EFFECTS OF VOLCANIC GAS (VOG) ON THE LUNG FUNCTION AND SELF-REPORTED SYMPTOMS OF HAWAI'I VOLCANOES NATIONAL PARK WORKERS

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I dedicate this dissertation to my son, Alexander I-Shiang "Miu-Miu" Krupitsky.

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ABSTRACT

Introduction: Kilauea, the largest stationary source of surfer dioxide (SO_2) in the nation, has been erupting continuously since 1986. The visible cloud (vog) formed by emitted gases in combination with moisture and sunlight may be directed by the wind and can be visible throughout the Hawai`i Islands. Kilauea is located in the Hawai`i Volcanoes National Park (HVNP) which has 5,000 visitors daily and is the workplace of 750 employees who have the highest exposure to vog.

Methods: This cohort study was designed to examine the association between volcanic emissions (vog) as indicated by the degree of particulate matter ($PM_{1.0}$), sulfur dioxideSO_2, and visual assessment (VVI) and its impact on self-reported symptoms and lung function measurements in HVNP workers. Self-reported symptoms and PEF and FEV1 measurements were recorded daily by park workers and volunteers.

Results: Visually observed vog, $PM_{1.0}$ and SO_2 were statistically significantly associated with self-reported symptoms: cough, wheeze, headache, shortness of breath, sore, itchy, watery eyes, and irritation of nose/sinus/throat but not with PEF and FEV1. Increases in SO_2 seemed to have an immediate (0 days lag) effect on symptoms; during maximum SO_2 days of the period of study ($SO_{2\,max}$ = 173 ppb) the odds of having symptoms increased by two fold for the same day compared to days with the lowest SO_2 measurement ($SO_{2\,min}$= 0 ppb). The greatest relationship between $PM_{1.0}$ and symptoms is delayed by one day; one day after the maximum $PM_{1.0}$ ($PM_{1.0}$ max = 7.85 um/m^3), the odds of having symptoms

increase by 1.5 times compared to days with the lowest $PM_{1.0}$ measurement ($PM_{1.0\ min}$= 0 ppb). In contrast, the relationship between visual vog index (VVI) and symptoms seem to be greatest two days after exposure; two days after "heavy haze" (VVI=3) the odds of having symptoms increase by 1.53 compared to "clear" days (VVI = 0).

Conclusion: Visual vog observers can provide reliable data which are correlated with data from SO_2 and $PM_{1.0}$ monitors. Visually observed vog is as useful tool of predicting self-reported symptoms as SO_2 and $PM_{1.0}$ monitors. Network of visual observes can provide useful assessment of the park.

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CHAPTER I

INTRODUCTION

For thousands of years, volcanoes have occupied a prominent place in human history, fascinating people with their mystery and beauty. These symbols of power can be creative, as well as potentially destructive. They not only helped to shape the lands surrounding them, but the ideas and culture of the people who came to inhabit them. At times these sentinels were viewed as the homes of deities like Pele, or themselves as governors of the natural world. In the more recent eras of human development, scientific methods have replaced superstition as a means of explaining the occurrences of natural calamities.

The eruptions of Santorini in 1628 BC and Vesuvius in 79 AD caused human history's most dramatic extinction and destruction up to that point, demonstrating the devastating capabilities of volcanoes. Today, one out of 12 people in the world inhabits a volcanic danger zone (Zuskin et al. 2007). Through the numerous of studies of volcanic activity, the scientific community gains a better understanding of the nature of these phenomena.

Volcanoes typically consist of mountains that are built up around vents that lead through the earth's crust to reservoirs of molten rock and gases. Pressure builds as these materials are forced against the earth's surface by the weight of the mountain above, causing an eruption through vents or surface weaknesses. Eruptive materials consist of lava, ash flow, and airborne ash and dust, called tephra. The accumulated solid rock on top

is heavier than the molten rock beneath, causing the buildup of pressure. During eruptions, lava often flows downhill from the vent due to gravity, but if pressure is high enough, it may also violently shoot into the air, or even explode from the top of the volcano. Larger fragments fall back and accumulate around the vent, while dust and ash may be carried by winds and land many miles away. Particulate matter (small airborne particles) and gases may be spread by stratospheric winds. The particulate matter (PM) refers to a complex mixture of solid and liquid particles that are composed of various chemical compounds and have range of physical properties (USGS, 2008).

Molten rock below the surface of the earth is referred to as magma, but it is called lava once it erupts from volcanic vents. In addition, magma is generally composed of some crystals, pieces of solid rock, and assorted dissolved gases, but its main components are oxygen, silicon, aluminum, iron, magnesium, calcium, sodium, potassium, titanium, and manganese. During the cooling process, liquid magma returns to its solid form as magmatic rock.

Due to its elevated temperature, lava is usually red as it erupts, but darkens as it cools, becoming burgundy, gray or black. Lava is more fluid when it is very hot and has high gas content, but as it cools, it becomes thicker, with chunks of solid rock. Cooler rock contains less gas, and is higher in silicon, sodium and potassium.

During eruption, dissolved gasses contained in the magma are released as the pressure is suddenly reduced. This release of gas occurs more easily from hot, fluid lava. Thicker, more viscous lava does not allow gas to escape as freely, which causes pressure to build up. In some cases, this produces explosive results. Pumice is very light volcanic rock that is riddled with holes from gas pockets. It is sometimes described as rock froth,

and can have the appearance of a sponge. It is produced by the separation of gasses from lava as it cools and solidifies.

Volcanic eruptions have occurred since the formation of the earth, long before the advent of human history. One of the major eruptions in history came to have a tremendous impact on the way people view volcanoes: the fateful eruption of Mount Vesuvius in Pompeii in AD 79, which ended the lives of thousands of men, women, and children (de Divitiis et al. 2004), burying their city and their culture for nearly 1700 years. Mount Vesuvius has erupted many times before and after the famous eruption of 79 AD, but this tragic event stood out as the most devastating volcanic occurrence in human history, which has haunted the imaginations of people for two millennia. Recent studies have made accurate reconstructions of the possible phases of the eruption. The archeological excavations there have brought us a rare glimpse of life in the ancient world, as the raining ash preserved well the human and material remains as they were on that fateful day. This event made an impact on local stories and legends, which continues to have force to this day, as evidenced by the many books and films that have been produced surrounding it.

Some of the other historical eruptions are as follows:

1. About 700,000 years ago, an enormous explosion occurred 4 miles beneath the earth's surface, which spewed molten rock, leaving a 10 by 20 mile depression, known today as the Long Valley Caldera, in California.
2. In 1669, the eruption of Mount Etna in Sicily sent a flow of lava into the town of Catania. The lava flow and other eruptive elements cost the lives of over 20,000 people in the region.

3. In 1783, the fishing and agricultural industries of Iceland were devastated by the eruption of Mount Skaptar, leading to famine and the starvation of 20 percent of the population there.
4. 1786 was the year of the last known eruption of Mount Shasta, in California, which is thought to erupt every 600 to 800 years.
5. In 1815, the eruption of Mount Tambora on Sumbawa Island in Indonesia, caused whirlwinds and tsunamis, resulting in nearly 12,000 lives lost.
6. In 1883, Krakatoa erupted with an explosion so large that 70 pound boulders were flung as far as 50 miles, and the explosion itself was heard 3,000 miles away. Villages including Sumatra and Java were devastated by a resulting 130 foot tsunami, and nearly 36,000 people were killed. For two years after the eruption, the moon appeared to have a blue or green hue, due to dust and air pollution that resulted.
7. In 1902, the entire population of the island of Martinique was suffocated by ash and poisonous gasses from the explosion of Mount Pelee.
8. From 1914 to 1915, Lassen Peak in California erupted, however no deaths were reported.
9. In 1980, Mount St. Helens in Washington State erupted, blowing off 1,300 feet of its top. 57 people lost their lives in the eruption.
10. In 1991, the eruption of Mount Pinatubo in the Philippines emitted 20 million tons of sulfuric acid as far as 12 miles into the stratosphere. Nearly 750 lives were lost from the eruption and its after effects.

11. Two of the most studied volcanoes are Kilauea and Mauna Loa, in Hawai`i, which erupt every couple of years. These eruptions, although a source of pollution, erupt nonviolently with few fatalities (Livescience, 2008).

Nearly half a billion people worldwide live in the shadow of volcanic threat, whether they are aware of it or not. There are about 500 active volcanoes throughout the world, with 10 to 40 eruptions observed annually (Zuskin et al. 2007), however, many eruptions go unobserved, such as those that occur on the ocean floor. The edges of tectonic plates, where magma may be forced through the crust, are where the majority of volcanoes are located. The renowned Ring of Fire, that surrounds the Pacific Ocean Plate, is one example.

Throughout the world, many cities and densely populated areas have been developed in the regions around volcanoes, which poses potential hazards to the lives and health of inhabitants. Risks are not exclusive to those directly around volcanoes. Because gas and ash may be dispersed by winds to far distances, even those who live thousands of miles from the site of an eruption may be affected by it, or affected indirectly through climate changes.

Some of these areas, recognizing risks, take precautionary actions to provide public safety. In 1994, Popocatepetl, the most famous volcano in Mexico, became active, emitting large amounts of gas and ash into the atmosphere. Because Popocatepetl is located in a densely populated area near Mexico City, geologists and local authorities set up an early warning system to monitor the volcano's activity. An eruption was predicted in 2000, which required the evacuation of neighboring populations . The system uses color codes, green for normal, yellow for alert, and red for evacuation. The system is intended to

be permanently in place, and includes a combination of resources from local authorities, to hospitals and medical centers, as well as systems to keep the public informed (Zeballos et al. 1996). Such plans usually involve volcanic risk management, disaster planning, treatment for the injured, epidemiological surveillance, health hazard research, and the dissemination of public information on health risks and safety.

In recorded history, the United States has seen the eruption of nearly fifty volcanoes, giving the United States a rank of third, after Indonesia and Japan, in the number of historically active volcanoes (U.S. Dept. of the Interior, Geological Survey, 2007).

CHAPTER II

LITERATURE REVIEW

2.1 Relationship between air quality measurements and human health.

There have been a variety of studies conducted on the health impacts of volcanic eruptions (Zuskin et al. 2007; Shimizu et al. 2007; Horwell 2007; Bruno et al. 2006; Shojimu et al. 2006; Fano et al. 2005; Perseius et al. 2005; Heikens et al. 2005; Biggeri et al. 2004; Forbes et al. 2003; Searl et al. 2002; Shinkura et al. 1999). In addition, individual and community economic conditions are affected by eruptions (Self 2006; Tobin and Whiteford 2002; Cooper et al. 1998). Physical conditions such as trauma, respiratory conditions, and mental conditions such as depression, anxiety, nightmares, and neurosis are among the health affects that people experience as a result of volcanic activity. Along with magma and steam, volcanoes release poisonous gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2), carbon monoxide (CO), hydrogen sulfide (H_2S), carbon sulfide (CS), carbon disulfide (CS_2), hydrogen chloride (HCl), hydrogen (H_2), methane (CH_4), hydrogen fluoride (HF), hydrogen bromide (HBr) and various organic compounds; these gasses are considered air pollutants. In addition, heavy metals - mercury, lead, and gold are released into the air during eruptions (Zuskin et al. 2007).

Levels of air pollution are constantly fluctuating due to various environmental factors (wind direction, wind speed, and humidity), natural disasters such as volcanic eruptions, and human activity. Ozone, nitrogen dioxide and sulfur dioxide are among the

most prominent gaseous pollutants associated with effects on human health, but other gases and particulate matter (PM) exist in the atmosphere as well. Since many of these pollutants are created through combinations or reactions of other gasses rather than being directly released into the atmosphere at particular sources (known as point sources), it can be difficult to predict or manage their prevalence.

It is challenging to measure airborne particles (particulate matter) since the size of particles may vary from a few nanometers to tens of micrometers. Numerous techniques have been developed to measure them, such as calculating the total mass of particles in a given volume of air and total number of parts per value of air. Different techniques also produce different results. Particulate matter is generally measured by total mass, by size (such as PM_{25}, PM_{13}, PM_{10}, $PM_{2.5}$ and $PM_{1.0}$) and number distribution, and by composition. For example, fine particles are 2.5 micrometers in diameter and smaller and are referred to as $PM_{2.5}$. U.S. Environmental Protection Agency (EPA) commonly differentiates PM based on size as either ultrafine ($PM_{1.0}$), fine ($PM_{2.5}$), or coarse (PM_{10}) (EPA, 2008).

Studies have shown that the same amount of ultrafine $PM_{1.0}$ can cause more injury than other size classes of PM. A review of epidemiological studies suggests that fine particles (PM with diameters less than 2.5 μm, or $PM_{2.5}$) are strongly associated with respiratory and cardiovascular effects. However, other studies have shown that larger particles (PM_{10}) do not contribute significantly to an increased risk of adverse health effects (EPA, 2008). PM composition also determines its effects on human health; for example, metal components of PM might be particularly harmful. A study conducted near a steel mill revealed that there was a significant decrease in hospital admissions for

respiratory and cardiovascular-related causes while the mill was closed (Ransom, 1995).

The effects of air pollution on mortality were estimated in an ecologic prospective cohort study conducted by Dockery and colleagues (1993). This study was conducted over a period of 14 - 16 years, and included 8,111 adults in six U.S. cities. This study concluded that cigarette smoking was strongly correlated with mortality. The authors additionally, observed strong correlations between air pollution and mortality after adjusting for smoking and other risk factors. The adjusted mortality rate ratio for highly polluted cities was 1.26 (95% CI [1.08, 1.47]) times greater than the least polluted cities. Mortality due to lung cancer and cardiopulmonary disease were significantly correlated with air pollution, however when mortality from all causes was considered together, no significant associations were observed. The greatest correlations were found between mortality and air pollution with fine particulates, including sulfates. Authors concluded that fine particulate matter (PM) contribute to increased mortality.

Biggeri and colleagues (2004) performed a meta-analysis of studies conducted in Italy that focus on the short-term effects of air pollution for the period 1996-2002 (MISA-2) in 15 Italian cities (10 million inhabitants). Each city was fitted with a generalized linear model (GLM) on daily counts of health events. The effects of pollution were recorded as an increase in the percentage of deaths or hospital visits correlated with an increase of 10 microg/m^3 of SO_2, NO_2 and PM_{10}, and 1 mg/m^3 of CO. An increase in mortality for natural causes was linked to an increase in air pollution (for NO_2 0.6% 95% CI [0.3%, 0.9%]; CO 1.2% [0.6%, 1.7]; PM_{10} 0.31% [-0.2%, 0.7%]). The authors observed similar findings for mortality and hospital visits for cardiac and respiratory conditions. Cumulative effects for 15 day periods indicated increased risk of respiratory

diseases (PM_{10} 1.65% CI 95% [0.3%, 3.0%]). The results of meta-regression, mortality for all causes (SMR) and PM_{10}/NO_2 ratio indicated a correlation between PM_{10} and increased incidence of mortality and hospital admissions.

