed by the state's Department of Environmental Quality (DEQ) and they collect hourly $PM_{2.5}$ readings 24/7. It is believed that $PM_{2.5}$ level readings obtained from the DEQ do not accurately reflect personal exposure to the pollutant. Without accurate measurements of $PM_{2.5}$ exposure, it is not possible to elucidate the role $PM_{2.5}$ plays in lung and cardiovascular functional decline. This study aimed to determine whether published DEQ data strongly correlates to individual's exposure to $PM_{2.5}$ by comparing readings from personal air monitors. We hypothesized that both within and across a population of individuals, the personal air monitor $PM_{2.5}$ readings would correlate poorly with the published $PM_{2.5}$ concentrations. For the study, 20 volunteer residents of Cache Valley wore an AirBeam personal environmental monitor for a period of 8-10 hours as they went about their typical days. The AirBeam $PM_{2.5}$ readings from each individual were adjusted using calibration equations to account for inter-instrument variability and deviations in accuracy from the DEQ monitors. The hourly averages of the

corrected values were then compared to the published DEQ data for the specific time frame the monitors were worn. For each participant, the DEQ data was plotted against the recorded AirBeam readings and linear regression equations were generated for each of the correlation graphs. Within subject R^2 values from all 20 correlation graphs were low, with an average of 0.10 ± 0.02 and range from 0.004 to 0.38. These low values indicate that within the group of volunteers, the DEQ published data did not accurately reflect individual $PM_{2.5}$ hourly exposures. Additionally, plotting the daily DEQ averages versus the AirBeam daily $PM_{2.5}$ averages generated a linear regression equation with a between subject R^2 value of 0.27. This, too, exhibited a moderately low R^2 value, which demonstrates a poor correlation between the DEQ and AirBeam data across subjects. These findings illustrate a need for the use of personal environmental monitors to accurately assess individual $PM_{2.5}$ exposure levels and possible cause and effect relationships to certain health outcomes.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to Dr. Michael Lefevre for taking me under his wing and helping me grow and learn. Thank you for teaching me all about $PM_{2.5}$ and its significance in this world, and for always being kind and understanding when I broke and/or lost certain items. The AirBeam devices and smartphones utilized in this project were provided by Dr. Lefevre's research lab, and were vital to the completion of this project. I would also like to thank Dr. Randal Martin for being willing to get involved as a committee member, to Janet Bergeson for helping Dr. Lefevre and I throughout this whole process (and for being a great comfort during my mini mental breakdowns), and to the volunteers willing to participate in this study. Without all these individuals, this project would never have been completed.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

In December of 1952, stagnant weather patterns lead to a dramatic increase in pollutant concentration in London, UK (Brunekreef and Holgate, 2002). A thick cloud of lethal smog settled over the city that remained for a period of several days. Sharp increases in morbidity and mortality immediately followed, with reported deaths triple the expected amount (Brunekreef and Holgate, 2002; Bell et al., 2004). Elevated mortality in the following months, previously believed to be attributed to an influenza outbreak, were determined to also be from lingering effects of the smog, reaching an overall estimated death toll of approximately 12,000 (Bell and Davis, 2001; Bell et al., 2004). The evident association between rising air pollution levels and mortality in this and several similar events prompted the development of measures like the Clean Air Act to promote public health and environmental protection (U.S. Environmental Protection Agency, 2017).

Air quality conditions have improved since that time; however, pollution remains one of the largest environmental risks to human health. An estimated 3 million deaths each year are attributed to ambient air pollution, and 6.5 million deaths were linked to both indoor and outdoor pollution (World Health Organization, 2016). Air pollution consists of various components, including volatile organic compounds and gaseous pollutants such as carbon monoxide, nitrogen oxides, sulfur dioxide and ozone (Bourdrel et al., 2017). Another important pollutant is particulate matter (PM). PM is a mixture of small particles that are suspended in the air (Yang et al., 2017). These particles can originate from either natural sources such as sea spray, pollen, dust, smoke from brushfires or it can develop from human activity, including vehicle emissions, household fuel, or industrial processes (Australian Government..., 2005). PM is classified by the aerodynamic diameter (size) of the particles into three main categories: "coarse" PM_{10} ($\leq 10\ \mu m$),

Figure 1. Particulate matter size. Particulate matter is divided into coarse (≤ 10 µm), fine (< 2.5 µm), and ultrafine (< 0.1 µm) particles. Approximately 5 PM_{10} molecules span the width of a human hair, and 4 $PM_{2.5}$ molecules fit the diameter of one particle of PM_{10}. Image taken from the U.S. Environmental Protection Agency.

"fine" $PM_{2.5}$ (< 2.5 µm), and "ultrafine" $PM_{0.1}$ (< 0.1 µm) (Yang et al., 2017; U.S. Environmental Protection Agency, 2017). Fine particulate matter ($PM_{2.5}$) appears to have the most serious health affects due to its ability stay suspended for longer periods of time and to penetrate the lungs and bloodstream (World Health Organization, 2016; Pope and Dockery, 2006).

Inhalation of $PM_{2.5}$ is associated with various health conditions. Several cohort studies found that elevated $PM_{2.5}$ exposure was linked to increased risk for lung cancer, and each 10-µg/m^3 rise in $PM_{2.5}$ concentration corresponded to an approximately 4%, 6%, and 8% elevated risk for all-cause, cardiopulmonary, and lung cancer-related mortality, respectively (Gharibvand et al., 2017; Pope et al., 2002). The Air Pollution and Health: a European Approach 2 Project also determined a positive association between elevated particle concentrations and number of hospital admissions for asthma, chronic obstructive pulmonary disorder (COPD) and other respiratory diseases (Atkinson et al., 2001). In addition to the respiratory effects, elevated air pollution was found to cause neuroinflammation and accumulation of amyloid β 42, both of which are early biomarkers for Alzheimer's and Parkinson's disease (Calderón-Garcideuñas et al., 2008; Wu et al., 2015). Another significant effect from $PM_{2.5}$ is on the cardiovascular system (Brook et al., 2010). Several meta-analyses have found notable increases in cardiovascular mortality in response to $PM_{2.5}$ exposure, an effect more strongly associated than mortality from respiratory diseases (Bourdrel et al., 2017; Hoek et al., 2013). Rises in $PM_{2.5}$ have additionally been found to increase the risk of and/or exacerbate myocardial infarction (MI), cardiovascular disease, cardiac arrhythmias, and congestive heart failure (Peters et al., 2001; Nawrot et al., 2011; Brook et al., 2010).

Although mechanistic details of how $PM_{2.5}$ contributes to these conditions are not completely known, existing data has identified several highly plausible biological pathways. Among these pathways is the release of proinflammatory cytokines induced by oxidative stress, leading to consequences such as systemic inflammation, increased blood coagulability, vascular dysfunction, and atherosclerosis (Brook et al., 2004; Brook et al., 2010; Pope and Dockery, 2006). One study specifically found that $PM_{2.5}$ exposure induced significant gene upregulation of receptors for interleukin 1 and 6 (IL-1 and IL-6), activating a signaling pathway to the inflammatory response (Watterson et al., 2007). Multiple studies have also determined a link between $PM_{2.5}$ and the synthesis of C-reactive protein, a biomarker of inflammation that is strongly associated with increased cardiovascular disease risk (Yang et al., 2017; Brook et al., 2004). While many biomarkers and possible pathways have been discovered, no single mechanism is known to be responsible for the health outcomes from exposure to $PM_{2.5}$ (Yang et al., 2017).

An important concern about $PM_{2.5}$ is that adverse health effects are not only observed with long-term elevated levels. Multiple studies have found that although the most serious health outcomes are from long-term $PM_{2.5}$ exposure, there is evidence of autonomic dysfunction as well as acute cardiovascular morbidity and mortality associated with short-term exposure (Brook et al., 2004; Atkinson et al., 2014; Rich et al., 2016). Moreover, these health effects were observed with concentrations below published guidelines and regulations (Brunekreef et al., 1995; Brook et al., 2004). No study has been able to determine a threshold level of $PM_{2.5}$ to which there are no health effects; however, a dose-dependent relationship between $PM_{2.5}$ exposure and health risk has been established (Johnson and Graham, 2005; Pope and Dockery, 2006).

To assess the risk for all the previously discussed health conditions, exposure levels need to be determined. Most studies use $PM_{2.5}$ concentrations that are measured and reported hourly or daily from centrally located air monitoring stations (classified as ambient fixed-site monitors) (Brunekreef and Holgate, 2002; Yin et al., 2017). In Utah, the government's Department of Environmental Quality (DEQ) manages the fixed-site monitoring stations in the state (Utah Department of Environmental Quality, 2017). A substantial limitation to this method of collection, however, is that it assumes that the $PM_{2.5}$ levels present at the fixed-site monitor is representative of exposure levels for all individuals within a population (Brunekreef and Holgate, 2002). Many researchers believe that the variable spatial and temporal characteristics make fixed-site monitoring inadequate for measuring personal $PM_{2.5}$ exposure levels (Yin et al., 2017). To obtain more accurate estimates of individual $PM_{2.5}$ exposure, portable air pollution monitors have become increasingly utilized (McKercher et al., 2017).

Cache Valley in northern Utah/southern Idaho is known for terrible inversions during the winter. In January of 2004, a $PM_{2.5}$ concentration of 132.5 $\mu g/m^3$ was recorded, a value that far exceeded the U.S. Environmental Protection Agency's National Ambient Air Quality Standard (NAAQS) of 35 μg/m^3, and is considered the "worst ever" PM pollution episode in the country (Malek et al., 2006). One of the rationales behind this study centers on the potential for minor elevations in $PM_{2.5}$ (but levels still considered in the "healthy range") to contribute to adverse health. By studying lower ranges (concentrations that are typically experienced throughout the year), it may be particularly important to obtain accurate measures of personal $PM_{2.5}$ exposure to assess its impact (or lack thereof) on health. Like other environmental researchers, we speculate that the fixed-site reports are not adequate representations of individual $PM_{2.5}$ exposure. The aim of this study, therefore, was to determine if $PM_{2.5}$ concentrations reported by the monitor station in Cache Valley are indeed representative of individual exposure or if personal environmental monitors are necessary to accurately assess risk for air pollution-related health conditions and mortality.