Similarly, in France, Dab and colleagues (1996) carried out a time series analysis of daily air pollutant levels in order to study the short term respiratory health effects of the Paris area population. In this analysis, air pollution was indicated by measurement of black smoke (BS) (15 monitoring stations), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter less than 13 microns in diameter (PM_{13}), and ozone (O_3) (4 stations). This study indicated that the mean daily concentration of PM_{13} and daily 1 hour maximum of SO_2 appreciably influenced daily mortality rates from respiratory factors. For an increase in the concentration of PM_{13} of 100 micrograms/m^3 above its 5th percentile value, a 17% increase in the risk of death from respiratory causes was observed. PM_{13} and BS were associated with hospital admissions from respiratory causes (an increased risk of 4.1% when the BS level increased above its 5th percentile value by 100 micrograms/m^3). SO_2 levels were consistently linked to hospital admissions for all forms of respiratory conditions, such as asthma and chronic obstructive pulmonary disease (COPD). Asthma was also associated with NO_2 concentrations. Additional studies that were performed as part of a wider research plan to study the connection between health and ambient air quality in Windsor, Ontario, Canada, from 1995 to 2000, also observed significant correlations between SO_2, NO_2 , CO, COH, or PM_{10} and daily hospital visits due to respiratory causes (Luginaah et al. 2005).

In the United States, Mar and colleagues (2004) observed a group of adults and children in the Washington State over many months and observed their respiratory

symptoms in relation to levels of particulate matter of various sizes ($PM_{1.0}$, $PM_{2.5}$, PM_{10}, and PM coarse fraction). Diaries were used to collect information on respiratory symptoms and medication use. Air pollution data were provided by the Washington State University and the local air agency. Spokane, WA, where data were collected, is located in a semiarid region with various sources of particulate matter including automobiles, woodstoves, the use of fire to dispose of agricultural debris, re-suspended road dust, and dust storms. 16 adults and 9 children took part in the Spokane study. Most of the adult subjects were involved for longer than 1 year and the children were observed for more than 8 months. The researchers observed a significant correlation between cough and PM_{10}, $PM_{2.5}$, PM coarse fraction, and $PM_{1.0}$ ($p<0.05$) in the child participants. PM_{10} and coarse fraction were indicated as contributing to mucus production and nasal drip, however no correlation between particulate matter and adverse respiratory conditions was observed in the adult participants. These findings may indicate that children have an increased susceptibility to air pollution above that of normal adults, or that children have a higher degree of exposure due to increased time spent outside, whereas adults spend more time indoors at home or at work. These results also indicate that conditions of people with asthma can be aggravated by both larger and smaller particles.

There have not been many studies conducted in China for the effects of $PM_{2.5}$ and $PM_{10-2.5}$ on human health, since $PM_{2.5}$ and $PM_{10-2.5}$ are not the criteria they use for air pollution. Of the studies conducted, there is great inconsistency between findings. Kan and colleagues (2007) performed a time series analysis to determine the direct effects of $PM_{2.5}$ and $PM_{10-2.5}$ on daily death rates in Shanghai, China beginning in January, 2004 and ending in December of 2005. Generalized additive model (GAM) was utilized with

penalized splines to study the death rates, levels of particulate matter and covariate data. The regular levels of $PM_{2.5}$ and $PM_{10-2.5}$ were 56.4 micrograms/m^3 and 52.3 micrograms/m^3 during the study period, and $PM_{2.5}$ was approximately 53.0% of the PM_{10} mass. The $PM_{2.5}$ concentration in Shanghai was much greater than the standards of the Global Air Quality Guidelines established by World Health Organization (10 micrograms/m^3 for annual mean) or the U.S. National Ambient Air Quality Standards (15 micrograms/m^3 for annual mean. There was a correlation between $PM_{2.5}$ and mortality from all causes as well as cardiorespiratory conditions in Shanghai, though $PM_{10-2.5}$ did not create an observable impact on mortality. An increase of 10 microgram/m^3 in the 2-day moving average level of $PM_{2.5}$ corresponded to a 0.36% (95% CI 0.11%, 0.61%), 0.41% (95% CI 0.01%, 0.82%) and 0.95% (95% CI 0.16%, 1.73%) increase of overall, cardiovascular and respiratory death rates. The impacts of $PM_{10-2.5}$ on mortality were not as defined. This study was somewhat of a milestone for China in showing the first statistically considerable substantiation of the adverse effects of $PM_{2.5}$ on the health of the Chinese population.

In experimental research studies, volunteers that agreed to exercise within a chamber while being exposed to sulfuric acid (H_2SO_4) reported acute health effects (Linn et al., 1997; Hackney et al., 1989). A key factor is length of time exposed to the substance. Short-term, high level exposures have a greater impact on health than long term, low level exposures for many substances (Klaassen, 1996). Another study was conducted where individuals were exposed to SO_2 at concentrations of 20 mg/m^3 for 5 days, 3 hours per day. Among the effects were a decrease in lung volume and pulmonary diffusing capacity, and an increase in lung weight and body weight ratio, protein level

and number of neutrophils in pulmonary lavage fluid. In addition, a single 1-hr exposure to 20 mg/m^3 resulted in an increase of bronchial reactivity. There was also an indication that SO_2 and sulfuric acid may have toxic interactions (Chen et al., 1992; Amdur and Chen, 1989).

Elevated levels of SO_2 and other sulfur species may put individuals at risk by either worsening current conditions or by direct irritation (Thompson et al., 2001; Norris et al., 2000; Amdur, 1989; Hackney et al.,1989; Linn et al., 1997). Adverse effects have been observed when human subjects or experimental animals have been exposed to sulfuric acid, and it has been seen to exacerbate the irritant response to ozone in both rats and humans (Amdur, 1989).

Air quality has been found to have effects on human metabolism regardless of the place of exposure (workplace, outdoor, or indoor) in cross sectional, case-control, cohort and experimental studies. The health outcome depends on the composition of the pollutant; exposure to crystalline silica mineral might lead to developing silicosis over a period of time whereas exposures to SO_2, SO_3, and H_2SO_4 might lead to more immediate respiratory responses. Fine and ultrafine PM were found to be associated with an increase in mortality from all causes and exacerbation of cardiorespiratory conditions.

2.2 Volcanic Phenomena and Associated Health Hazards.

A number of hazards exist between, as well as during, volcanic eruptions. Ash and other particulate matter may linger in the air for many months after eruptions, occasionally stirred up again by wind or other factors and redistributed for thousands of miles (USGS Fact Sheet 002-97). Primary volcanic hazards are a product of direct volcanic activity and

its immediate effects, whereas secondary hazards are indirectly realized and can continue for a long period after an eruption. Lava flows, mud slides, earthquakes, tsunamis and gaseous pollutants are examples of hazards that are manifest during or after an eruption and are centrally located around the volcano. Eruptions are frequently accompanied by volcanic earthquakes, which themselves can do a significant amount of damage. Such quakes may be spontaneous and unpredictable. They may also occur at any time, even when the volcano is inactive. Transportation and communication systems may be affected, as well as water contamination, waste disposal, crop destruction, building collapse, fewer periods of rain and many other conditions (Cooper et al., 1998; Cronin and Sharp, 2002; Tobin and Whiteford, 2002; Self, 2006; Zuskin et al., 2007). Secondary hazards include the impact of toxic gas and ash, and subsequent respiratory conditions (Hansell and Oppenheimer, 2004), eye and skin conditions (Convit et al., 2006), and psychological effects (Perseius et al., 2005), all of which may occur great distances from their original source.

A systematic literature review was done by Hansell and Oppenheimer (2004) of primary sources dealing with volcanic gas and its impact on human health. In some of those sources, they identified SO_2 and acid aerosols from eruptions as adverse agents on respiratory illness and increased death rates. Additionally, deaths from asphyxiation were reported as being caused by volcanic and geothermal H_2S and CO_2 emissions. Long term exposure is indicated as a cause of damage to the nervous and respiratory systems. Some large scale impacts have been recorded as well, such as the Laki fissure eruption, which cast a volcanic haze from Iceland to Syria in 1783-84.

Fano and colleagues (2005) carried out a study in 2002 to determine the health

effects of Mount Etna's eruption in Sicily through increased mortality and hospital visits, as compared to statistics from the year before (same day of the week). Increased levels of suspended particulate matter were recorded (over 200 micrograms/m^3) in the vicinity of the volcano. No effects were recorded on overall and cause-specific mortality during this period, however hospitalizations increased for patients suffering cardiovascular symptoms (ischemic diseases: RR=1.31, 95% CI [1.10-1.56]; myocardial infarction: RR 1.34, 95% CI [1.02-1.76]) and for cerebrovascular diseases (RR=1.24, 95% CI [1.05-1.47]). These increases showed most prominently among the older population, however the researchers indicate that stress may be the causal factor, as daily hospitalizations for cardiovascular disease did not correlate to levels of PM_{10}.

On the 9th of April, 1992, Cerro Negro in Nicaragua erupted, emitting approximately 1.7 million tons of ash, which dispersed over a 200 square kilometer area. Malilay and colleagues (1992) conducted a study to determine the impact this would have on nearly 300,000 residents. They obtained information from the national epidemiologic surveillance system, which they used for this assessment. Comparing figures before and after the eruption, respiratory illnesses were found to be 3.6 times greater in the area near the disaster zone and 6.0 times higher within the disaster zone. Hospital admission for acute diarrhea increased by 6.0 times in both areas, a common condition associated with volcanic eruptions; this implies the contamination of water supplies by volcanic ash. Children appeared to be at the greatest risk for these conditions, as most of the hospitalizations were for children 5 and under.

Bradshow and colleagues (1997) examined the effects of exposure to airborne volcanic ash from the eruption of Mount Ruapehu in New Zealand on previously diagnosed

asthmatics. To this end, they engaged 1,392 asthmatic volunteers; however, after four years the target group was reduced to 1,155 due to failure to follow-up. Two months after a major eruption, the remaining 1,155 subjects were asked to participate in a symptom survey. 361 of the subjects inhabited the exposed area while 794 occupied the non-exposed areas. The results of the surveys indicated that there was no correlation between living in a volcanic ash exposed area and the prevalence of asthma or use of asthma medicine. 29.3% of the exposed group experienced nighttime shortness of breath as compared to 24.7% (OR = 1.26, 95% CI [0.83-1.78]) in the non-exposed group. Likewise, 30.9% of the exposed group experienced an asthma attack during the two month period, while 31.9% (OR = 0.96, 95% CI [0.69-1.33]) of the non-exposed group experienced one. Asthma medication was taken by 48.4% of the exposed group during this 2 month period after the eruption compared to 53% of the non-exposed group (OR = 0.83, 95%, CI [0.61-1.12]). The slight increase in nighttime difficulty breathing in the exposed group was not deemed significant.

Five years later, another New Zealand study was authored by Bates and colleagues (2002) that looked at the health effects of continued exposure to hydrogen sulfide (H_2S). The city of Rotorua is located over a geothermal area and it population is consequently the largest population in the world to be naturally exposed to H_2S. The authors categorized certain areas within or around Rotorua as high, medium, or low-H_2S exposure areas. Standardized incidence ratios were computed for respiratory, neurological and cardiovascular responses using 1993-1996 morbidity data. Exposure-response trends for all three emerged, strongly indicating that exposure to H_2S leads to chronic health problems.

33 volcanoes in the United States have been the sites of 45 eruptions and 15 cases of "notable volcanic unrest" since 1980 (USGS, 2006). Witham (2005) conducted a comprehensive worldwide review that indicated that 4-6 million have been adversely affected by approximately 490 incidents of volcanic activity in the 20th Century. Approximately 50% of these incidents resulted in the loss of human life, totaling in 80,000 - 100,000 deaths. Mudflows, tsunamis, illness outbreaks and deprivation are among the major causes of post-volcanic fatalities. A detailed review of health risks associated with volcanic activity are presented in Table 1.

Table 1. Hazards associated with volcanic phenomena*.

Hazard type	Brief description	Potential health effects	Example
Acid rain	Acidic volcanic gas. Rain becomes acidic when falling through volcanic gas and acid particle emissions and may dissolve metal roofs.	Irritant to eyes, skin. Secondary effects on vegetation, property and water quality. (Rainwater collected from metal roofs may be contaminated with metals such as lead, due to corrosion.)	Masaya, Nicaragua, which has been degassing from 1986 to the present.

Table 1. (Continued) Hazards associated with volcanic phenomena*.

Hazard type	Brief description	Potential health effects	Example
Ash and tephra	Ash is a collective term for fine pyroclasts (solid fragments 2 mm diameter, ejected from volcanoes). Tehpra is the collective term for solid fragments such as ash or pumice ejected from volcanoes that have fallen to the ground from an eruption cloud.	Airborne ash—respiratory and cardiovascular hazard (asthma, bronchitis, pneumoconiosis) Irritant to eyes and skin. Ash falls—can lead to property damage, contaminate water (e.g. with fluorine carried on ash or by causing turbidity), contaminate or bury agricultural land. Mesothelioma risk reported from weathered volcanic ash in certain areas.	Soufriere Hills, Montserrat 1995-present; Mount St. Helens, USA, 1980 Laki, Iceland, 1783-4. Famine. Biancavilla, Eastern Sicily.
Ballistics (bombs, Blocks) Global climate change.	Rocks or lava lumps ejected during major and minor eruptions Massive eruptions cause release of acid aerosols and fine ash into the stratosphere, that block sunlight and are associated with global cooling and may accelerate ozone loss.	Impact injuries, burns. Secondary property damage. Indirect impact via reduced crop yields.	Galeras, Columbia, 1993 Laki fissure eruption, Iceland 1783 ; Krakatau eruption, Indonesia 1883
Earthquakes.	Earthquakes can be associated with volcanic activity.	Property damage resulting in impact injuries. May cause tsunami.	El Chicho´n, Mexico, 1982

Table 1. (Continued) Hazards associated with volcanic phenomena*.