MATERIALS AND METHODS

The AirBeam

Small, low-cost personal air environmental monitors have become commercially available in the last decade to facilitate collection of individual air pollution exposure. For this

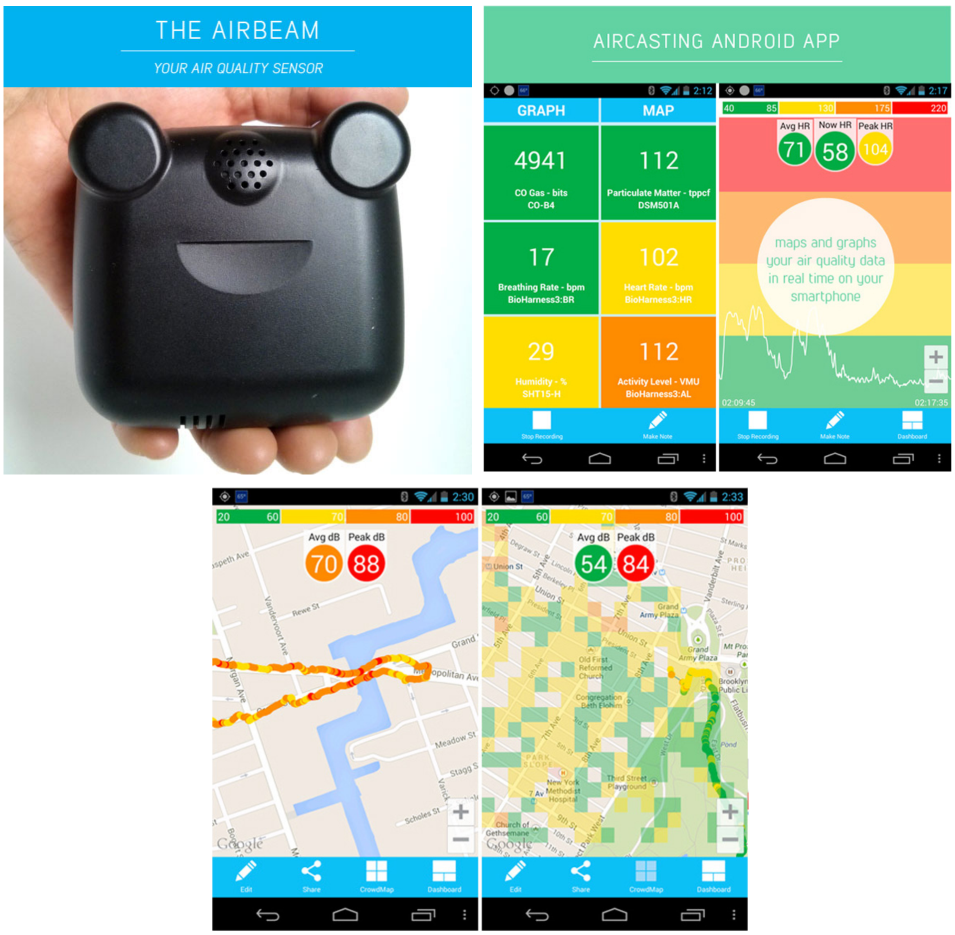


Figure 2. AirBeam and AirCasting app. The AirBeam personal air monitor collects surrounding air and using light scatter technology measures the concentration of $PM_{2.5}$ in the air. The data is sent to the AirCasting Android app, which graphs and maps the data. Image taken from the AirCasting website.

study, we used the AirBeam personal environment monitor developed from the non-profit organization HabitatMap. The AirBeam is a palm-sized device which draws air from the surrounding environment into the machine, wherein LED light is scattered off the particles (HabitatMap, 2017). A detector registers the light scatter and converts it into an estimated measurement of particle concentration in the air. These measurements are communicated via Bluetooth to the AirCasting Android smartphone app. Since the app also collects GPS location information in real-time along with the recorded $PM_{2.5}$ levels, the data is both graphed and mapped on the AirCasting app. Due to the lower cost of these devices, questions of their overall performance have arisen. One study found that when compared to reference instruments, the AirBeam showed a correlation of 0.7-0.96 (Sousan et al., 2017). The device does have excellent precision, however requires proper and frequent calibration (Yang et al., 2017).

Calibration and Cross-Correlation

This project utilized 4 AirBeam monitors. A cross-correlation was performed on the devices to assess their accuracy and inter-instrument variability. All 4 AirBeams were set up at the Smithfield monitoring station and recorded $PM_{2.5}$ readings for a 24-hour period. The values during that time were in a range between 20-35 μg/m^3. To supplement this 24-hour data, 5 additional 5-minute recordings were done that covered lower $PM_{2.5}$ levels (range between 0-10 μg/m^3). Data from each AirBeam was plotted against the other AirBeam readings, then the data from each AirBeam was also plotted against the DEQ $PM_{2.5}$ levels. R^2 values were determined for each of these plots. Evidence provided by this information indicated that the instruments needed to be calibrated individually. This calibration was achieved by generating power function curves for each of the AirBeam vs DEQ graphs, which were then used as post-hoc correction factors.

Participant Data Collection

Collection of $PM_{2.5}$ exposure levels was conducted during the months of April and May. 20 volunteers were recruited to participate in this project, all of which were residing in Cache Valley during the time of the study. Each participant received an orientation session in which he/she was given an AirBeam and an Android smartphone with the AirCasting app pre-downloaded on it. During the orientation, the participant signed an informed consent form (approved by the USU IRB, protocol #8339) and was taught how to use the AirBeam and navigate the mobile phone and app. The following day, the participant carried the AirBeam and phone and collected $PM_{2.5}$ readings for an 8-10-hour period as he/she carried out their typical day. Since we only had 4 air monitors, just 1 or 2 participants would collect data on a given day. Upon completion of the collection process, the participants returned the devices, and information from their recording sessions were emailed and uploaded to a computer for further analyses.

Data Processing and Analysis

The $PM_{2.5}$ data obtained from each volunteer needed adjustments to account for the overall moderate accuracy of the devices. Using the power function curves generated from the calibration graphs, the $PM_{2.5}$ values were corrected according to which AirBeam device was used. To evaluate the correlation within subjects, the average hourly adjusted $PM_{2.5}$ values for each participant were plotted against published values from the DEQ for that respective day, creating a total of 20 different graphs. Linear regression equations and R^2 values were then generated that fit the corresponding data for each graph. Average, standard deviation, and range of all the R^2 values were then computed. For determination of across subject correlation, the daily averages from each participant were plotted on a single graph against the daily DEQ averages of the particular days of data collection. A linear regression equation and R^2 value were generated.

Location Information

A subset of the participant data was further analyzed by observing $PM_{2.5}$ level variations in conjunction with location changes. The adjusted AirBeam readings from 5 subjects and the corresponding DEQ data were plotted in time (average minute value) vs $PM_{2.5}$ concentration graphs. Using Google Maps, the recorded GPS coordinates determined the locations of the participants during instances in which the AirBeam and DEQ data either deviated markedly from each other or periods of stable exposure levels. The location data was added as annotations to each participant's exposure graphs.

RESULTS

Cross-Correlation and Calibration Data

Data obtained from the 24-hour and supplemental Smithfield collection periods were used to generate plots comparing each AirBeam with one another and with the DEQ's published data. R^2 values were computed for each of the 10 graphs. These values (shown in Fig. 3A) indicated whether the AirBeams correlate well with each other and if their $PM_{2.5}$ readings were close to the values obtained from the DEQ. The individual AirBeams correlated very well with one another, with an average R^2 value of 0.97. However, the average R^2 for the AirBeams compared to the DEQ was 0.71. The personal air monitors therefore correlated only moderately with the published DEQ data. This moderate correlation indicated an overall moderate accuracy

A

	DEQ	AirBeam-1	AirBeam-2	AirBeam-3	AirBeam-4
DEQ	1.00	0.74	0.73	0.70	0.67
AirBeam-1	0.74	1.00	0.97	0.96	0.94
AirBeam-2	0.73	0.97	1.00	0.98	0.98
AirBeam-3	0.70	0.96	0.98	1.00	0.97
AirBeam-4	0.67	0.94	0.98	0.97	1.00

B

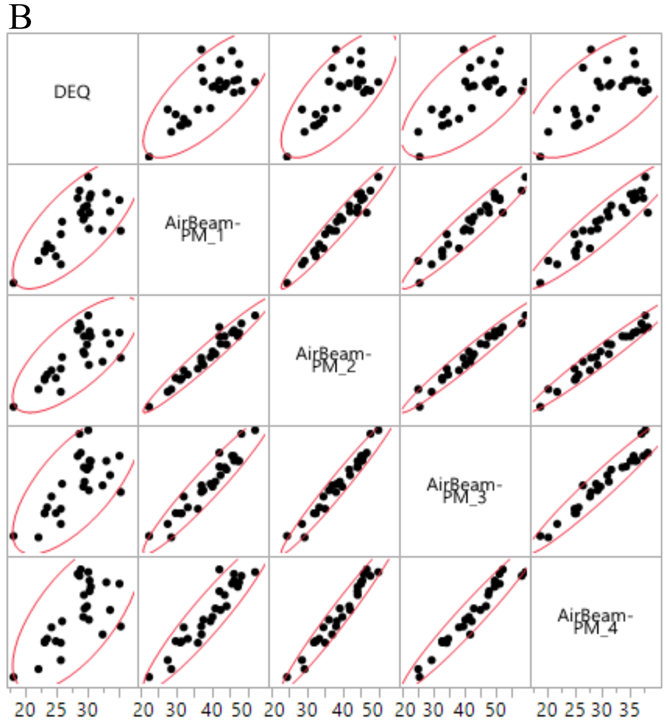


Figure 3. AirBeam cross-correlation. Table of R^2 values for each of the cross-correlation plots (A), and scatterplot matrix of the same graphs (B). The individual AirBeams correlated very well with each other, as indicated by the high R^2 values in A (average 0.97) and the tight collection of datapoints in B. The lower R^2 (average 0.71) shown in A and the more dispersed datapoints in B demonstrate a lower correlation for the AirBeams compared to the DEQ. This lower correlation suggests a moderate overall accuracy of the devices.

for the AirBeams, and demonstrated a need for the individual calibration of the air monitors against the DEQ.

Post-hoc correction factors were used as a means of calibration for the AirBeam devices. The power function curves created from the AirBeam vs. DEQ plots of the Smithfield collection period were used as the correction factors (shown in Fig. 4). The equations used as the correction factors are: $y=1.8841x^{0.7404}$ (AirBeam_1), $y=1.819x^{0.75}$ (AirBeam_2), $y=2.1954x^{0.685}$ (AirBeam_3), and $y=2.1322x^{0.761}$ (AirBeam_4).

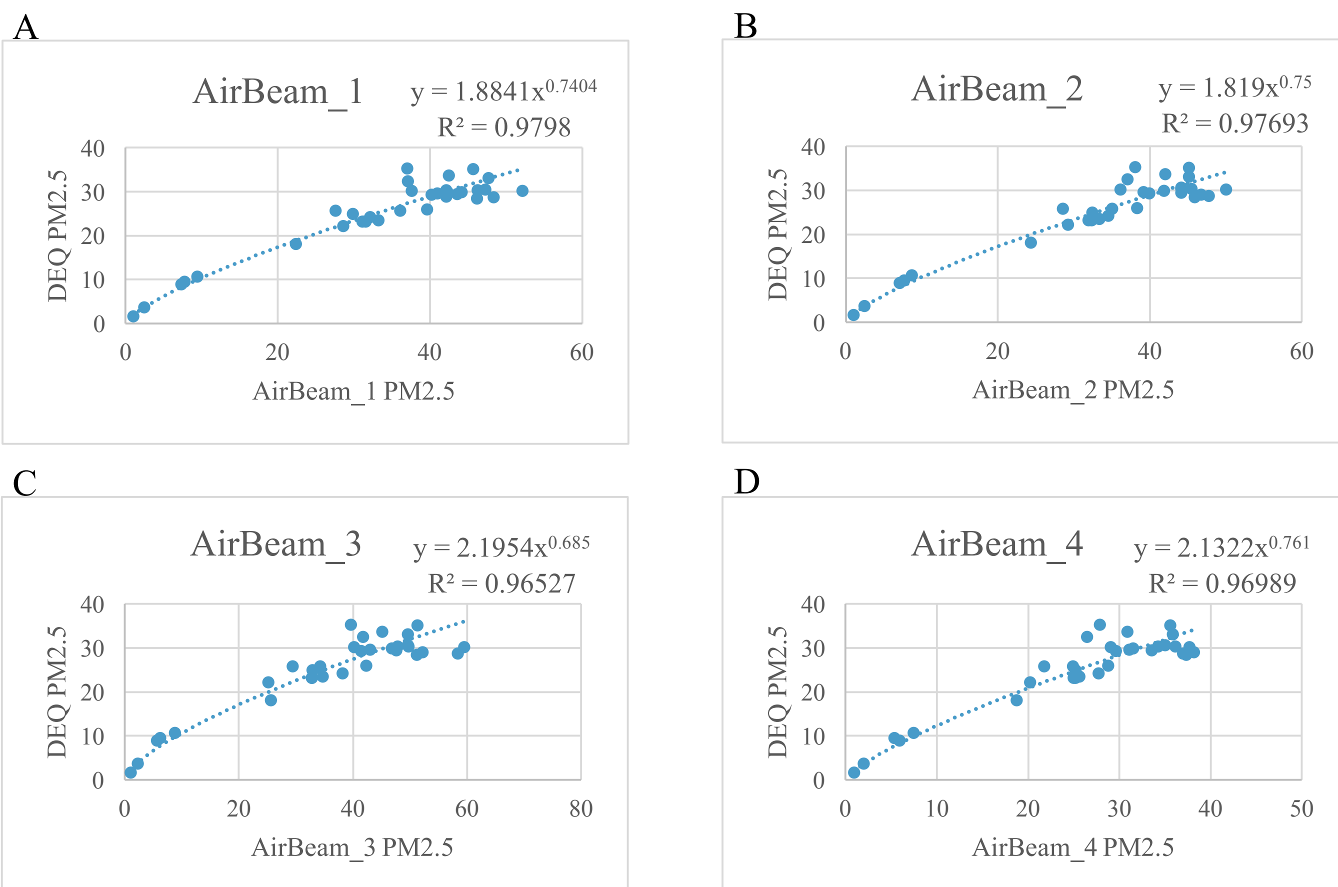


Figure 4. AirBeam calibration graphs and equations. The AirBeam devices required individual calibration. Each AirBeam was plotted against the DEQ readings and power function curves were generated from the graphs (A-D). These were used as equations to adjust the $PM_{2.5}$ values recorded by participants in the data collection process.

Participant Data

The hourly average $PM_{2.5}$ levels obtained from each participant, after being adjusted using the correct calibration equation, were plotted against the DEQ's hourly $PM_{2.5}$ readings for the respective collection period (shown in Fig. 6A-T). 3 out of the 20 participants (15%) had an hourly average $PM_{2.5}$ exposure level within the "Unhealthy to Susceptible Groups" range of the EPA's Air Quality Index (AQI), 1 of which even reached into the "Unhealthy Range" (Utah Department of Health, 2017). Looking at the average minute values, 8 of the 20 participants (40%) had readings within the susceptible group range, 3 of which also had values that extended into the unhealthy range.

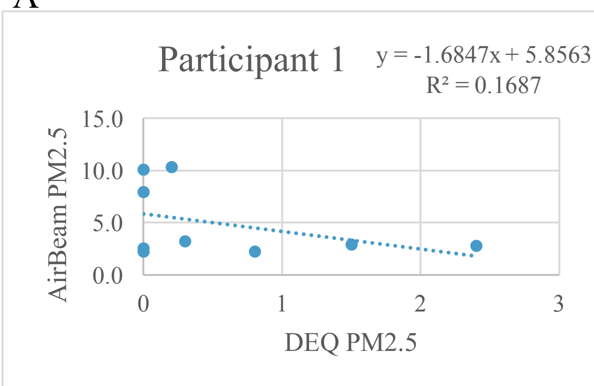
Air Quality Index (AQI)	PM 2.5	Ozone
Good	0 - 12.0 µg/m³	0 - 0.054 ppm
Moderate	12.1 - 35.4 µg/m³	0.055 - 0.070 ppm
Unhealthy for Sensitive Groups	35.5 - 55.4 µg/m³	0.071 - 0.085 ppm
Unhealthy	55.5 - 150.4 µg/m³	0.086 - 0.105 ppm
Very Unhealthy	150.5 - 250.4 µg/m³	0.106 - 0.200 ppm
Hazardous	Above 250.5 µg/m³	Above 0.201 ppm
	Based on a 24-hour average.	Based on an 8-hour average.

Figure 5. Air Quality Index (AQI). Index of $PM_{2.5}$ concentrations, classified by the potential to affect human health. 15% of the participants for this study had an hourly average in the "Unhealthy for Sensitive Groups" range, and 40% had minute averages within this range. Image taken from the Utah Department of Environmental Quality.

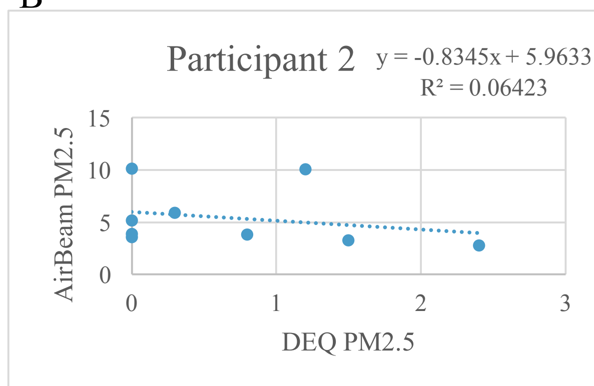
For each of the 20 graphs that were created, a linear regression equation and an R^2 value were generated. Analysis of the R^2 values for the graphs gave a mean of 0.10, with a standard deviation of 0.10 and standard error 0.02 (0.10 ± 0.02). R^2 values ranged from 0.004 to 0.38.

This low average and range indicates that the R^2 values for all 20 graphs were markedly small, providing evidence of a low correlation between the AirBeam and the DEQ readings within the group of participants. To assess across subject correlation, the daily averages from each participant were plotted against the daily DEQ averages for those days of collection (shown in Fig. 7. The R^2 generated from that graph was 0.27, another a low value. The DEQ $PM_{2.5}$ readings thus also correlated poorly with the individual readings across subjects.