Hazard type	Brief description	Potential health effects	Example
Gas and acid particle emissions.	Emissions of SO_2, sulfuric acid aerosol, HCl, HF, CO_2, H_2S, radon and other gases may occur in association with eruptions or through degassing activity. Soil gas emissions of gases such as CO_2, H_2S, and radon are common in many volcanic areas (radon emissions are problematic only in houses with ground gas diffusion where CO_2 forms a carrier gas).	Acid gases: bronchoconstriction, aggravation of respiratory disease; eye and skin irritation. CO_2: asphyxiation; secondary effects on vegetation, e.g. areas of ''tree-kill''. H_2S: asphyxiation; low level long term population exposures potentially impacting on respiratory, cardiovascular, and nervous system. Radon: lung cancer risk with long term exposure.	Acid gas effects: occupational study of park rangers in Hawai'i Volcanoes National Park (reference Stephenson, 1991 on OEM website). CO_2: Sinila volcano, Dieng Plateau, Indonesia, 1979,139 deaths. Earthquake released large amounts of CO_2 held under pressure in a hydrothermal system. H_2S: death of a geothermal power plant worker (reference Kage, 1998 on OEM website); population exposures in Rotorua, New Zealand. No studies specifically in relation to volcanic exposures.
Landslides, debris avalanches and lahars	Debris avalanches are fast moving, gravity driven currents of partially or fully water saturated volcanic debris. If the debris flow consists of a significant fraction of clay sized particles it is called a lahar or mudflow. May be triggered by eruptions, gravity, earthquakes, or heavy rain.	Drowning, impact injuries. Secondary damage to property and agricultural land.	Nevado del Ruı´z/Armero, Columbia 1985. Lahar caused by a small eruption melting snow and ice, resulted in 23,000 Deaths. Mount St Helens, USA, 1980. Kelut, Java 1966. Hundreds of deaths from lahars caused by eruptive activity destroying a crater lake.

Table 1. (Continued) Hazards associated with volcanic phenomena*.

Hazard type	Brief description	Potential health effects	Example
Ground deformation Jo¨kulhlaups	Subsidence and ground cracking Melt water flood resulting from a volcanic eruption under a glacier.	Secondary effects on property and roads. Those of flooding: drowning and impact injuries. Secondary effects on property and agricultural land.	Mount Etna, Italy, 2001. Skeiðara` rsandur, Iceland, 1996.
Landslides, debris avalanches and lahars	Debris avalanches are fast moving, gravity driven currents of partially or fully water saturated volcanic debris. If the debris flow consists of a significant fraction of clay sized particles it is called a lahar or mudflow. May be triggered by eruptions, gravity, earthquakes, or heavy rain.	Drowning, impact injuries. Secondary damage to property and agricultural land.	Nevado del Ruı´z/Armero, Columbia 1985. Lahar caused by a small eruption melting snow and ice, resulted in 23,000 Deaths. Mount St Helens, USA, 1980 Kelut, Java 1966. Hundreds of deaths from lahars caused by eruptive activity destroying a crater lake.
Lava flows	Flows of molten rock. May emit acidic gases. Steam explosions may result from contact with groundwater.	Usually relatively slow moving, therefore allowing evacuation. Thermal injuries. May cause forest and property fires. Methane explosions can occur as lava moves over vegetation.	Nyiragongo, Congo 1977 and 2002 where fast flowing lava resulted in 700 and 170 deaths respectively.
Laze	HCl gas clouds resulting from lava entering sea water.	Chemical conjunctivitis and respiratory effects.	Lava from Pu'u O'o vent, Hawai'i.
Lightning in volcanic clouds	Common in volcanic ash clouds related to eruptions.	Electrocutio.	Paricutı´n, Mexico, 1943. Three killed.

Table 1. (Continued) Hazards associated with volcanic phenomena*.

Hazard type	Brief description	Potential health effects	Example
Pyroclastic density currents	Flows of hot ash, gas and rocks, resulting from the effects of gravity on a volcanic eruption cloud.	Thermal injury and death. A high death: injuries ratio of 10:1 among exposed individuals.	Vesuvius, Italy, AD 79: the major cause of death in Herculaneum and Pompeii; Mont Pele´e, Martinique, 1902: 28,600 deaths.
Tsunami	Tidal wave from volcanic debris avalanches into oceans or lakes or occasionally volcanogenic. Earthquakes.	Drowning and injuries from property damage.	Krakatau, Indonesia 1883: 36,000 deaths in Java and Sumatra.

* Taken from the book: 'Francis P, Oppenheimer C. Volcanoes, 2nd edition. Oxford: Oxford University Press, 2004.' (Francis and Oppenheimer 2004)

The respiratory system is the part of the human body most commonly affected by volcanic activity. The majorities of hazard assessments focus on this aspect of the after affects of volcanic phenomena and utilize the study of past events in order to gain a better understanding, make predictions and develop precautions for future events. Several studies have been conducted to determine the effects of ash and other particles on health. Together, they stress the importance of reducing exposure and the necessity of being aware or potential dangers resulting from volcanic activity.

The Soufriere Hills volcano, Montserrat, has been erupting since July 18, 1995 and has emitted ash and other pollution into the air surrounding the island during the majority of this eruptive phase. The ash contains copious amounts of respirable particles and abnormally high quantities of cristobalite (15-20%), which is a crystalline silica mineral. A study was conducted by Searl and colleagues (2002) between December 1996 and April 2000, to ascertain the degrees of personal exposure of islanders to volcanic ash and

cristobalite so as to advise them of the possible dangers involved and the actions that need to be taken to minimize such exposure. The amount of respirable contaminants was measured using cyclone samplers. DUSTTRAK instruments were also utilized to observe levels of PM_{10} in the air at certain locations. The authors determined that periods of dry weather contributed to the amount of airborne dust and ash, and that levels were greater at sites where larger amounts had been deposited. The risk of exposure to particulate matter in the air is greater to those who work or spend a lot of time outdoors, such as landscapers, roofers, and road workers. During the year 1997, numerous such individuals exceeded the recommended limit of occupational exposure to cristobalite. A dozen or more individuals have had great enough exposure to cristobalite for long enough time to develop silicosis, a respiratory condition. However, over 4500 people have lived continually on the island during this eruption period without sufficient exposure to develop this condition. Silicosis involves inflammation or scarring of the lungs, and is developed through regular inhalation of silica. Grinders or potters are at the highest risk. Another study examined how school aged children responded to the sudden increase in airborne particles from the volcano. The results indicated that wheezing was more common among those children previously exposed to low levels of volcanic ash. Among those currently exposed to high concentrations of ash at the time of testing, exercise-induced bronchoconstriction (EIB) was four times (OR=3.85) more prevalent than among those currently exposed to lower levels. Ash emission, therefore, was indicated in worsened lung function of Montserrat children, underlining the effects of exposure and need for treatment of respiratory conditions (Forbes et al., 2003).

In another instance, the Miyake volcano in Japan erupted in August, 2000. A

middle aged woman who was exposed to the ash without a mask suffered inflammation of the lungs, with irregular darkened areas appearing from an air bronchogram during a chest computed tomography diagnosis. Cellular-bronchiolitis appeared surrounding crystals in a thoracoscopic lung biopsy. In a mineralogical analysis, these particles resembled volcanic ash. This supports the conclusion that lung inflammation is correlated to volcanic ash exposure (Shojima et al., 2006).

Later, when Japan's Mount Asama erupted on September 1, 2004, it provided another opportunity to examine the direct effects of the volcanic ash emitted. This was done in a cross-sectional study. The results indicated that 42.9% of patients with asthma exhibited worsened conditions from the ash fall of over 100 g/m^2 area, including symptoms of wheezing, tightness of the chest and cough. These results confirmed the hypothesis that ash fall of over 100 g/m^2, which contained inhalable 10 microm diameter particles and high levels of silica, is indicated in worsening of asthmatic patients. The authors suggested that individuals should take action to avoid this level of exposure. The authors stated that a rise in the numbers of patients suffering from asthmatic conditions such as wheeze and cough in affected areas can be considered diagnostic clues for determining ash-induced asthma (Shimizu Y et al., 2007).

Determining the size of particles and what potential risks are present is an important part of providing public health during future events. Claire Horwell, of the Durham University's Institute of Hazard and Risk Research, has designed a sieving technique which was intended to analyses the grain size of volcanic ash to ascertain its possible threat to human beings. Horwell concluded that characterization of the grain-size distribution (GSD) of volcanic ash was important in determining potential dangers to humans.

Catagorizing particulate matter in terms of their relevance to human health is difficult, however. The fraction of respirable (<4 microm) $PM_{4.0}$ particles varies from 0-17 vol % based upon a range of factors including the style of eruption involved and the distance from the source. A stable relationship was observed between <4 ($PM_{4.0}$) and <10 (PM_{10}) microm particles without regard to eruption style or distance from the source and a weaker correlation between the <4 ($PM_{4.0}$) and <63 (PM_{63}) microm particles. The sieving technique developed by Horwell would an inexpensive means of determining potential hazards without the use of more expensive equipment (Horwell, 2007).

2.3 Hawai`i Islands.

The Hawai`i Island chain was formed by volcanic activity (Figure 1). The Hawaiian Islands are a hot spot extending more than 1,500 miles. This is the result of tectonic plate activity as far as 2000 miles underground, which forces magma to the surface creating 82 volcanoes in the area. This continued activity has been going on for at least 70 million years. The Islands themselves are slowly making their way across the Pacific Ocean at a rate of 5-10 centimeters per year. The estimated lifespan of the islands is 5 to 10 million years, before which they are expected to return beneath the ocean floor.

All of the Hawai`i volcanoes are shield volcanoes, which are noted for being short and squat as low viscosity lava spreads out farther before it cools. This is opposed to high viscosity lava which flows slower, allowing it to cool before it can travel far from the source vents, which results in taller volcanoes with steeper slopes. There are five shield volcanoes that contributed to the construction of the Big Island of Hawai`i, the

largest and most southeastern island of the chain: Kilauea, Mauna Loa, Mauna Kea, Hualalai, and Kohala.

Figure 1. Satellite Image of Hawai`i Islands.

Source: http://www.physics.unlv.edu/~jeffery/astro/earth/geology/Hawai`i_001.jpg.

Nearby Loihi is a young active volcano that has yet to break free of the ocean's surface; it still lies approximately 1,000 meters under water. Haleakala, on the island of Maui, is the only other active volcano in the island chain. Of these, Mauna Loa is the largest, as well as being the earth's most massive mountain. It covers a 10,000 cubic mile area. The highest is Mauna Kea at 13,796 feet. Kilauea is the youngest of these volcanoes and perhaps one of the world's most active. The Kilauea Caldera is 2 miles wide by 3

miles long (Figure 2). It was formed in 1790 by an eruption. Calderas form when remaining magma drains away, leaving a crater at the top of the mountain.

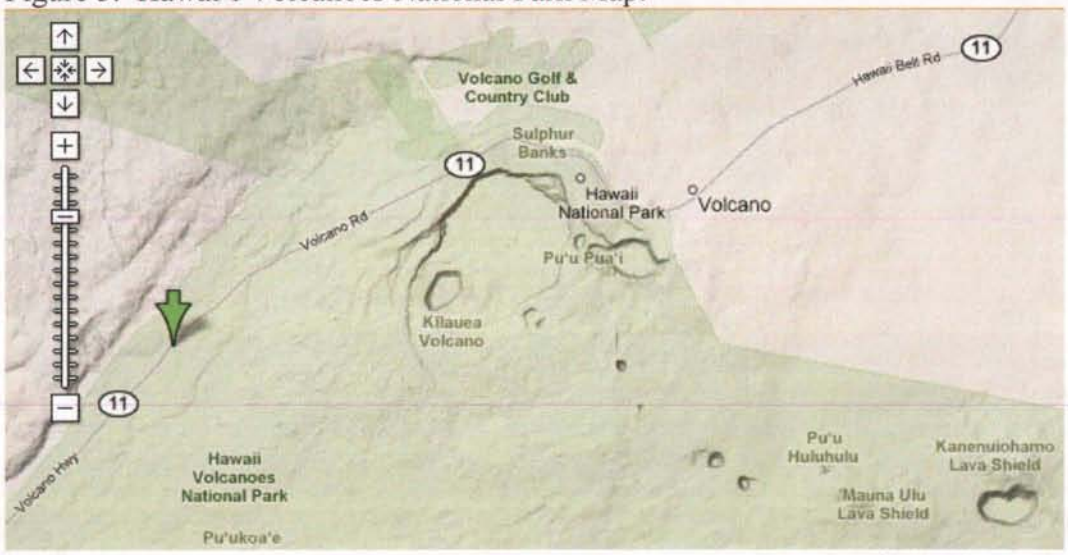
Figure 2. Hawai`i Volcanoes National Park Satellite Image.

Source: Google, 2008.

2.4 Hawai`i Volcanoes National Park.

The Hawai`i Volcanoes National Park, located on the Big Island of Hawai`i, sits on 230,000 acres of land, and was the first designated national park in Hawai`i and the eleventh in the entire United States. It was established in 1916, and has been a World Heritage Site since 1987.

Figure 3. Hawai`i Volcanoes National Park Map.



Source: Google, 2008.

Whereas areas of the park vary in height from sea level to 13,000 feet, climates and temperatures also vary, ranging from 20 to 80 degrees Fahrenheit. Moisture-laden trade winds from the northeast bring abundant rain to the slopes, but they warm and dry out as they near the volcanoes. Because of the diversity of climate and landscape, the park features extreme shifts from humid tropics to hot deserts, and from cool misty forests to open areas of bare rock and, at times, snow.

During eruption, Kilauea emits many gases and particles, including sulfur dioxide, Hg, ash, CO_2 and H_2S. 1,000-2,000 tons of sulfur dioxide have been released into the air daily from Kilauea since 1986 mostly from Pu`u `O`o Vent (Elias and Sutton, 1996), when eruptions became more regular. In 1990, a visible increase was recorded in the quantity of lava flowing above ground and in the volume of volcanic gas released. In March of 2008, Halema`uma`u vent began to expel similar amounts of $SO_2$ as Pu`u `O`o Vent, doubling the amount of SO_2 and ash expelled in the HVNP.

Prevailing trade winds would routinely blew volcanic gas away from island populations during the episodic activity at Pu`u `O`o vent due to there being enough time between containing events (Pearson and Vitousek, 2002). But when the eruption style changed, this was no longer the case. The Big Island of Hawai`i has since seen the effects of lingering volcanic pollution, some of which include damage to natural vegetation and agriculture, automobiles, and other machinery.