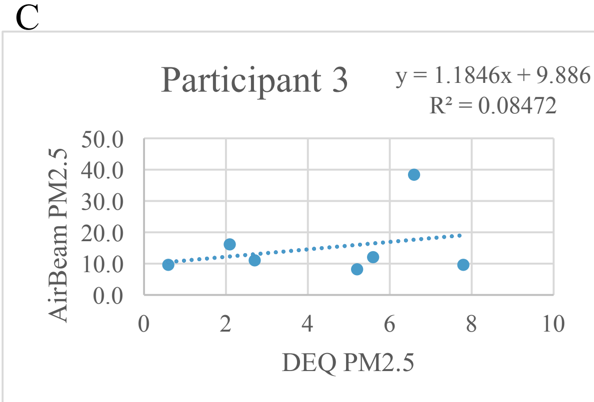
A



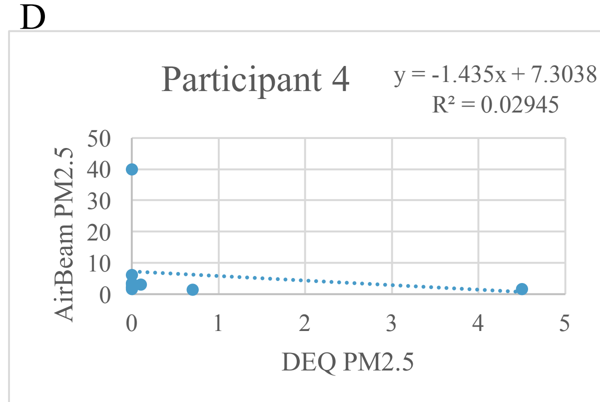
B



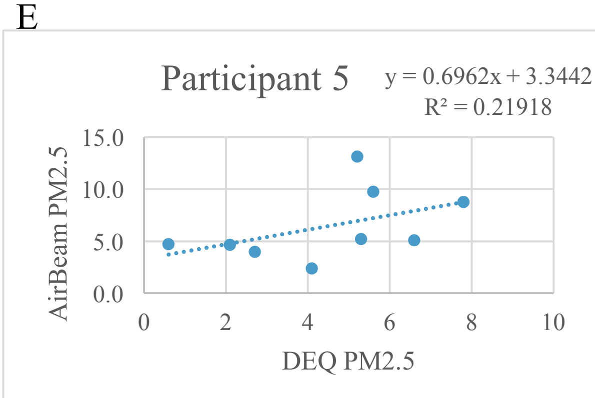
C



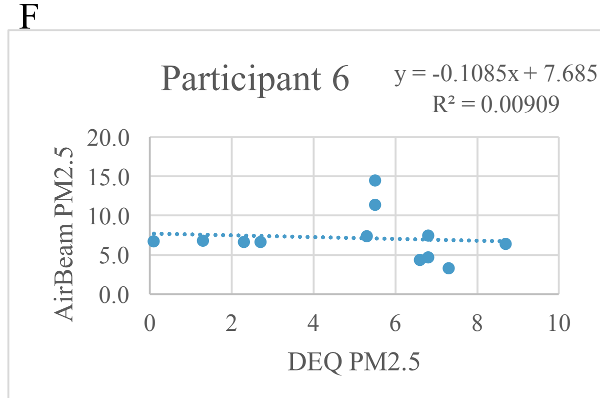
D



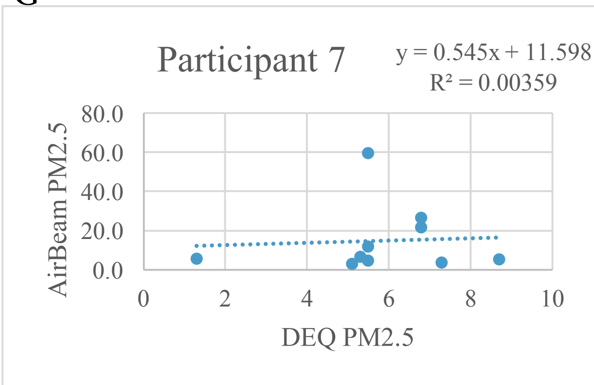
E



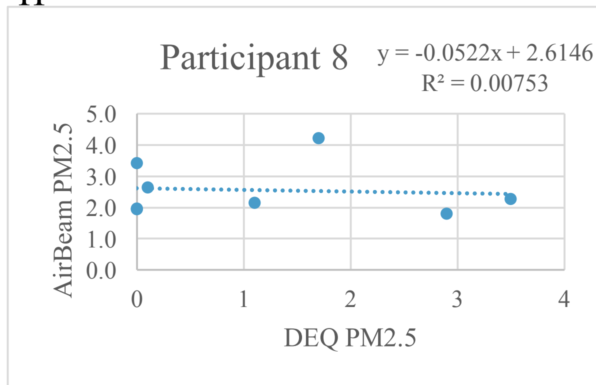
F



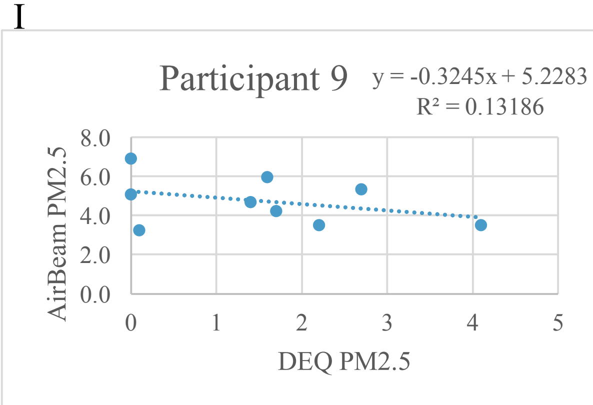
G


Participant 7
y = 0.545x + 11.598
R² = 0.00359
AirBeam PM2.5
DEQ PM2.5

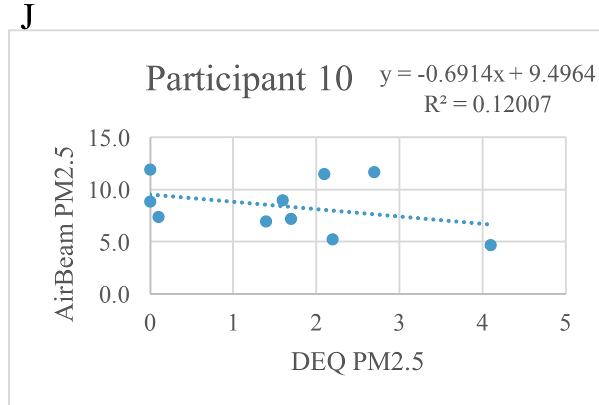
H


Participant 8
y = -0.0522x + 2.6146
R² = 0.00753
AirBeam PM2.5
DEQ PM2.5

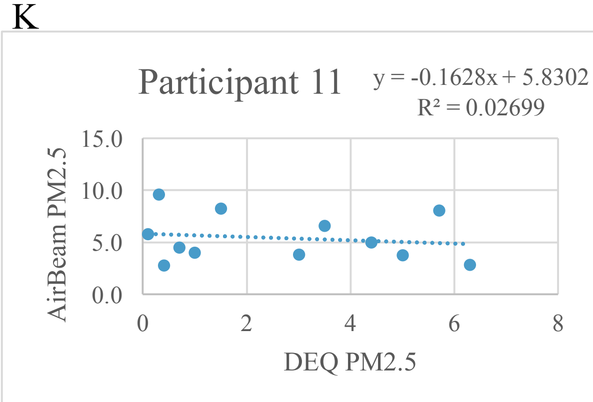
I


Participant 9
y = -0.3245x + 5.2283
R² = 0.13186
AirBeam PM2.5
DEQ PM2.5

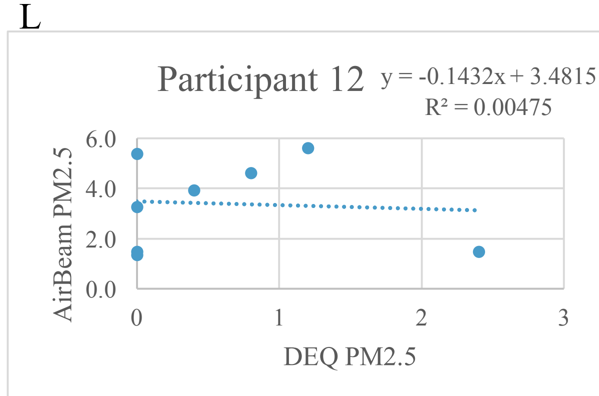
J


Participant 10
y = -0.6914x + 9.4964
R² = 0.12007
AirBeam PM2.5
DEQ PM2.5

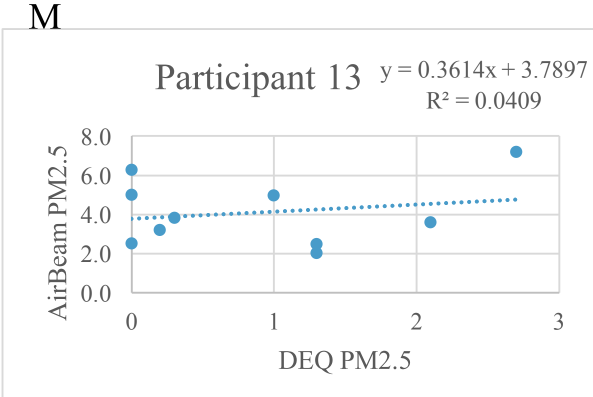
K


Participant 11
y = -0.1628x + 5.8302
R² = 0.02699
AirBeam PM2.5
DEQ PM2.5

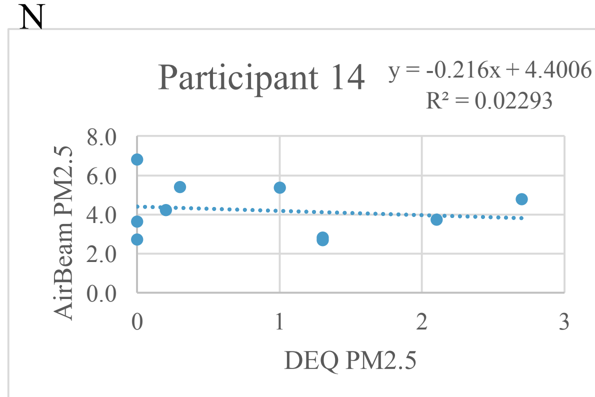
L


Participant 12
y = -0.1432x + 3.4815
R² = 0.00475
AirBeam PM2.5
DEQ PM2.5

M


Participant 13
y = 0.3614x + 3.7897
R² = 0.0409
AirBeam PM2.5
DEQ PM2.5

N


Participant 14
y = -0.216x + 4.4006
R² = 0.02293
AirBeam PM2.5
DEQ PM2.5

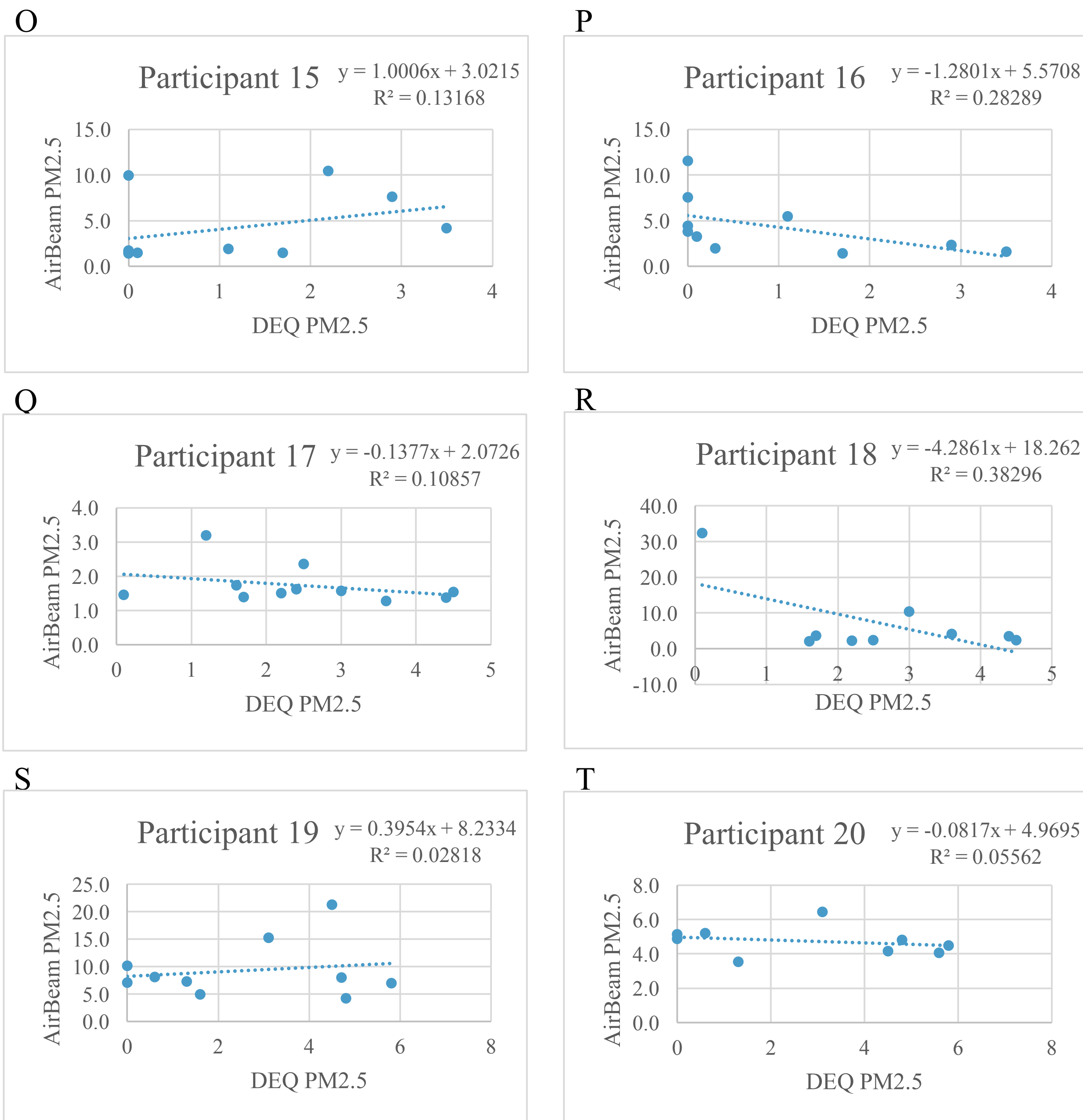


Figure 6. Participant data vs. DEQ graphs. For a within subject assessment, $PM_{2.5}$ readings from each of the 20 participants were plotted against the published DEQ readings for the respective period (A-T). Linear equations and R^2 values were generated for each graph. All R^2 values were found to be markedly low, indicating low correlation within the group of subjects. Note that each plot has its own scale due to varying exposure levels for each individual.

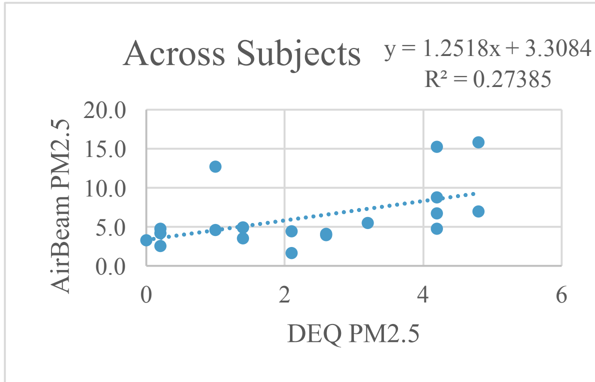
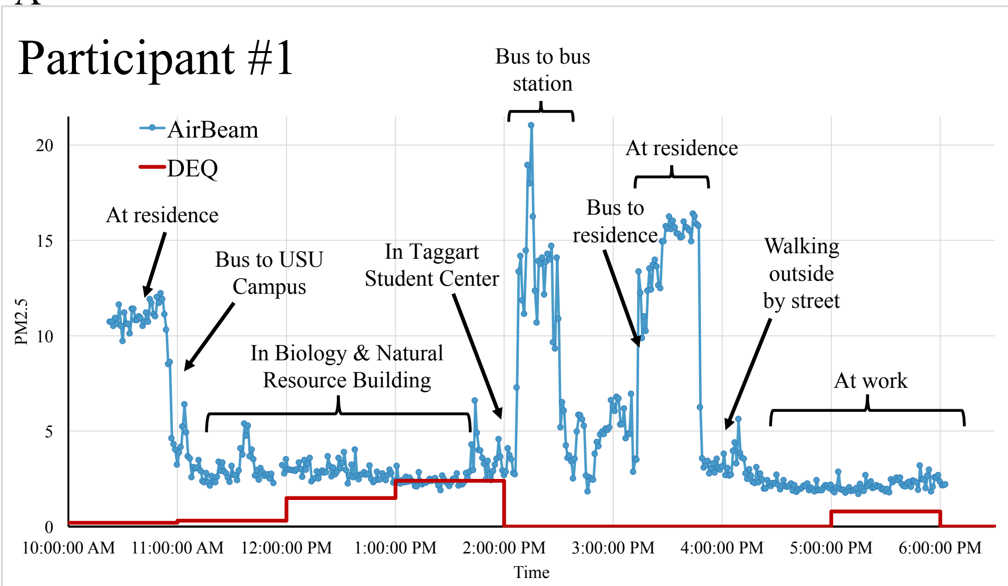


Figure 7. Across subject correlation graphs. To study correlation across subjects, daily averages from each participant were plotted against the DEQ daily averages on one graph. The R^2 value generated was also markedly low, indicating poor correlation across subjects.

Location Data

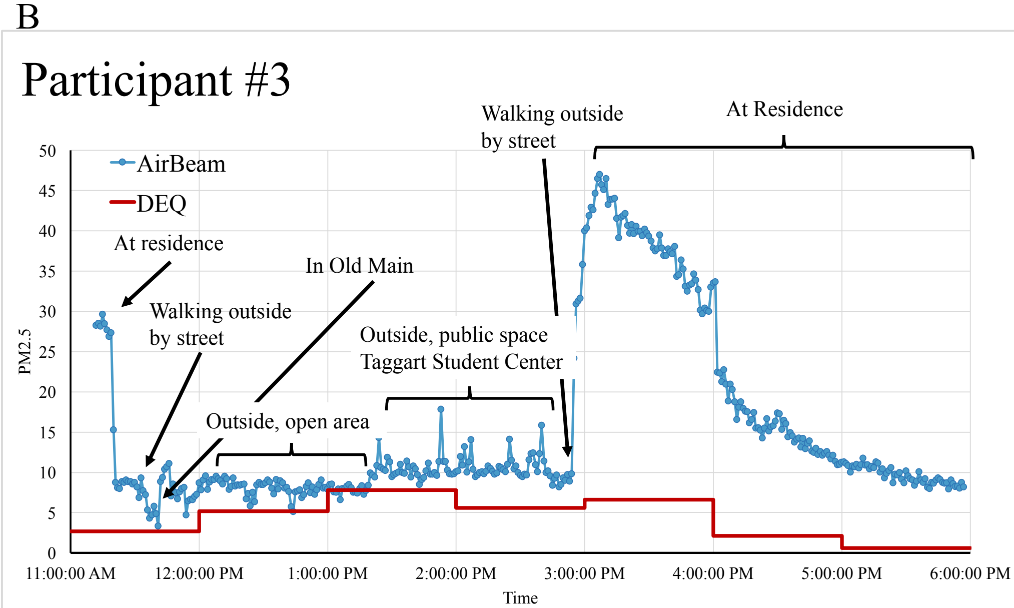
$PM_{2.5}$ readings taken from Participants 1, 3, 5, 15, and 20 were additionally analyzed to observe the link (or lack thereof) between changes in location and variations in $PM_{2.5}$ exposure levels. Both $PM_{2.5}$ readings from the AirBeams and DEQ were plotted in Time (minute value) vs. $PM_{2.5}$ graphs, and location information (taken from inputting GPS coordinates into Google Maps) was annotated on the graphs (shown in Fig.8). 3 out of the 5 charts exhibited marked differences between AirBeam and DEQ readings when the participant was at his/her residence (Fig. 7A, 7B, and 7D). At times when the participants were either in a building on the Utah State University campus or at their places of work, the individual $PM_{2.5}$ levels were at or close to the DEQ's published readings. However, there was one instance in which the $PM_{2.5}$ levels inside the building were markedly high, but leveled off to near DEQ levels (seen in Figure 7C). Most the $PM_{2.5}$ concentration peaks recorded by the AirBeams were in conjunction with travel either by bus or car.