The surface area of Kilauea is relatively young, being formed by lava flows less than 1,100 years ago, with only 10% of the surface area estimated to be older than that. In fact, 70% of its surface area is estimated to be less than 600 years old (USGS, 1999).

2.5 Hawai`i Volcanoes National Park - Health Hazards.

The HVNP Health Hazard Evaluation (HHE) was prompted by the increased risks posed to staff and visitors due to elevated exposure to volcanic gasses and ash. Sulfur dioxide (SO_2) is among the gases present, as well as asphalt decomposition products, which are released when lava covers a roadway, and acid fog (laze). Volcanic smog, which is referred to as "vog", and Pele's hair are also concerns. Pele's hair is a fibrous glass-like material that is formed when lava comes into contact with the ocean causing rapid cooling. During the National Institute for Occupational Safety and Health (NIOSH) CDC evaluation conducted in March of 1990, none of these hazards were observed in the park with the exception of SO_2 emissions (Pearson and Vitousek, 2002). Stoiber and Malone (1975) were the first to measure sulfur dioxide (SO_2) emissions from Kilauea, which have been measured on a regular basis since 1979 (Greenland et al., 1985; Elias et al., 1993; Elias and Sutton, 1996).

An acidic steam cloud, known as laze, is formed when lava encounters sea water (Figure 5). The occurrence presents a health concern to the Hawai'i Volcanoes National Park (HVNP) and the nearby town of Kalapana, when laze is directed there by island winds. Environmental measurements to characterize the contaminants of laze produced by Kilauea were developed by Kullman and colleagues (1994) Air samples were collected to determine levels of respirable dust particles, fibers, crystalline silica and other mineral compounds, inorganic acids, trace metals, and organic and inorganic gases. Elevated levels of Hydrochloric acid (HCl) were found in the laze, with dense clouds of laze closer to the sea also containing larger amounts of hydrofluoric acid (HF). The level of HCl found averaged at 7.1 ppm. 5 ppm is the occupational exposure cap for HCl. Samples also included sulfur dioxide at 1.5 ppm, as well as chloride salts. There were not significant amounts of crystalline silica. Samples of settled dust consisted mostly of glass flakes and fibers. 1 in every 11 samples of airborne fibers contain quantifiable levels, and indicated their composition as predominantly that of hydrated calcium sulfate. The results of these studies stress the importance of reducing one's exposure to condensed laze clouds close to their source.

Figure 5. Visual Laze in the Hawai`i Volcanoes National.

Source: U.S. Geological Survey, 2008.

Figure 6. Visual Vog in the Hawai`i Volcanoes National Park.

Source: JP Michaud.

Table 2: Summary of Fatal and non-Fatal Tourist Incidents in Hawai`i Volcanoes National Park, 1997-2002.

Date reported	Incident classification	Description of the incident
07/97	Aircraft	Two tourists from California suffered serious injuries when their rented 1935 WACO biplane replica lost its propeller in mid air and crash landed
08/97	Backcountry	A 38-year old female from Colorado collapsed from heat exhaustion while hiking
10/97	Backcountry	A male tourist from Canada was found dehydrated and suffering from multiple abrasions after being lost for 3 days. The tourist was attempting to follow a trail described in a new guidebook
11/97	Backcountry	A 61-year old German male became disoriented and lost while attempting to follow a trail described in a new guidebook. The tourist sustained only minor injuries
11/97	Backcountry	Two adult visitors from California became lost when attempting to follow a trail described in a new guidebook. The couple were suffering from fatigue when located
01/98	Backcountry	A 51-year old male was found suffering from exhaustion after becoming lost during a night hike to active lava flows
04/98	Backcountry	A 26-year old tourist guiding six other tourists died after falling 10 m onto cooling lava. The illegal tour had entered the park from a restricted entry. Steam from the cooling lava reportedly fogged the glasses of the guide
07/98	Road	A tour bus crashed after the driver died from a heart attack. No passenger injuries were reported
08/98	Backcountry	A 43-year old American male complained of severe chest pains while hiking but refused further medical treatment after being rescued
08/98	Backcountry	Three American brothers, aged 7, 9 and 18, sustained minor scrapes and abrasions while attempting to hike to active lava flows at night
08/98	Backcountry	A male tourist experiencing chest pains and complaining about a shortness of breath was air evacuated from a backcountry hiking trail
04/99	Backcountry	Three hikers from Canada became lost while hiking to the active Pu'u O'o Vent in bad weather. Two of the tourist sustained minor injuries after spending a night in a forest
06/99	Backcountry	A 19-year old female tourist from New York fell 30m into an earth crack. She was hiking at night with no flashlight, ignored warning signs, and sustained multiple scrapes, abrasions, and lacerations to her head and legs
08/99	Aircraft	Two Australian, one German, and six American tourists were killed when their tour plane crashed at 3100 m on the upper slopes of Mauna Loa Volcano. The pilot was attempting an illegal instrument panel flight between Mauna Loa and Mauna Kea Volcano
09/00	Frontcountry	A 50-year old American male tourist sustained second degree burns to his legs after falling into a steam vent. The tourist was walking off-trail at the time of the incident

Table 2: (Continued) Summary of fatal and non-fatal tourist incidents in Hawai`i Volcanoes National Park, 1997-2002.

Date reported	Incident classification	Description of the incident
11/00	Backcountry	The body of a 41-year old American female and a 42-year old American male were found 40 m from the point where active lava was flowing into the ocean. The cause of death was determined to be pulmonary edema from environmental exposure to volcanic fumes
04/01	Frontcountry	University of Oregon geology student sustained multiple abrasions after falling 30 m into an earth crack. The male student was intoxicated and wandering off-trail in the dark 07/01
08/01	Frontcountry	A 26-year old American male slipped 25 m down a cliff after reaching for a hat that had been blown off by the wind. The man was able to stop his fall by grabbing hold of a tree. He sustained multiple lacerations and a broken toe
09/01	Frontcountry	A female tourist sustained minor injuries after becoming lost in a rainforest She was hiking off-trail at the time of the incident
05/02	Road	A tour bus was hit by a car driven by a local resident. The 19 tourists on the bus reported no injuries at the time of the press release
07/02	Frontcountry	A 67-year old man from CA was revived by park rangers with an external defibrillator (AED). The man had recently undergone quadruple bypass surgery and was visiting an area of the park with heavy volcanic fumes
07/02	Frontcountry	A press release reported that 13 tourists were stung by centipedes while viewing advancing lava flows at night. It was suggested in the report that heat from advancing lava flows was forcing the centipedes out of their natural territory
10/02	Backcountry	The body of a 45-year old female from Florida was found near active lava flows. The body had contact burns from lava but the cause of death was determined to be environmental exposure to volcanic fumes. The woman was a day visitor from a cruise ship, hiking by herself, and had a pre-existing heart condition

Source: Reported fatal and non-fatal incidents involving tourists in Hawaii Volcanoes National Park, 1992–2002. Travel Medicine and Infectious Disease, Volume 3, Issue 3.

There are 4000 - 5000 visitors to HVNP daily. The hazards to these visitors depend largely on the attractions visited, time spend in the park, method of travel, activities performed and accommodations (Heggie and Heggie, 2004; Boulware, 2004; Bentley et al., 2000).

A report released by the Hawai`i Volcanoes National Park of past accidents of park visitors is depicted in Table 2. Not all of them are related to respiratory conditions but they are given here to illustrate many hazards posed by volcanoes and the park itself.

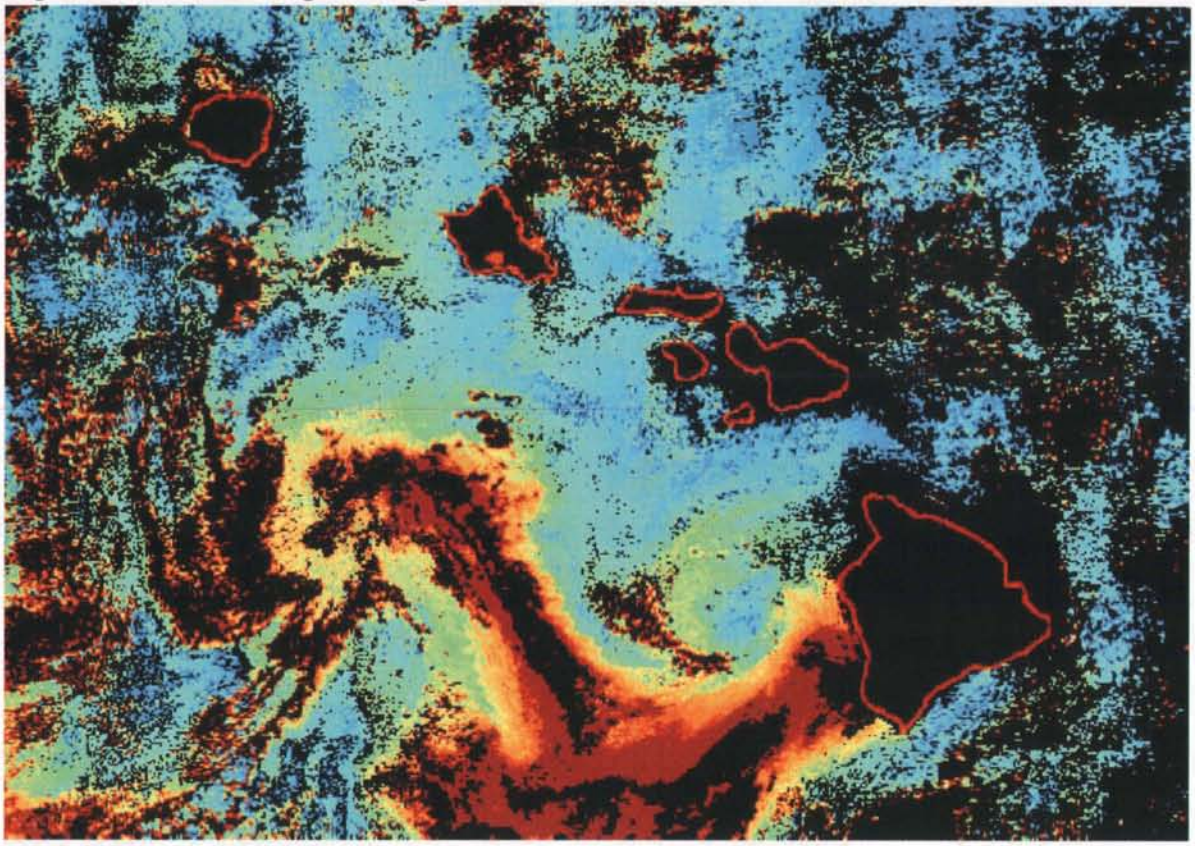
There were reports of a small number of deaths in Japan and Hawai`i-usually of asthmatic tourists-related to high levels of SOi from degassing episodes, but few details were available (Pearson, H. L., Vitousek, P.M. 2002).

2.6 Composition of Vog in the Hawai`i Volcanoes National Park.

Larger cities are faced with the difficulties of smog and acid rain. The word 'smog' is derived from a combination of the words 'smoke' and 'fog', and describes a lingering, visible cloud of smoke. Similarly, the word 'vog' refers to a cloud of volcanic gas that comes into contact with oxygen, humidity and sunlight. Both contain SO_2 as a key ingredient. Smog is produced mainly by smoke and emissions from combustion engines, where vog is produced naturally through volcanic activity. Both present a hazard to plant and animal life and cause aggravation of respiratory functions. Both of these fog types are visible to the naked eye and appear as a gray haze (Figure 6).

During the reaction between sulfur dioxide, humidity, oxygen and dust, a mixture of sulfate (SO_4^{2-}) aerosols, sulfuric acid (H_2SO_4), and other oxidized sulfur species and metals are formed, however the metals are not the primary concern as only low levels of airborne metals are found in the park region and they do not correlate toxicologically with reported health concerns related to vog, which are mostly related to irritation of the eyes and respiratory system (Morrow, 2000). Volcanic smog is mainly a combination of water vapor, sulfur dioxide (SO_2), and fine sulphates, mostly sulfuric acid aerosols (mean diameter P 0.3 mm); the volcanoes in Hawai`i are unique in emitting greater volumes of SO_2 and fewer quantities of ash than other volcanoes (Chuan, 1995).

Figure 7. Satellite Image of Vog Aerosol Particles.



Source: USGS, 2008
note: vog aerosol particles are blown to the west and southwest; satellite image illustrates increasing amounts of vog aerosol particles in yellow, orange, and red, respectively.

Kilauea has been erupting consistently since 1986. The visible cloud formed by this combination may then be directed by the wind. In the island of Hawai`i, trade winds that typically move in a southwesterly direction, carry the vog south around the island where they can then travel up the leeward or Kona coast (Pearson and Vitousek, 2002). During the absence of trade winds, or when they change direction, vog can remain on the eastern side of the island or even be directed toward inhabited areas of neighbor islands. Both sides of the island are known to have episodes of dense vog based on these conditions (Huebert, 1997; Morrow, 2000; Watson and Rose, 2000; Pearson and Vitousek, 2002).

The aerosol was detected in Johnston Island and as far as 1000 km north from the Big Island (Clarke and Porter, 1991) (Figure 7).

While the force from explosive eruptions can propel particulate matter and gas into the stratosphere, Kilauea's steady, unforceful eruption releases gasses into the lower troposphere, where they can cause more damage to humans and property. The continuous nature of Kilauea's eruptions means that the adverse conditions created by its pollutants pose a long term hazard for human beings, rather than the effects caused by volcanoes that only rarely become active. The constant nature of the exposure may constitute an adverse living condition.

2.7 Hawai`i Volcanic National Park - Effects of Vog and Health Hazards.

In the past two decades, Hawai`i has been one of the highest states in asthma related mortality. In Hawai`i, the age-adjusted asthma mortality rate is 21.9, while the average for the United States is 15.4 per 1,000,000 (CDC, 1999). The Behavioral Risk Factor Surveillance System (BRFSS) during 2000-2006, indicates that the life-time prevalence of asthma for Big Island adult residents was 1% greater than the state average. Concentrated levels of sulfur species or sulfate aerosols (SO_4^{2-}) present a possible health risk either directly, or by worsening symptoms that already exist (Thompson, 2001).

Many in the islands are aware of the risks of vog exposure and it is occasionally given prominence in news coverage as something that affects everyone in the islands, including visitors. There have been individual reports that link vog to various symptoms, such as headache, cough, asthma attack, allergic reaction, sinusitis, shortness of breath, and eye irritation. Despite the upswing of public interest in air quality after the 1986 change in

the eruption style on Kilauea, studies on the effects volcanic emissions have on human health are scarce in the literature.