A



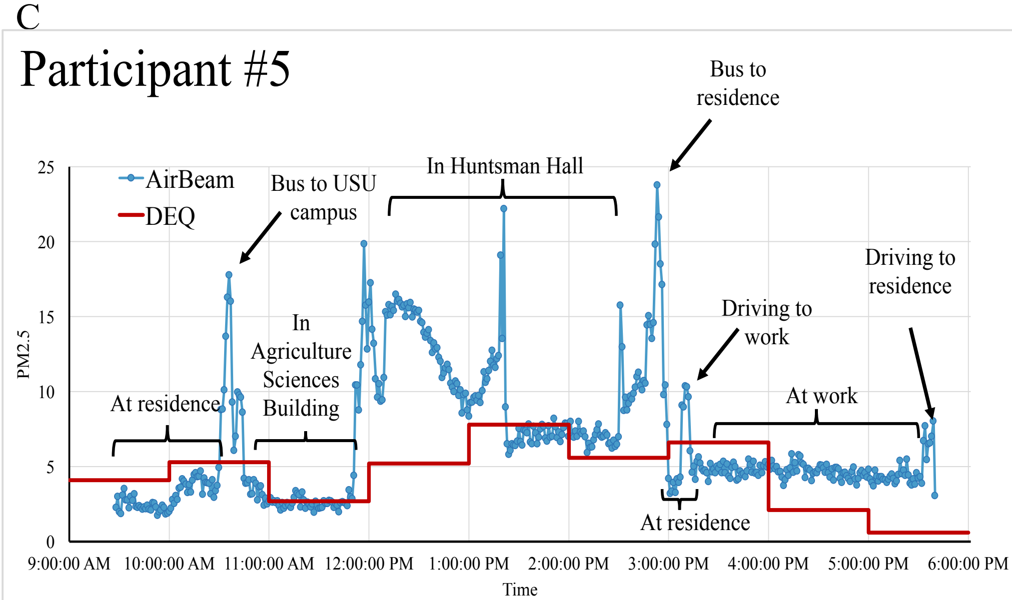
Participant #1
AirBeam
DEQ
PM2.5
Time
At residence
Bus to USU Campus
In Biology & Natural Resource Building
In Taggart Student Center
Bus to bus station
Bus to residence
At residence
Walking outside by street
At work
0
5
10
15
20
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM

B



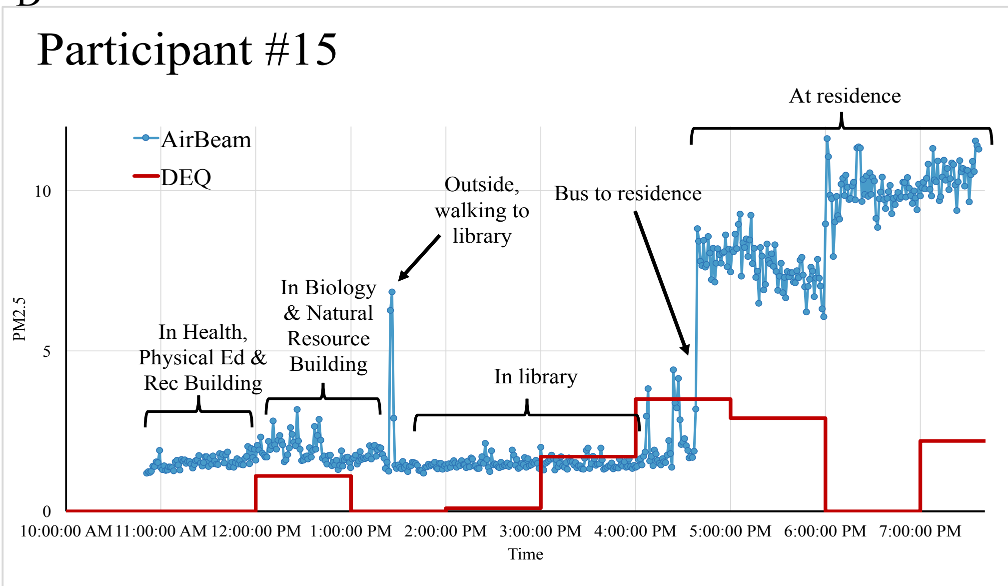
Participant #3
AirBeam
DEQ
PM2.5
Time
At residence
Walking outside by street
In Old Main
Outside, open area
Outside, public space Taggart Student Center
Walking outside by street
At Residence
0
5
10
15
20
25
30
35
40
45
50
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM

C



Participant #5
AirBeam
DEQ
PM2.5
Time
At residence
Bus to USU campus
In Agriculture Sciences Building
In Huntsman Hall
Bus to residence
Driving to work
At residence
At work
Driving to residence
0
5
10
15
20
25
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM

D



E

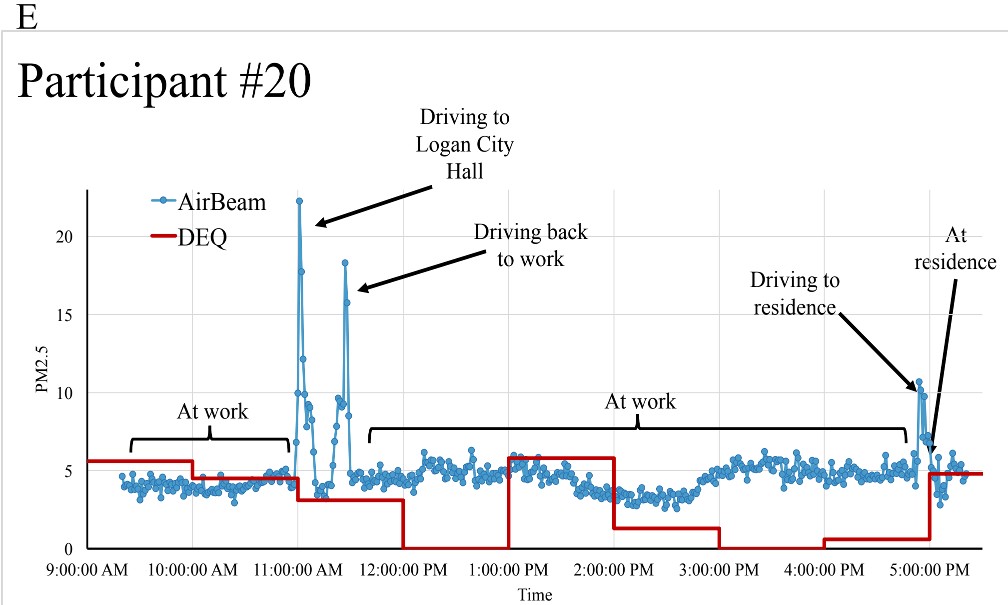


Figure 8. $PM_{2.5}$ readings with annotated location information. AirBeam (blue) and DEQ (red) $PM_{2.5}$ data from Participants 1, 3, 5, 15, and 20 were graphed against time in minute increments (A-E). Location information revealing instances of marked differences between AirBeam and DEQ data were annotated on the 5 graphs. Large AirBeam peaks were mostly attributed to car/bus travel, and for Participants 1, 3, and 15 $PM_{2.5}$ exposure increased when at their residences. Again, each graph has its own scale due to varying exposure levels.

DISCUSSION

DEQ vs. AirBeam

The purpose of this study was to determine if $PM_{2.5}$ levels recorded by the fixed-site monitoring station in Smithfield accurately represent the $PM_{2.5}$ exposure experienced by the individual within Cache Valley. When studying population-level health effects of air pollution, obtaining readings from fixed-site stations is a sufficient form of measurement; however, at the individual level, $PM_{2.5}$ exposure concentrations can vary greatly due to spatial and temporal changes that sparsely located monitor stations cannot precisely measure (Strickland et al., 2013; Mead et al., 2013). Using published $PM_{2.5}$ data from these stations to assess individual health risk, therefore, may cause error. Utilization of personal environmental monitors is believed to help more accurately quantify individual exposure, thus minimizing this measurement error (Steinle et al., 2013). We hypothesized that when comparing $PM_{2.5}$ concentrations from personal air monitors to the published DEQ data, they would correlate poorly with each other for both within and across a group of individuals.

The AirBeam personal environmental monitor was chosen as the specific device used for this study. Although other instruments were found to have marginally better overall performance, the AirBeam was sufficient for our needs (Sousan et al., 2017). Plotting the measured $PM_{2.5}$ levels against the DEQ readings for each participant created 20 different scatterplots. Linear regression equations and R^2 values generated from each graph provided the information necessary to evaluate the correlation between DEQ and AirBeam data.