Lung inflammation and aggravation of symptoms had been a documented result of exposure to sulfur dioxide. SO_2, SO_3 and sulfuric acid additionally may cause constriction of the bronchial passages and difficulty clearing sputum when exposed to elevated levels for a greater duration. These conditions affect residents (especially whose who work at the HVNP) more than visitors, who are not typically exposed for long enough. Higher concentrations, however, can replace longevity with regards to the seriousness of the exposure and subsequent lung damage. Acidic sulfate aerosols constitute the majority of $PM_{1.0}$. SO_2 levels within the HVNP are two times that of Hilo. These conditions place the park's air quality below the National Ambient Air Quality Standards (Michaud, et al, 2005).

In March of 1990, symptom questionnaires were issued to all park personnel to determine health hazards. Half of the questionnaires were returned (forty-three employees) before May, 1990. Over half of the respondents experienced symptoms such as headache, eye irritation, throat irritation, cough, and phlegm, which they attributed to work-related causes. Additional symptoms that were often reported were chest tightness or wheezing and difficulty breathing. Air quality samples were taken of the general vicinity, which indicated that certain locations within the park were prone to elevated levels of SO_2 emissions, such as Sulfur Banks and the trail at Halema`uma`u. Symptoms associated with vog include irritation of the eyes, nose, skin, lungs, throat, tissues, and mucous. The small size of particulate matter contained in vog allows the particles to enter into the respiratory system causing lung conditions such as asthma, lung cancer and bronchitis. Long term

exposures may cause irreparable lung damage. Susceptibility, symptoms and recovery vary by individual and the type and longevity of exposure.

Similar findings were reported by Mannino colleagues (1996), who looked at trends and patterns of emergency room visits and hospitalizations for respiratory disease on the island of Hawai`i from 1981 to 1991. The authors found that when comparing emergency department visit and hospitalization rates for asthma and chronic obstructive pulmonary disease (COPD) for the period 1987 to 1991 with those of the period from 1981 to 1986, rates had increased island wide. The authors also found that emergency department visits for asthma increased by 15% during the weeks the winds blew from the west, which directed the air pollution toward Hilo. This supports the hypothesis that volcanic air pollution adversely affects respiratory health. One of the draw backs of this study, however, was that pollution measurements were not incorporated for establishing the direct association between air pollution and asthma or COPD.

Another study conducted by Michaud et al (2005) in Hawai`i Volcanoes National Park indicated that the range of SO_2 exposures near Kilauea usually meets National Ambient Air Quality Standards (NAAQS; EPA, 2004) for SO_2 (500 ppb for 3-h average, 140 ppb for 24 h, 30 ppb for yearly), however, hourly averages of SO_2 in excess of 500 ppb were occasionally recorded. On these 'high-exposure' days, visitors often report symptoms. Passive sampling conducted outside the park at Mountain View school indicated a much lower concentration of SO_2 than what is recorded in the park, indicating that closeness to the source is an important factor for SO_2 levels.

In order to study the health effects of recurrent contact with fine sulphate particle air pollution and SO_2 emitted from Kilauea, an environmental-epidemiological cross-

sectional study was carried out by Lonqo and colleagues (2008) using 335 adult volunteers, twenty years of age, who had lived in the study area for 7 years. Air quality in the downwind area was sampled to determine concentration levels, and to substantiate non-exposure in a reference area. Prevalence was estimated based on cardio respiratory responses as well as self-reported symptoms and conditions. Effects of exposed and unexposed groups were compared using logistic regression models. Chronic exposure was indicated as contributing to worsened symptoms including cough, mucus, runny nose, sore throat, congestion, wheezing, eye irritation and bronchitis. The level of correlations varied depending on the degree of exposure to SO_2 and fine sulphate particulate matter. The authors determined that a negative impact to cardiorespiratory function may result from living in an area with active volcanic emission.

However, Michaud et al 2004 examined the relationship between potential health effects (for Asthma/COPD, cardiac, flu, cold and pneumonia, and gastroenteritis with 0,1,2 or 3 days lag) and emissions (SO_2 and $PM_{1.0}$) in the Hilo Medical Center between January, 1997 and May, 2001 (Michaud et al., 2004). They found relationships between vog and the aforementioned symptoms, except gastroenteritis. SO_2 levels with 3 days lag and PM_{10} with 1 day lag had strong associations with asthma/COPD. Nevertheless, air quality was not as greatly correlated to asthma/COPD than the month of the year. In fact, air quality could not account for most of the fluctuations in asthmatic and chronic obstructive pulmonary conditions.

Later, during five three-month periods, data on daily lung function, symptoms and medication was collected on adults and children for the purpose of comparing respiratory function with airborne levels of sulfur dioxide (SO_2) and sub-micron particulate matter

($PM_{1.0}$). Two of the periods followed 60-70 children who were chosen for asthma, and three periods followed 60-70 adults who were not chosen for asthma. For the study, lung function, symptoms and medication use were considered. PEF (peak expiratory flow) and FEV1 (forced expiratory volume in one second) were measured using an electronic peak flow meter. Subjects were weighed against their own individual health status measures. Subjects who were significantly exposed to other sources of pollution as well (such as forest fire) were withdrawn from the study. This study indicated that daily self-reported symptoms were related to SO_2 and $PM_{1.0}$, however; no robust relationships between air quality and lung function with 0, 1, 2 or 3 days lag were detected. The authors concluded that air quality was not a sufficient predictor of PEF and FEV1 for both Spirometry and $PM_{1.0}$ (Michaud et al, 2006).

SO_2 inhalation can affect the operation of the upper airways, causing increased pulmonary resistance (WHO, 1979). Dose-response associations have been observed at a variety of thresholds in healthy, non-asthmatic adults for various activity levels and lengths of exposure (Koenig J, 2000). Children, adolescents, the elderly and people with previous respiratory or cardiac conditions are among groups who have an elevated sensitivity to SO_2 exposure (Schlesinger, 1999; Koenig J, 2000). Fine sulphates are respiratory irritants that adversely impact both sensitive and general populations by causing irritation of the respiratory tract and negatively affecting natural lung defenses (Holgate et al., 1999).

2.8 Summary.

It is estimated that nearly 500 million people reside in proximity to the world's 600 active volcanoes, and may be negatively impacted by constant exposure to these

conditions. Research focusing on the adverse health conditions caused by Kilauea have discovered an association with an increase in the number of hospital admissions for respiratory causes as well as aggravating the respiratory symptoms of asthmatic children (Mannino et al., 1996; Michaud et al., 2004; Morrow, 2000), although a previous study discovered the highest prevalence of asthma in children in low exposure areas, suggesting the presence of alternative causal factors (Tam et al., 2006).

A great deal of study of volcanism has focused on the various dangers presented by their eruptions, emissions, and overall potential damage. Worldwide, dense populations and cities have sprung up around volcanoes, which places them at risk. This makes the research extremely relevant to most people. Living, working and visiting closer to active volcanoes greatly increases risks associated with them as the destructive potential increases in relation to the proximity of individuals to the original source. Explosions, lava flow, mud slide, floods, volcanic gas and ash have been known to have overwhelming impacts to infrastructure, ecology, geography and other areas, polluting rivers and water supplies, and damaging farmlands and forests.

The many studies that have been conducted indicate that volcanic emissions (SO_2, SO_3, H_2S, and ash) released during eruptions are another mode of destruction caused by these phenomena, and are known to lead to a wide array of adverse effects on respiratory functions. These chemicals are the primary components of the Kilauea volcanic emissions, especially SO_2, however Kilauea emits less volcanic ash, setting it apart from other volcanoes. Very few studies have previously examined human effects of vog, making this an important area of focus.

In order to provide a better understanding of how volcanic emissions impact health in terms of self-reported symptoms and lung function measurements, this study will examine the short-term health effects of vog on workers and volunteers in the Hawai`i Volcanoes National Park.; three different methods for measuring presence of vog and their relationship to self-reported symptoms and lung function measurements The park workers are prime candidates for the study since they are exposed to the highest level of vog of any other State of Hawai`i residents. To determine the effects of vog on the park workers' self-reported symptoms and lung function, these 5 research hypotheses were examined.

2.9 Five Research Hypotheses.

Hypothesis 1: the observed vog measurements between the individual vog observers are in agreement with each other.

Hypothesis 2: visually-observed vog and the instrument-measured vog (SO_2 and $PM_{1.0}$) for the same day are positively associated; during the voggy days, the daily SO_2 and $PM_{1.0}$ are higher than on non-voggy days, as assessed by the observers.

Hypothesis 3: Lung function measurements (FEV1 and PEF) of the Hawai`i Volcanoes National Park workers are negatively associated with the visually observed vog; whereas, self-reported symptoms are positively associated.

Hypothesis 4: The visually-observed vog is as a good a predictor of reduced lung function and self-reported symptoms as instrument-measured vog (SO_2 and $PM_{1.0}$).

Hypothesis 5: Individuals who believe that vog adversely affects their symptoms are more likely to have elevated daily self-reported symptoms during vog episodes (defined by

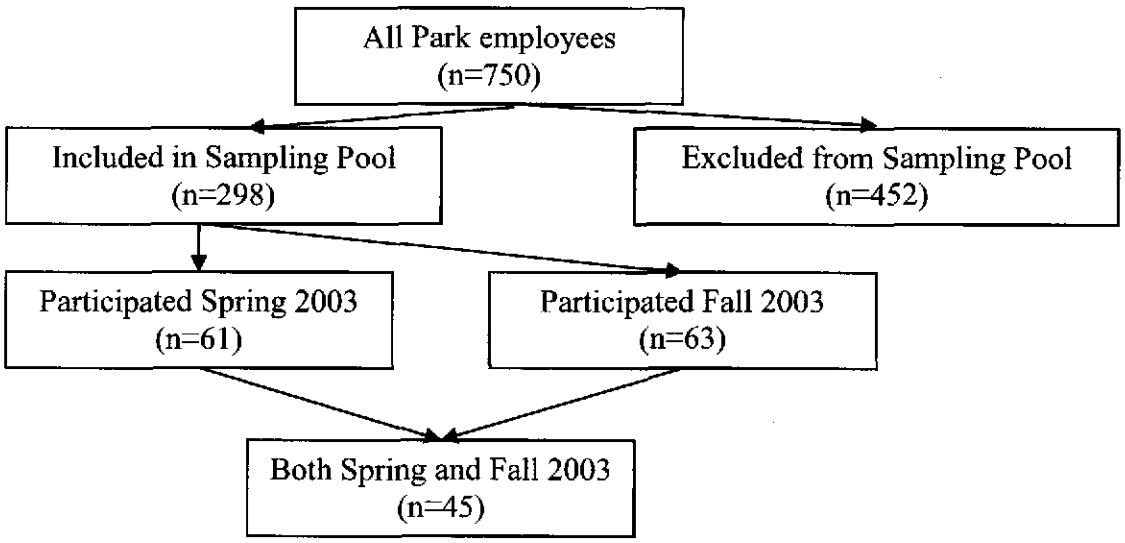
instrument-measured and visually-observed vog) than individuals who do not believe that vog adversely affects their symptoms.

CHAPTER III

METHODS

This study is a cohort study design of Hawai`i Volcanoes National Park workers and volunteers. The 209,695-acre Hawai`i Volcanoes National Park is a place of work for 750 federal, state, city and county government workers and volunteer workers: the United States Geological Survey (USGS) Hawai`i Volcanoes Observatory (25 employees), USGS Biological Resources Division (20 employees), United States Department of Agriculture (USDA) Division of Forestry (5 employees) United States Department of Interior, National Park Service, Hawai`i Volcanoes National Park (130 employees), Kilauea Military Camp (110 employees), and Hawai`i County Fire Department (8 employees); other organizations that were located in the park are the Volcano House, Hawai`i Natural History Association, and Hawai`i Volcanoes Art Center Gallery (Figure 8).

Figure 8. Hawai`i Volcano National Park Subject Sampling.



This study received approval from the Internal Review Boards (IRB) of both the Hawai`i State Department of Health and the University of Hawai`i; all subjects who participated gave their written informed consent. The Methods section has been divided into five subsections (each corresponding with the 5 previously stated research hypotheses), each describing data collection and analysis. Volunteers reported on their physical changes and measured their lung function, which were compared to data obtained by the various methods used to ascertain the presence of vog. These methods were compared for their reliability against changes in human physical condition.

3.1 Hypotheses 1: The observed vog measurements between the individual vog observers are in agreement with each other.

3.1.1 Air Quality Measurement: Observed Visual Vog.

Visual vog presence was monitored by five observers independently who were selected from a pool of volunteers based on:

- Location in the park to ensure that the sample represents the park air quality (Figure 10).
- Amount of time spent in the office (volunteers were chosen that traveled less inside and outside of the park to ensure consistent data sample).
- Office windows face open air with large visual distances.
- Observers' diligence to keep records.

Each observer was asked to record data in his/her individual calendar twice a day whenever possible (a.m. and p.m.) based on the vog sighting daily scale (Figure 9):

Figure 9. Example of the Visual Vog Calendar.

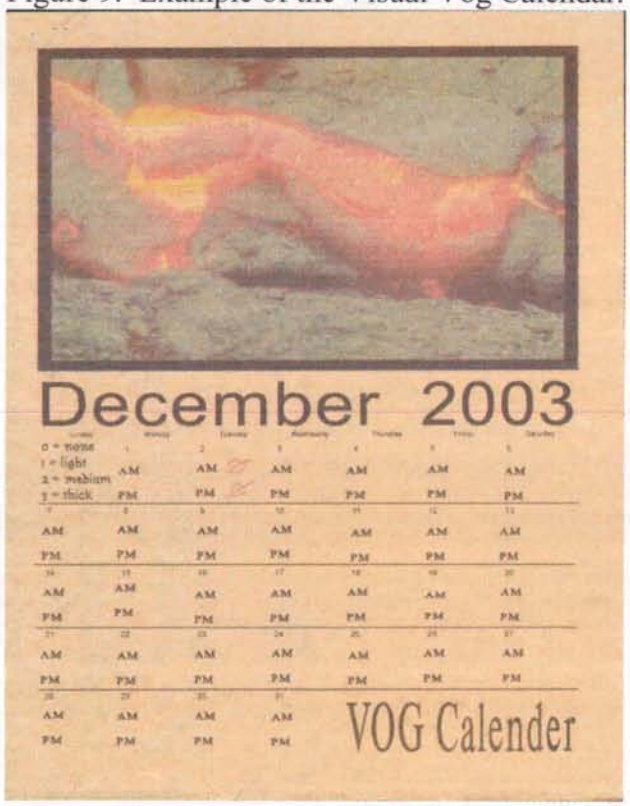
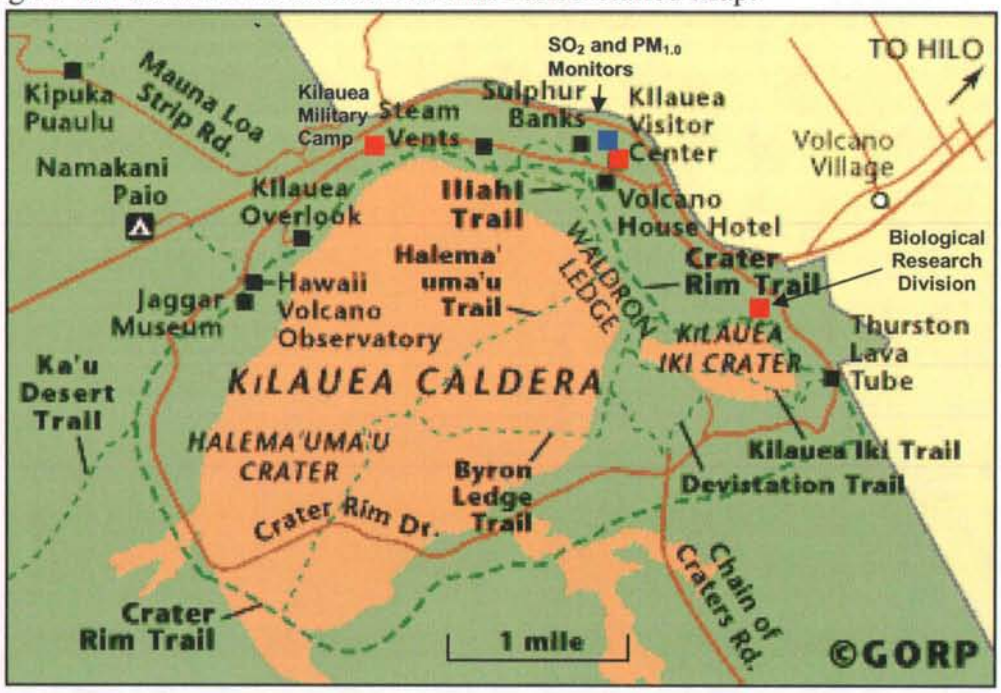


Figure 10. Hawai`i Volcanoes National Park Detailed Map.



■ Location of the visual vog observers. ■ Location of $PM_{1.0}$ and SO_2 Monitors.
Source: Adventure Travel and Outdoor Recreation - GORP.com.

Table 3. Visual Vog Index Scale.

0 = clear

1 = light haze

2 = moderate haze

3 = heavy haze

Any recordings above these values were truncated to the nearest allowable value (e. i. recorded vog index of 4 was changed to 3) (Table 3).

All of the observers were park employees. To avoid or reduce information bias, none of the vog observers participated in the study otherwise - i.e. did not keep health diaries or collect the health information (see below). The data were collected during the Spring study period from January 14, 2003 to April 17, 2003 and during the Fall study period from September 15, 2003 to December 2, 2003 (Table 4).

Table 4. Visual Vog Observers Complacence.

Obv	Time Period	Location	Days	Recorded a.m./p.m.
1	January 27, 2003 - April 13, 2003	Biological Research Division	33	Inconsistent
2	January 14, 2003 - April 15, 2003	Kilauea Military Camp	67	No
3	January 15, 2003 - April 16, 2003	Kilauea Military Camp	91	No
4	January 14, 2003 - April 6, 2003	Visitor Center/Park Headquarter	61	No
5	January 15, 2003 - March 29, 2003	Visitor Center/Park Headquarter	43	No
1	Sept. 15, 2003 - Dec. 2, 2003	Biological Research Division	47	Yes
2	Sept. 17, 2003 - Dec. 2, 2003	Kilauea Military Camp	79	Yes
3	Sept. 15, 2003 - Dec. 2, 2003	Kilauea Military Camp	79	No
4	Sept. 15, 2003 - Dec. 1, 2003	Visitor Center/Park Headquarter	36	Yes
5	Sept. 15, 2003 - Dec. 2, 2003	Visitor Center/Park Headquarter	44	Yes

3.1.2 Analysis.

The relationships between the visual vog reports among the observers were examined using Pearson correlation, Cohen's Kappa, and logistic regression.

Since some participants recorded the vog index only once and others two times (a.m. and p.m.), the maximum daily measurement was used to compare measurements between the observers (Figure 9, Table 4)

Cohen's kappa coefficient is a statistical measure of inter-rater reliability, which is generally thought to be a more robust measure than simple percent agreement calculation; Kappa takes into account the agreement occurring by chance. Cohen's kappa measures the agreement between two raters who each classify N items into C mutually exclusive categories.

$$\text{Kappa} = (\Pr(a) - \Pr(e))/(1-\Pr(e))$$

Where $\Pr(a)$, probability of a, is the relative observed agreement among raters, and $\Pr(e)$ is the probability that agreement is due to chance. If the raters were in complete agreement then $\kappa = 1$. If there is no agreement among the raters (other than what would be expected by chance) then $\kappa \leq 0$ (Cohen, 1960). The following criteria will be used to determine the measure of the agreement between two visual vog observers (Table 5).

Table 5. Interpretation of Kappa Value

Kappa	Interpretation
< 0	Poor agreement
0.0 — 0.20	Slight agreement
0.21 — 0.40	Fair agreement
0.41 — 0.60	Moderate agreement
0.61 — 0.80	Substantial agreement
0.81 — 1.00	Almost perfect agreement

The Pearson correlations (r^2) along with p-value were concluded between each observer separately for each study (Fall 2003 and Spring 2003). The data were presented in the table where each observer is present from both the rows and columns (Attachment B).

In addition, the study was investigated on how consistently the observers recorded the presence of vog (dichotomous variable: yes/no) (Table 6). Any measurements higher than zero was considered as "vog present" and similarly any "0" measurements were considered as "no vog present." The data were presented in the table format; each observer is presented in both columns and rows. The cell indicates the percent agreement between two observers.

Table 6. Interpretation of Visual Vog Index.

Visual Vog Index	Vog Presence*
0 = clear	No
1= light haze	Yes
2 = moderate haze	Yes
3=heavy haze	Yes

*this variable used in the logistic regression models.

Logistic regressions were computed to estimate the likelihood that one observer could predict the presence of vog by other observers (Table 6). Similarly to kappa statistics, the results of logistic regression analysis were presented in a similar format. Data manipulation including formatting, matching tables, and combining tables were performed with Microsoft Access 2003 (Microsoft Corporation, Seattle, Washington). The graphs and histograms were created and edited with Microsoft Excel 2003. The data were exported to SAS 9.1 software package (SAS Institute Inc., Cary, North Carolina, USA) where all the statistical analysis was performed. PROC MEANS and PROC FREQ were used to derive descriptive statistics.

PROC FREQ was used to compute the Cohen's kappa between two observers. PROC FREQ requires that both observers have the same levels (to create a square table). "When the AGREE option in the TABLES statement, PROC FREQ computes tests and measures of agreement for square tables (that is, for tables where the number of rows equals the number of columns). However, in rectangular table case, this is fixed by adding pseudo-observations, which supply the unused category(ies), but which are assigned very

small weight. This makes SAS process the table as square and calculate kappa." (SAS, 2007). Since observers 2, 3, and 4 during Fall 2003 and observer 1 during Spring 2003 study periods did not report daily visual vog higher than 2, pseudo-observations were created for all observers for the values 0, 2, 3, 4 with assigned weight=0.00000001. All recorded observations were assigned weight = 1.

Lastly, the logistic models were also examined where presence or absence of any vog (Yes/No) was defined as the dependent variable. PROC GENMOD was used assuming binomial regression distribution "dist=binomial" with logistic regression function "link=logit". PROC GENMOD does not compute the odds ratio. Odds ratios (Table 7) and corresponding confidence interval were determined based on the following formula (Formula 1).

Formula 1. Calculating Point Estimate and Confidence Interval with PROC GENMOD.

Point Estimate: $OR = EXP^{\text{parameter estimate from GENMOD}}$

Confidence Interval: $OR = EXP^{\text{parameter estimate +/- standard error from GENMOD}}$

Table 7. Calculating Odds Ratio.

		Observer B	
		Vog present (VVI≥1)	Vog is not present (VVI=1)
Observer A	Vog present (VVI≥1)	A	B
	Vog is not present (VVI=1)	C	D

OR (Odds Ratio) = (A *D)/(C *B)

Both logistic regression (odds ratio with 95% confidence interval, and Kappa statistics with 95% confidence interval) were presented in two tables where columns and rows heading represent the observer identified (5x5 table).

3.2 Hypotheses 2: visually-observed vog and the instrument-measured vog (SO_2 and $PM_{1.0}$) for the same day are positively associated; during the voggy days, the daily SO_2 and $PM_{1.0}$ are higher than on non-voggy days, as assessed by the observers.

This is a comparison of the methods of measuring air quality and detecting the presence of vog. Visually-observed refers to vog that can be detected by human visual perception without any aid, whereas instrument-measured refers to detection which relies on the aid of detection equipment (nephelometer and sulfur dioxide monitor).

3.2.1 Instrument-measured Air Quality: Particulate Matter.

Hourly particulate matter less than 1 μm in size ($PM_{1.0}$) was measured by "a near infrared (880 nm) Mie-scattering nephelometer (Data Ram-2000, Monitoring Instruments for the Environment, now Thermo MIE) which was plumbed immediately downstream from a heated inlet followed by a thermally well-insulated inertial impaction 1 mm size selector (Figure 11). Because sulfate aerosols are easily hydrated and gain size at high humidity, the air sample stream was heated immediately upstream of the well-insulated impactor and optical chamber. This was done to reduce the sensitivity of aerosol size selection and measurement to the large changes in relative humidity common in Hawai`i (Michaud JP, et al, 2005).

Figure 11. Nephelometer Photo with Technical Specifications.

Source: Thermo MIE, 2002.

The data collection periods were January 8, 2003 - March 13, 2003, April 4, 2003 - May 21, 2003 and September 9, 2003 - December 19, 2003. Between March 14, 2003 and April 3, 2003, nephelometer was mistakenly set to collect data every five seconds which lead to memory overload thus all data from this time period was excluded from analysis. Once per month, the nephelometer was connected to a personal computer with Windows 2000 Professional Operating System (OS) (Microsoft Corporation, Seattle, Washington). Microsoft Hyper Terminal 2000 software, an integrated part of the Windows 2000 Professional OS, was used to download data from the ESC logger to the personal computer via a serial port in comma delimited format. The data were then exported to Microsoft

Excel 2003 software where additional formatting was performed before the data were exported to Microsoft Access 2003.

3.2.2 Air Quality Measurement: Sulfur Dioxide.

The hourly SO_2 was continuously operated and monitored by the Hawai`i Volcanoes National Park from 2000, thus data for the entire 2003 calendar year (with the exception of 17 days 5/16, 5/17, 5/18, 5/19, 5/20, 5/21, 5/22, 5/23, 5/24, 5/25, 5/26, 5/27, 5/28, 5/29, 8/5, 8/6, and 8/13 when the monitor malfunctioned, calibrated, or data were found to be invalid) were available. The SO_2 was measured by pulsed fluorescence (model 43-C SO_2 monitor, Thermo Environmental Instruments, formerly Thermo Electron Corporation (TECO), Cheswick, PA, USA) (Figure 12).

Figure 12. Thermo Environmental Instruments, Model 43-C SO_2 Monitor Photo.

Source: TECO, 2003.

This instrument was set up to auto calibrate once every 24 hours by EPA approved methods (span and zero gas and flow stream switching). The instrumental operation

utilizes the principle of "Pulsed Fluorescence" that is based on the fact that sulfur dioxide molecules absorb light at the UV), producing electronically an excited SO_2 molecule with a known spectral decay rate to the ground state. The fluorescence emitted by the reaction is detected by a photo multiplier tube and the signal is a converter proportional to an electronic output signal. The signal is then processed to digital and analog outputs and captured by an ESC data logger located at each site. The data were regularly downloaded by the Park personnel. The monitor's preset ranges were 0-0.05, 0.1, 0.2, 0.5, 1, 2, 5, and 10 ppm or 0-0.2, 0.5, 1, 2, 5, 10, 20 and 25 mg/m^3. The extended ranges were 0-0.5, 1, 2, 5, 10, 20, 50 and 100 ppm or 0-2, 5, 10, 20, 50, 100, 200 and 250 mg/m^3 at the custom ranges of 0-0.05 to 10 ppm or 0-0.2 to 250 mg/m^3. The lower detectable limit are 2.0 ppb (10 second averaging time), 1.0 ppb (60 sec avg. time), 0.5 ppb (300 sec avg. time). Zero Drift (24 hour) Less than 1 ppb and span Drift (24 hour) +/-1%. Response time 80 seconds (10 second average time), 110 seconds (60 second average time), 320 seconds (300 second average time). The precision reading is 1% or 1 ppb (whichever is greater). The linearity +/-1% of full scale ≤ 100 ppm (Model 43C SO_2, Product Specifications, 2004)

3.2.3 Air Quality Measurement: Observed Visual Vog.

The methods of determining the observed visual vog indexes were described in the section 3.1.1.

The arithmetic mean of five observers for each study period was computed. During the study period (January 13 2003 - April 18, 2003 and September 14, 2003 - December 2, 2003), the majority of the arithmetic daily average, the visual vog index (VVI), was computed based on all five observers (n= 44); the VVI was computed based on the 4

observers for 43 days, 3 observers for 38 days, two observers for 27 days, one observer for 20 days, and missing daily VVI for one day (February 22, 2003). The maximum individual daily observation was represented as the individual daily observation for individuals that collected data both a.m. and p.m.

3.2.4 Analysis.

Data Manipulation including formatting, matching tables based on date of measurement, and combining tables were performed with Microsoft Access 2003 (Microsoft Corporation, Seattle, Washington). The graphs and histograms were created and edited with Microsoft Excel 2003. The data were exported to SAS 9.1 package (SAS Institute Inc., Cary, North Carolina, USA), where all the statistical analyses were performed. All histograms and graphs were created with Microsoft Excel 2003.
The daily (24 hour) arithmetic averages were calculated based on the hourly measurements of sulfur dioxide and particulate matter; the daily average started from 12:00 a.m. and finished 11:59 p.m. Missing hourly measurements were excluded if the measurement was marked invalid by the measuring instruments. In the event that the instrument provided a negative measurement such as $PM_{1.0}$ = -1 um/m^3, the measurement was considered to be 0 ug/m^3. Any measurements below -2 ppb SO_2 and -2 ug/m^3 for $PM_{1.0}$ were considered as invalid/missing, thus excluded from analysis.