This study was conducted during the months of April and May, both of which typically have lower reported $PM_{2.5}$ levels. If the DEQ reports do indeed accurately reflect individual exposure, we would have also observed lower $PM_{2.5}$ concentrations reported by the AirBeams. While this was true for most of the collection time, there were several instances in which $PM_{2.5}$

exposure levels were higher and within the "Unhealthy to Susceptible Groups" range of the EPA's AQI. Additionally, the R^2 values generated from the graphs all were considerably low for both within and across the group of participants. The AirBeam devices were calibrated directly against the DEQ, allowing us to recognize that any deviations in $PM_{2.5}$ concentration between AirBeam and DEQ were likely not due to instrument inaccuracy. If the DEQ data accurately represents individual exposure, then both DEQ and the AirBeam adjusted values should strongly correlate with one another. The low R^2 values observed in the graphs, however, demonstrate that they were in fact not similar.

Inspection of the 20 DEQ vs AirBeam scatterplots revealed that there was no common relationship between the sets of information. 14 of the graphs exhibited lines of best fit with negative slopes, while the remainder were positive. Furthermore, these graph slopes all had varying levels of steepness, ranging from -4.2 to +1.2. The lack of a visible pattern illustrates that people can experience varying levels of $PM_{2.5}$ exposure at the same time due to being in different locations. This suggests that a fixed-site monitor reporting one single $PM_{2.5}$ concentration for individuals in differing locations may not accurately represent their personal exposure.

Because the fixed-site monitor stations are static, they are limited to making estimates of $PM_{2.5}$ levels for a large area. More concentrated locations within that area can therefore be misrepresented, and likewise $PM_{2.5}$ levels for places of lower concentrations can be over-estimated. Through observation of participants' location data, fluctuations in exposure levels were seen in conjunction with specific locations. During times when the participants were inside public buildings, the AirBeam readings were generally at, near, and sometimes even below the DEQ's reported values, whereas markedly higher $PM_{2.5}$ levels were found at times of travel by bus or car. It is presumed that the increased exposure levels at these times were attributed to automobile exhaust, but further investigation may be prudent.

An interesting finding from the participant location information is that a few subjects had prominent increases in $PM_{2.5}$ exposure when they were at their places of residence. These readings could be due to several different factors, including infiltration of outdoor air pollutants, firsthand/secondhand smoke, cooking, or combustion of fuels for heating (Li et al., 2017). Since indoor $PM_{2.5}$ has a different composition than outdoor pollutants, these marked increases in exposure levels prompted a follow up with the participants in question (Abdel-Salam, 2015). Participant 1 confirmed that he/she cooked both at the beginning of the recording session and upon return to his/her residence. Participant 3 reported the use of candles in the morning and the burning of incense by a roommate upon arrival back home. Participant 15 revealed that he/she cooked at the very end of the recording session (around 7:00pm). The World Health Organization (WHO) recommends a daily maximum indoor $PM_{2.5}$ concentration of 25 $\mu g/m^3$ (Gurley et al., 2013). While only 1 of the 3 subjects surpassed this value, this high variability of $PM_{2.5}$ concentrations observed within households may be an important area of further study in evaluating air pollution-related risks to health.

Study Limitations

Data collection was aimed to occur during the earlier months of the year (February through May); however, restrictions inhibited collection from beginning until April. This is a relatively short period for a study, therefore $PM_{2.5}$ concentrations were less varied than expected. A greater diversity of $PM_{2.5}$ data would have strengthened our findings. Additionally, 20 participants may be too small of a group to obtain results representative of all residents of Cache Valley. Although low R^2 values were consistently seen with all the participants, the R^2 average may be less accurate of a value due to the smaller sample size. Increasing the number of subjects would increase confidence in the accuracy of our results.

Another significant limitation to this study was the available subject location information. 2 of the mobile phones utilized for the study were unable to capture GPS coordinates, which was not discovered until after the data collection process was completed. Of the 20 participants, only 11 recorded location data. Lack of the other 9 participants' GPS information inhibited a thorough analysis of $PM_{2.5}$ fluctuations relative to variations in location.

Conclusion

Although several factors limited the data obtained, these findings are nevertheless an adequate collection of preliminary data, which will prove useful for future studies on personal $PM_{2.5}$ exposure. The low R^2 values observed from the DEQ vs AirBeam graphs, coupled with a lack of visible pattern and fluctuating individual exposure levels, indicate that DEQ and AirBeam $PM_{2.5}$ level readings were poorly correlated with one another both within and across subjects. These findings confirm our hypothesis that $PM_{2.5}$ concentrations published from fixed-site monitoring stations do not adequately reflect the dynamic nature of individual $PM_{2.5}$ exposure. This underscores the need to implement personal monitoring systems to aid in the evaluation of individual risk for respiratory diseases, cardiovascular disease, congestive heart failure, and numerous other air pollution-related health conditions.

CAPSTONE REFLECTION

The USU Honors Program strives to provide a well-rounded education for its students. One of the ways it does so is by advocating and aiding in the pursuit of real-world experiences, beyond the scope of the classroom. A form of practical experience Honors students are encouraged early on to get involved in is research.

My initial exposure to the field of scientific research was a little rocky. I learned a great deal and gained experience working in a laboratory setting, but the specific work I was doing did not particularly interest me. I began as a volunteer in a research lab that was studying the pathogenesis of certain neuropsychiatric disorders. My work in this lab consisted of aiding in the care of the mice colonies, tagging and tailing the mice, performing PCR, and sectioning mice brains. As an aspiring physician, I enjoy interacting with people, and although the work being done in that research lab was related to human health and was conceptually interesting, it did not allow me that human interaction that I wanted.

When I first contacted Dr. Lefevre about working together on my Honors Capstone Project, I wasn't entirely sure of what I wanted to do. As part of the NDFS department, Dr. Lefevre is typically involved in dietary-related research on functional foods and bioactive chemicals, but he has a strong interest in the health effects of air pollution, particularly in Cache Valley. Conversing with him sparked my interest in air pollution and $PM_{2.5}$, and we were able to develop a project. Dr. Lefevre allowed me to spearhead the entire project, but provided much guidance and assistance when needed.

Initially, in addition to comparing individual exposure to the DEQ readings, this project aimed to observe how variations in $PM_{2.5}$ exposure levels correlated to changes in Heart Rate Variability (HRV). Measuring HRV—the variation in time between one heartbeat and the next—is a way to assess autonomic function, and therefore risk for cardiovascular conditions. Because we were using human subjects in the project, approval from the University's Institutional Review Board (IRB) was needed. Two separate proposals were made for each component of the study. The HRV component was approved later than expected, so due to time constraints we were unable to include that component in my project. Dr. Lefevre has chosen to continue that portion of the study on his own.

Despite not being able to study HRV, completing this capstone project was an excellent learning experience for me. Frequent meetings with Dr. Lefevre allowed me to learn more about the experimental design process. I discovered the fundamental steps to developing and starting a study, such as the generation of a project proposal, applying for IRB approval, calibrating the necessary machinery, and recruiting individuals as participants. While conducting the project, I learned how to use certain scientific equipment (the AirBeam) to collect data as well as how to process and analyze the information obtained from those devices. Additionally, I had the opportunity to present this project at USU's Student Research Symposium. Dr. Lefevre taught me how to compose a suitable poster for the presentation. At the time of the research symposium, however, data collection had not yet begun, so Dr. Lefevre guided me in how to create an informative poster.

While undergoing this entire process, I learned about the many pitfalls that can occur during research. The first problem encountered was the time restraint caused by the late IRB approval. The IRB is exceedingly important in protecting human participants in research from potential risks, but the time needed to obtain approval from them was unanticipated. Because the project started later than expected, we missed out on more varied levels of $PM_{2.5.}$ Although we still got a decent variation in exposure levels, a wider range of data would have strengthened the project. With this experience, I learned that many hoops must be jumped through just to even begin a study, and that sufficient time needs to be allotted to get through these obstacles.

Another instance that was thought to be problematic was the accidental loss of the smartphone used for the calibration collection period. Although the phone was eventually recovered, this loss allowed us to discover how reasonably priced Android phones are without a service plan. In addition to being an Android smartphone, the AirBeam devices only require a phone with Bluetooth connection and the ability to connect to wifi, so a service plan was not essential. We were concerned that using only Android owners as participants would considerably limit our data; however, the affordable nature of the plan-less smartphones allowed us to purchase a phone for each of the AirBeams and thus prevent this limitation.

But unfortunately, 2 of the phones somehow had their location information turned off, which deprived us GPS coordinates from 9 participants. This limited our ability to observe $PM_{2.5}$ changes in conjunction with specific locations. We were able to obtain interesting findings with the data we had, but information from all the participants would have been beneficial. Had I checked the participant data immediately after receiving it, I would have caught this problem early on and been able to fix it, minimizing the loss. This experience taught me for future potential projects to look at data after each collection period, not just during the data analysis process.

Despite all these obstacles, we conducted the study and collected a great deal of information on $PM_{2.5}$ exposure, which will be used as a good starting point for further investigation. I absolutely enjoyed doing this project, both because the subject matter was fascinating and it allowed me to interact with people. I learned a great deal from the experience, and hope that I can pass what I've learned to future Honors students. I highly encourage getting involved in research early, both to gain experience and to figure out likes/dislikes. Enough time needs to be allotted for everything (figuring out a project, making the capstone proposal, IRB approval, collection of necessary materials, etc.). And it is exceedingly important to double check everything, especially the instruments being used in the event of errors or faulty equipment. But most importantly, don't worry about messing up or having to start over again. It is all part of the learning process. Everything will be okay!

LITERATURE CITED

Abdel-Salam, M.M. (2015). Investigation of $PM_{2.5}$ and carbon dioxide levels in urban homes. Journal of the Air & Waste Management Association, 65: 930-936.