The descriptive statistics (compute the mean, 95% confidence interval, and number of observations) were computed with PROC MEANS. In addition, PROC MEANS with CLASS option was used to estimate instrument-measured air quality by the average daily VVI; the average daily VVI was rounded up to the nearest whole number to assure that

each category has enough sample size, for example, 2.75 was rounded up to 3 (Table 9, Appendix B).

The relationships between the air quality observed by volunteers and that which were instrument-measured ($PM_{1.0}$ and SO_2) were examined using Pearson correlation and simple linear regression.

The simple linear regression models were also computed to examine the relationship between air quality measurements; PROC REG was used. The models were evaluated based on beta1 (the slope or strengths of association) and R^2 (the proportion of variability in a data set that is accounted for by a statistical model) and an F-test (which measures the overall fit over the model); since the model is the simple linear regression, F-test is the square of t-test and has the same significance level as the t-test.

In addition, 3 visual representations in the form of graphs were examined where each parameter (SO_2, $PM_{1.0}$, and VVI) was compared to each other using Microsoft Excel 2003 (Figure 22).

3.3 Hypotheses 3: lung function measurements (FEV1 and PEF) of the Hawai`i Volcanoes National Park workers are negatively associated with the visually observed vog; whereas, self-reported symptoms are positively associated.

3.3.1 Visually Observed Vog:

The detailed description for the visual vog data collection is presented in this section 3.1.1. The daily VVI was derived from arithmetic average from up to five observers described in section 3.2.3.

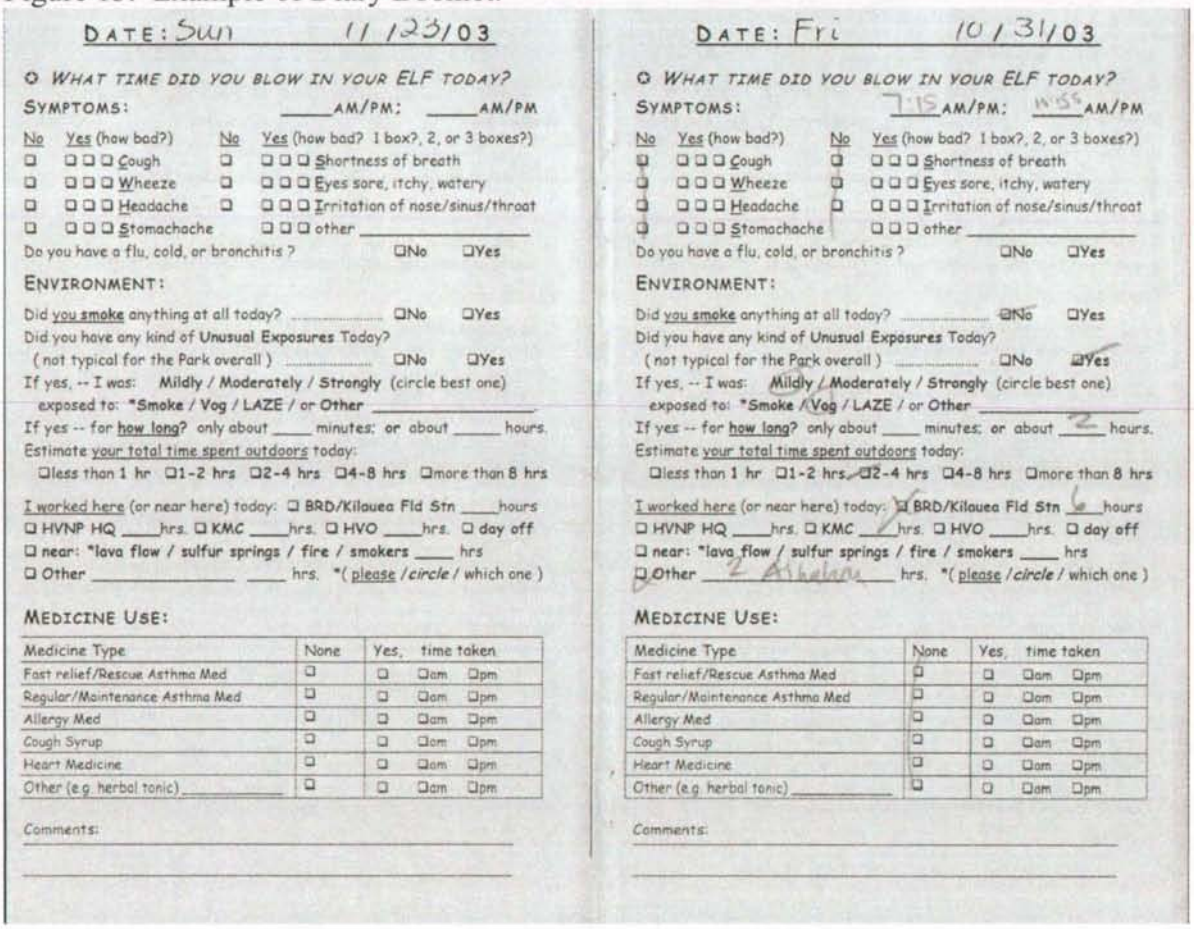
3.3.2 Subject Recruitment:

During two study intervals of 3-4 months each, the HVNP workers were recruited via public speaking engagements at HVNP and by participants voluntarily picking up enrollment and consent forms from the Park Information Center. These adult populations were not recruited (nor excluded) for asthma, however, 'regular smokers' (3 cigarettes more per week) were excluded. 72 participants were recruited for the Fall 2003 study period and 62 for the Spring 2003. The majority of participants (n= 45) that participated in the Spring 2003 were also recruited for the second time period. All subjects were employees and volunteers at the HVNP.

The participants' age was determined based on the date of birth provided at the time of their enrollment and the date of enrollment. The derived age was round to the nearest whole number. During the Spring 2003 study period, the average age of participants was 47 years old (medium was 48 years old); the participants' ages ranged between 21 and 74 years old. Almost half of the participants (52%) were females. During the Fall 2003 time period, the average age of the participants was 45 years old (STD=14), with the minimum age being 22 years old and the maximum age being 75 years old, and with a median age of 48 years old. Almost half of the participants (51 %) were females (Table 24).

3.3.3 Data Collection Methods: Self-reported Symptoms.

Figure 13. Example of Diary Booklet.



DATE: Sun 11/23/03

WHAT TIME DID YOU BLOW IN YOUR ELF TODAY?

SYMPTOMS: _____AM/PM; _____AM/PM

No	Yes (how bad?)	No	Yes (how bad? 1 box?, 2, or 3 boxes?)
☐	☐☐☐ Cough	☐	☐☐☐ Shortness of breath
☐	☐☐☐ Wheeze	☐	☐☐☐ Eyes sore, itchy, watery
☐	☐☐☐ Headache	☐	☐☐☐ Irritation of nose/sinus/throat
☐	☐☐☐ Stomachache		☐☐☐ other _____

Do you have a flu, cold, or bronchitis ? ☐No ☐Yes

ENVIRONMENT:

Did you smoke anything at all today? ..... ☐No ☐Yes

Did you have any kind of Unusual Exposures Today?
(not typical for the Park overall) ..... ☐No ☐Yes

If yes, -- I was: Mildly / Moderately / Strongly (circle best one)
exposed to: *Smoke / Vog / LAZE / or Other _____

If yes -- for how long? only about ____ minutes; or about _____ hours.

Estimate your total time spent outdoors today:
☐less than 1 hr ☐1-2 hrs ☐2-4 hrs ☐4-8 hrs ☐more than 8 hrs

I worked here (or near here) today: ☐ BRD/Kilauea Fld Stn ____hours
☐ HVNP HQ ____hrs. ☐ KMC ____hrs. ☐ HVO ____hrs. ☐ day off
☐ near: *lava flow / sulfur springs / fire / smokers ____ hrs
☐ Other _____ ____ hrs. *(please /circle / which one)

MEDICINE USE:

Medicine Type	None	Yes, time taken
Fast relief/Rescue Asthma Med	☐	☐ ☐am ☐pm
Regular/Maintenance Asthma Med	☐	☐ ☐am ☐pm
Allergy Med	☐	☐ ☐am ☐pm
Cough Syrup	☐	☐ ☐am ☐pm
Heart Medicine	☐	☐ ☐am ☐pm
Other (e.g. herbal tonic) _____	☐	☐ ☐am ☐pm

Comments: _____

DATE: Fri 10/31/03

WHAT TIME DID YOU BLOW IN YOUR ELF TODAY?

SYMPTOMS: 7:15 AM/PM; 11:55 AM/PM

No	Yes (how bad?)	No	Yes (how bad? 1 box?, 2, or 3 boxes?)
☐	☐☐☐ Cough	☐	☐☐☐ Shortness of breath
☐	☐☐☐ Wheeze	☐	☐☐☐ Eyes sore, itchy, watery
☐	☐☐☐ Headache	☐	☐☐☐ Irritation of nose/sinus/throat
☐	☐☐☐ Stomachache		☐☐☐ other _____

Do you have a flu, cold, or bronchitis ? ☐No ☐Yes

ENVIRONMENT:

Did you smoke anything at all today? ..... ☐No ☐Yes

Did you have any kind of Unusual Exposures Today?
(not typical for the Park overall) ..... ☐No ☐Yes

If yes, -- I was: Mildly / Moderately / Strongly (circle best one)
exposed to: *Smoke / Vog / LAZE / or Other _____

If yes -- for how long? only about ____ minutes; or about 2 hours.

Estimate your total time spent outdoors today:
☐less than 1 hr ☐1-2 hrs ☐2-4 hrs ☐4-8 hrs ☐more than 8 hrs

I worked here (or near here) today: ☐ BRD/Kilauea Fld Stn 6 hours
☐ HVNP HQ ____hrs. ☐ KMC ____hrs. ☐ HVO ____hrs. ☐ day off
☐ near: *lava flow / sulfur springs / fire / smokers ____ hrs
☐ Other 2 Akaka ____ hrs. *(please /circle / which one)

MEDICINE USE:

Medicine Type	None	Yes, time taken
Fast relief/Rescue Asthma Med	☐	☐ ☐am ☐pm
Regular/Maintenance Asthma Med	☐	☐ ☐am ☐pm
Allergy Med	☐	☐ ☐am ☐pm
Cough Syrup	☐	☐ ☐am ☐pm
Heart Medicine	☐	☐ ☐am ☐pm
Other (e.g. herbal tonic) _____	☐	☐ ☐am ☐pm

Comments: _____

Symptoms were recorded by subjects daily and included cough, wheeze, headache, stomachache, shortness of breath, sore/itchy/watery eyes, irritation of nose/sinus/throat, and other symptoms. The severity scale was assigned by the subjects and ranged from 0 to 3, where 0 is asymptomatic and 3 is very severe (Figure 13).

In addition, diaries included an environmental section which allowed subjects to record exposure to smoke, duration of exposure, amount of time worked outdoors, and working location (Headquarters, Biological Research Division/Kilauea fuel station, Kilauea Military Camp, Volcano Observatory, other, or day off)

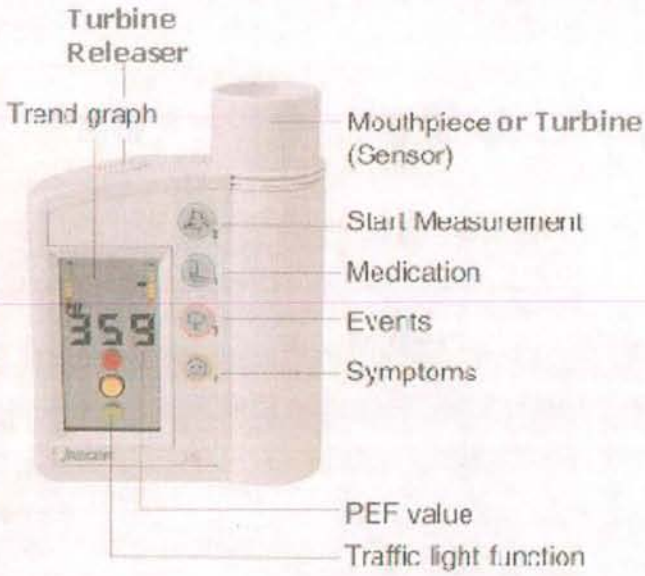
Also, the participants were asked to report the use of fast relief/rescue asthma medication, regular/maintenance asthma medication, allergy medication, cough syrup, and heart medication. If the subject took any of the above listed medication, the subject was asked to indicate whether it was taken during a.m. or p.m.

The completed diaries were digitized twice by two separate individuals. The files were then compared and the discrepancies were corrected -- achieving one hundred percent verification.

3.3.4 Data Collection Methods: Individual Spirometry (Asthma Monitor 1)

To collect consistent, precise and unbiased measurement of lung function, each subject was assigned a personal electronic peak flow meter with the data logger. The Asthma Monitor 1 a.k.a. AM-1 (Jaeger, Germany) was selected because it was portable and affordable (under $200), measures and stores PEF, FEV1, FVC, FEF25, FEF50, FEF 75, MMEF and variability (Figure 14).

Figure 14. Asthma Monitor 1 (AM-1) Photo with Technical Specifications.



Accuracy of measurement:
Accuracy:
PEF ± 4% or 10 l/min
FEV1 ± 3.5% or 0.05 l
FVC ± 4% or 0.1 l
Deviations within a device:
PEF 3% or 10 l/min
FEV1 3% or 0.05 l
FVC 4% or 0.1 l
Deviations between several devices:
PEF ± 4% or 10 l/min
FEV1 ± 3% or 0.05 l
FVC ± 4% or 0.1 l
Measuring range:
Measurement Display
PEF 60 to 840 l/min 0 to 999 l/min
FEV1 0.5 to 8 l 0 to 9,99 l

Resolution:
PEF from 1l/min to 20l/min over the entire range (resolution decreases from 1l/min in the lower flow range up to 20 l/min in the upper flow range).
FVC 15 ml
FEV1 15 ml
Resistance: 7 Pa/l/s by 1l/s
Storage capacity: (E2PROM)
496 measurements (AM-1)
(Standard setting: automatic determination of best measurement within 10 minutes)

Source: Jaeger, Germany, 2003.