Atkinson, R.W., Anderson, H.R., Sunyer, J., Ayres, J., Baccini, M., Vonk, J.M., Boumghar, A., Forastiere, F., Forsberg, B., Touloumi, et al. (2001). Acute effects of particulate air pollution on respiratory admissions: Results from APHEA 2 project. Air pollution and health: A European approach. American Journal of Respiratory and Critical Care Medicine, 164: 1860-1866.

Atkinson, R.W., Kang, S., Anderson, H.R., Mills, I.C., Walton, H.A. (2014). Epidemiologic time series studies of $PM_{2.5}$ and daily mortality and hospital admissions: A systematic review and meta-analysis. Thorax, 69: 660-665.

Australian Government Department of the Environment and Energy. (2005). Particles [fact sheet]. Parkes, ACT. Accessed June 2017 at www.environment.gov.au.

Bell, M.L., Davis, D.L. (2001). Reassessment of the lethal London fog of 1952: Novel indicators of acute and chronic consequences of acute exposure to air pollution. Environmental Health Perspectives, 3: 389-394.

Bell, M.L., Davis, D.L., Fletcher, T. (2004). A retrospective assessment of mortality from the London smog episode of 1952: The role of influenza and pollution. Environmental Health Perspectives, 112(1): 6-8.

Bourdrel, T., Bind, M.A., Béjot, Y., Morel, O., Argacha, J.F. (2017). Cardiovascular effects of air pollution. Archives of Cardiovascular Diseases, 1875-2136(17): 30130-30134.

Brook, R.D, Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Luepker, R., Mittleman, M., Samet, J., Smith, S.C., Tager, I. (2004). Air pollution and cardiovascular disease: A statement for healthcare professionals from the expert panel on population and prevention science of the American Heart Association. Circulation, 109: 2655-2671.

Brook, R.D., Rajagopalan, S., Pope, III C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V., Holguin, F., Hong, Y., Luepker, R.V., Mittleman, M.A., et al. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation, 121(21): 2331-2378.

Brunekreef, B., Dockery, D.W., Krzyzanowksi, M. (1995). Epidemiologic studies on short-term effects of low levels of major ambient air pollution components. Environmental Health Perspectives, 103(2): 3-13.

Brunekreef, B., Holgate, S.T. (2002). Air pollution and health. Lancet, 360(9341): 1233-1242.

Calderón-Garcidueñas, L., Solt, A.C., Henríquez-Roldán, C., Torres-Jardón, R., Nuse, B., Herritt, L., Villarreal-Calderón, R., Osnaya, N., Stone, I., García, R., et al. (2008). Long-term air pollution exposure is associated with neuroinflammation, an altered innate immune response, disruption of the blood-brain barrier, ultrafine particulate deposition, and accumulation of amyloid β-42 and α-synuclein in children and young adults. Toxicologic Pathology, 36(2): 289-310.

Gharibvand, L., Shavlik, D., Ghamsary, M., Beeson, W.L., Soret, S., Knutsen, R., Knutsen, S.F. (2017). The association between ambient fine particulate air pollution and lung cancer incidence: Results from the AHSMOG-2 study. Environmental Health Perspectives, 125(3): 378-384.

Gurley, E.S., Salje, H., Homaira, N., Ram, P.K., Haque, R., Petri, W.A., Bresee, J., Moss, W.J., Luby, S.P., Breysse, P., Azziz-Baumgartner, E. (2013). Seasonal concentrations and determinants of indoor particulate matter in a low-income community in Dhaka, Bangladesh. Environmental Research, 121: 11-16.

HabitatMap (2017). AirCasting. Accessed March 2017 at www.aircasting.org.

Hoek, G., Krishnan, R.M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., Kaufman, J.D. (2013). Long-term air pollution exposure and cardio-respiratory mortality: a review. Environmental Health, 12: 43.

Johnson, P.R.S., Graham, J.J. (2005). Fine particulate matter national ambient air quality standards: Public health impact on populations in the northeastern United States. Environmental Health Perspectives, 113(9): 1140-1147.

Li, Z., Wen, Q., Zhang, R. (2017). Sources, health effects and control strategies of indoor fine particulate matter. Science of the Total Environment, 586: 610-622.

Malek, E., Davis, T., Martin, R.S., Silva, P.J. (2006). Meteorological and environmental aspects of one of the worst national air pollution episodes (January 2004) in Logan, Cache Valley, Utah, USA. Atmospheric Research, 79: 108-122.

McKercher, G.R., Salmond, J.A., Vanos, J.K. (2017). Characteristics and applications of small, portable gaseous air pollution monitors. Environmental Pollution, 223: 102-110.

Mead, M.I., Popoola, O.A.M., Stewart, G.B., Landshoff, P., Calleja, M., Hayes, M., Baldovi, J.J., McLeod, M.W., Hodgson, T.F., Dicks, J., et al. (2013). The use of electrochemical sensors for monitoring urban air quality in low-cost, high-density networks. Atmospheric Environment, 70: 186-203.

Nawrot, T.S., Perez, L., Künzli, N., Munters, E., Nemery, B. (2011). Public health importance of triggers of myocardial infarction: A comparative risk assessment. Lancet, 377: 732-740.

Peters, A., Dockery, D.W., Muller, J.E., Mittleman, M.A. (2001). Increased particulate air pollution and the triggering of myocardial infarction. Circulation, 103: 2810-2815.

Pope, III C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA, 287(9): 1132-1141.

Pope, III C.A., Dockery, D.W. (2006). Health effects of fine particulate air pollution: Lines that connect. Journal of the Air & Waste Management Association, 56(6): 709-742.

Rich, D.Q., Peters, A., Schneider, A., Zareba, W., Breitner, S., Oakes, D., Wiltshire, J., Kane, C., Frampton, M.W., Hampel, R., et al. (2016). Ambient and controlled particle exposures as triggers for acute ECG changes. Health Effects Institute, 186: 5-75.

Sousan, S., Koehler, K., Hallet, L., Peters, T.M. (2017). Evaluation of consumer monitors to measure particulate matter. Journal of Aerosol Science, 107: 123-133.

Steinle, S., Reis, S., Sabel, C.E. (2013). Quantifying human exposure to air pollution—Moving from static monitoring to spatio-temporally resolved personal exposure assessment. Science of the Total Environment, 443: 184-193.

Strickland, M.J., Gass, K.M., Goldman, G.T., Mulholland, J.A. (2015). Effects of ambient air pollution measurement error on health effect estimates in time series studies: a simulation-based analysis. Journal of Exposure Science and Environmental Epidemiology, 25: 160-166.

U.S. Environmental Protection Agency. (2017). Overview of the Clean Air Act and Air Pollution. Washington, D.C. Accessed June 2017 at www.epa.gov.

U.S. Environmental Protection Agency. (2017). Particulate matter (PM) basics [fact sheet]. Washington, D.C. Accessed June 2017 at www.epa.gov.

Utah Department of Environmental Quality. (2017). Utah Air Monitoring Program. Accessed June 2017 at www.airmonitoring.utah.gov.

Utah Department of Health. (2017). Air pollution and public health in Utah: Air quality conditions. Accessed July 2017 at www.health.utah.gov.

Watterson, T.L., Sorensen, J., Martin, R., Coulombe, Jr. R.A. (2007). Effects of $PM_{2.5}$ collected from Cache Valley Utah on genes associated with the inflammatory response in human lung cells. Journal of Toxicology and Environmental Health, 70(20): 1731-1744.

World Health Organization (2016). WHO releases country estimates on air pollution exposure and health impact [Press release]. Retrieved from http://www.who.int/mediacentre/news/releases/2016/air-pollution-estimates/en/.

Wu, Y., Lin, Y., Yu, H., Chen, J., Chen, T., Sun, Y., Wen, L., Yip, P., Chu, Y., Chen, Y. (2015). Association between air pollutants and dementia risk in the elderly. Alzheimer's & Dementia: Diagnosis, Assessment & Disease Monitoring, 1(2): 220-228.

Yang, L., Hou, X., Wei, Y., Thai, P., Chai, F. (2017). Biomarkers of the health outcomes associated with ambient particulate matter exposure. Science of the Total Environment, 579: 1446-1459.

Yin, W., Hou, J., Xu, T., Cheng, J., Wang, X., Jiao, S., Wang, L., Huang, C., Zhang, Y., Yuan, J. (2017). Association of individual-level concentrations and human respiratory tract deposited doses of fine particulate matter with alternation in blood pressure. Environmental Pollution, 230: 621-631.

AUTHOR BIOGRAPHY

Kristina Renee Krepinski was born in Portland Oregon on November 22, 1994. When she was just 1 year old, her family moved to Parker, Colorado. Kristina attended Chaparral High School, where during her junior year she took a 6am Pre-Med class that sparked her interest in medicine. Despite the early class hour, she found herself excited every day to learn more about the healthcare field, especially on the cadaver lab days. Upon graduating high school in 2013, she decided to pursue a career in medicine. Kristina attended Utah State University from the fall of 2013 to the summer of 2017, graduating with a Bachelor of Science degree in Human Biology and with minors in Chemistry and Spanish. During her time at USU, Kristina was involved in the Honors Student Council, in which she aided in the organization of various events held for Honors students. She additionally volunteered in 2 different research labs, 1 in the Psychology department and another in the Animal, Dairy and Veterinary Sciences department. As part of completion for her Spanish minor, Kristina also had the opportunity to study abroad in Spain for 4 weeks during the summer of 2016, where she was able to experience and submerge herself into a different culture.

Kristina plans to take a year off from school, during which she will work and gain experience in the healthcare field. After that time, she will apply to medical schools, and (hopefully) will be accepted and will further her education in the medical field.