Suitable for field work, this unit has a field washable removable turbine sensor that can be replaced if damaged or worn out, AM-1 can store around 400 blows/efforts before requiring a data download and according to the manufacturer, the batteries should last for 6 months with regular use. 142 units have been purchased from Jaeger USA and Ferraris.

The measurement principle is a rotary flow sensor TripleV ® with optical (IR) scanning, and the measurement range is 60-840 L/min for PEF, 0.5-8 L for FEV1, and 0.5-8 L for FVC. Resolution for PEF from 1-20 L/min over the entire, range (resolution decreases in the upper flow range); resolution for FVC and for FEV1=15 ml. Accuracy: PEF ±4% or 10 L/min, FEV1 ±3.5% or 0.05 L, FVC ±4% or 0.1 L whichever is greater. Deviations within a device are PEF 3% or 10 L/min, FEV1 3% or 0.05 L, FVC 4% or 0.1 L. Deviation between devices was specified as PEF ±4% or 10 L/min, FEV1 ± 3% or 0.05 L, and FVC ± 4% or 0.1 L (Schuelke, 2000). The AM-1 was approved by the FDA on 9/20/1996 (K500 is K960078) with a decision that it is "Substantially Equivalent" to the calibration equipment (FDA, 2008).

AMOS 1.0 (Jaeger, Germany) software, provided with the AM-1 units, was used to configure AM-1 and download lung function data. The AMOS 1.0 was designed for DOS (Microsoft Office, Seattle Washington) and Microsoft Windows 3.1 (Microsoft Office, Seattle, Washington) computer operating system (OS). One Toshiba Satellite Pro laptop (Toshiba Corp., location) with Microsoft Windows 3.1 OS was dedicated for this task. AM-1s were connected to the laptop with a serial cable provided by Jaeger. After successfully downloading the data from AM-1s to AMOS 1.0, the data were exported to the tab delimited text file. AMOS 1.0 software created one text file for each subject. To increase efficiency and reduce impartation errors, the text files were merged into Microsoft

Excel by custom designed software. The custom-designed software was programmed with Microsoft Visual Basic 6.0 and the Microsoft FileSystem Object 2.1. The exported data were verified and spot checked for inconsistencies with the AMOS 1.0 tables and graphs. The data were then exported from Microsoft Excel to Microsoft Access for additional data manipulations and analysis.

Prior to field use, all AM-1 digital spirometers were compared to a digital calibration syringe (Flow-Volume Calibrator [FVC-3000], Jones Medical Instrument Company, Oak Brook, IL) and any individual AM-1 units that did not agree to within +/- 1.7% of the Jones digital syringe values for calibrated FEV1 volumes were rejected and not used in this study (n=14 units were rejected). All AM-1 data were also cleared of any previously stored data and the AM-1 internal clock was synchronized with the computer clock.

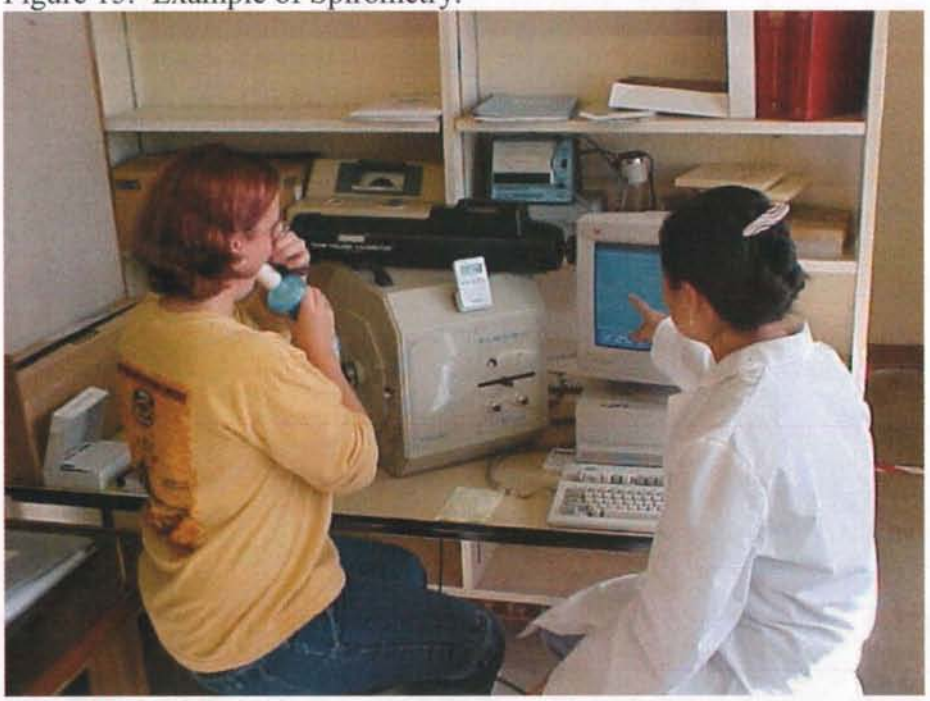
Subjects were to use the AM-1 twice daily. Subjects were trained to properly use and maintain the AM-1 monitor before the beginning of the study and were reminded a month later. Subjects were asked to use them three times in the morning and in the evening within 10 minutes and wash it in warm (non-running) water with mild soap. The subjects were instructed that their personal AM-1 is "for their mouth only" and not to be shared with anyone. Data were examined for quality control during each training/retraining; implausible and inconsistent data were removed from the analysis.

Even though the AM-1's were designed to be continuously operational for long periods of time (12 months) and 3 AAA batteries in each unit designed to last for 6 months, 12 AM-1 units had their batteries replaced before this study period was over; a new set of batteries were installed in each AM-1 in the beginning of each study period. Lessons

learned during the Spring 2003 study period were applied for the Fall 2003 study period, and the subjects were provided an additional set of the 3 AAA batteries and were trained to replace them if necessary. Four AM-1's failed to start up during the Spring 2003 study period and 6 during the Fall 2003 study period and were replaced with new units. After multiple attempts, data from two AM-1's were unable to download using AMOS software; units were issued to those subjects. Only one unit was misplaced or lost and was not able to be recovered.

3.3.5 Data Collection Methods: Spirometry (Spiro-232).

Figure 15. Example of Spirometry.



Source: Michaud JP, 2003.

Spirometry is the most common of the Pulmonary Function Tests (PFTs), measuring lung function, specifically the measurement of the amount (volume) and/or

speed (flow) of air that can be inhaled and exhaled. Spirometry is an important tool used for generating pneumotachograph to assessing conditions such as asthma, pulmonary fibrosis, and COPD. The patient was asked to take the deepest breath, and then exhale into the spirometer sensor as hard and as long as possible. It was directly followed by a rapid inhalation (inspiration). The following lung function measurements were collected:

Forced Expiratory Volume in 1 Second (FEV1) is the amount of air that one can forcibly blow out in one second (liters).

Peak Expiratory Flow (PEF) is the maximum speed of the air moving out of one's lungs at the beginning of the expiration (liters per second).

Forced Vital Capacity (FVC) is the total amount of air that one could be forcibly blow out after full inspiration (liters).

Forced Expiratory Flow 25% (FEF25) is the average flow (or speed) of air coming out of the lung during the first quarter portion of the expiration (liters per second).

Forced Expiratory Flow 50 % (FEF50) is the average flow (or speed) of air coming out of the lung during the middle portion of the expiration (liters per second).

Forced Expiratory Flow 75 % (FEF75) is the average flow (or speed) of air coming out of the lung during the first quarter portion of the expiration (liters per second).

Although the test provides very valuable information on the lung function, the maneuver is highly dependent on patient cooperation and effort, and is repeated at least three times to ensure reproducibility. Spirometry depends on patient cooperation, FEV1 and FVC can only be underestimated, never overestimated. Therefore, only the best out of three spirometries and peak flow measurements were used in the analysis.

Full effort spirometry with Spiro-232, Morgan Scientific Spirometer (P.K. Morgan, Rainham, Kent, UK; www.morgansci.com), was collected by trained technicians at least once during the period of the study whenever possible (Figure 15). Each technician was extensively trained by the leading Hawai`i pneoumonologist physician, Elizabeth K. Tam, M. D.

In total, 89 accepted (both spirometry software and technician) spirometries were performed by 43 subjects; one subject had 4 spirometries, 12 subjects had 3 spirometries, 20 subjects had 2 spirometries, and 11 subjects had 1 spirometry performed during the study.

Spirometry was used as a tool for training and monitoring subjects in the use of the personal AM-1, and to assess the precision of the AM-1 instruments. The best effort was made to train subjects bimonthly, however, because of the subjects' busy time schedules (most of them were full-time park employees) this schedule proved to be unfeasible for some employees. During the first data collection period (Spring 2003), 14 trainings were conducted; half of them trained/retrained less than five subjects. The total 72 subjects were trained/retrained. 89% of the time subjects could use their personal AM-1 correctly prior to the training and 100% performed correctly after the training. Similarly, during the second

data collection period (Fall 2003), 4 training sessions were conducted; each training 22, 16, 14, and 2 subjects were trained. 74% of the time subjects demonstrated correct use of their AM-1 prior to the training and 100% demonstrated correct use after the training.

The secondary goal was to compare and examine the relationship between the spirometry measurements and "home" measurements from AM-1 for the same individual and the same date. These examinations were meant to validate the personal PM-1 measurements.

3.3.6 Analysis Methods.

Data Manipulation including formatting, matching tables, and combining tables were performed with Microsoft Access 2003. The graphs and histograms were created and edited with Microsoft Excel 2003. The data were exported to SAS 9.1 (SAS Institute Inc., Cary, North Carolina, USA) package where all the statistical analysis was performed. PROC MEANS and PROC FREQ were used to derive descriptive statistics. PROC CORR was used to compute the Pearson correlation coefficients and the p-values. PROC GLM was used to measure the association between Spiro-232 and AM-1 lung function measurements (PEF and FEV1).

"*Dependent variables were examined: lung function* (FEV1 from AM-1 and PEF from AM-1), symptom index, dichotomous variable and presence of any symptoms (yes, no). Independent variables were examined and visual vog index from observers (VVI). Individuals were compared to their own baseline (non-exposed) health status measures to eliminate variations in genetics and environmental factors. The REPEATED statement specifies the covariance structure of multivariate responses for GEE model fitting in the

GENMOD procedure" (SAS 9.1 help manual). Since the air quality, symptoms, and lung function were not independent (requirements of simple regression), PROC GENMOD was used with "type=exch" or exchangeable with the link function "link=log". Models were examined for auto-correlation.

The assumptions of regression model are (1) normality (dependent variable is normally distributed) (2) independent. The assumption of regression model is that the dependent variable is normally distributed; however, the symptom index is heavily skewed to the left. The log and reciprocal transformations of the dependent variable were unsuccessfully attempted to meet the normality criteria (|kurtosis| < 3.0 and |skewness| $<$ 0.8) (Table 8). Finally, the logistic model was also examined where presence or absence of any symptoms (cough, wheeze, headache, stomachache, shortness of breath, eye irritation, and nose irritation). Same PROC GENMOD was used assuming binomial regression distribution "dist=binomial" with logistic regression function "link=logit".

PROC GENMOD was not used to compute the odds ratio; only parameter estimates were computed. Odds ratios and corresponding confidence interval were determined based on the following formula.

Point Estimate: $OR = EXP^{\text{parameter estimate from GENMOD}}$

Confidence Interval: $OR = EXP^{\text{parameter estimate +/- standard error from GENMOD}}$

Since changes in respiratory health status or the physiological response to the environmental trigger might be hours or days, time series analysis allows for a range of lag (same day, 1, 2, 3 days lag) times between the lung function /symptoms and the visual vog index (VVI) were examined.

Models were controlled for potential confounders such as: the use of fast-acting and maintenance medication. These bronchodilators and anti-inflammatory medications might be able reduce the inflammation caused by vog and thus reduce symptoms and improve overall lung function.

Table 8. Visual Vog Index and Symptoms Transformation.

Transformation type	Formula	Kurtosis	Skewness	Acceptance Criteria for regression model: |kurtosis| < 3.0 and |skewness| < 0.8
Symptoms	(no transformation)	3.613	21.707	unmet
Symptom Square root	Symptom^0.5	2.345 √	6.862	unmet
Symptom Log	log(symptom)	14.869	308.672	unmet
Symptom Square	Symptom^2	-1.786 √	2.712	unmet
Symptom Reciprocal	1/(1+symptom)	1.620 √	1.915	unmet
Visual Vog Index (VVI)	(no transformation)	3.228 √	11.395	unmet
VVI Square root	(VVI)^0.5	0.949 √	-0.705 √	met
VVI log	log(VVI)	0.894 √	-1.010	unmet
Sulfur dioxide	(no transformation)	2.026 √	4.011	unmet
Particulate matter ($PM_{1.0}$)	(no transformation)	1.323 √	1.541	unmet
FEV1	(no transformation)	0.299 √	0.485 √	met
PEF	(no transformation)	0.537 √	0.370 √	met

3.4 **Hypotheses 4: the visually-observed vog is as good a predictor of reduced lung function and self-reported symptoms as instrument-measured vog (SO_2 and $PM_{1.0}$)**

3.4.1 Data Source: Instrument Air Quality.

The same methods applied as in section 3.2.1 and 3.2.2.

3.4.2 Data Source: Visually Observed Vog.

The same methods as described in section 3.1.1.

3.4.3 Data Source: Lung Function Measurements.

The same methods as described in sections 3.3.4 and 3.3.5.

3.4.4 Data Source: Self-reported Symptoms.

The same methods as described in section 3.3.3.

3.4.5 Data Analysis.

Similarly to the Methods Described in Section 3.3.6, data manipulation including formatting, matching tables, and combining tables were performed with Microsoft Access 2003 (Microsoft Inc., Seattle, Washington) The graphs and histograms were created and edited with Microsoft Excel 2003. The data were exported to SAS 9.1 package where all the statistical analysis was performed. PROC MEANS and PROC FREQ were used to derive descriptive statistics. PROC CORR was used to compute the Pearson correlation coefficients and the p-values. PROC GLM was used to measure the association between Spiro-232 and AM-1 lung function measurements (PEF and FEV1)

Dependent variables were examined: lung function (FEV1 from AM-1 and PEF from AM-1), symptom index, dichotomous variable and presence of any symptoms (yes, no). In the contrast to the methods listed in section 3.2.3, visual vog index (VVI) were examined as well as daily average $PM_{1.0}$ and SO_2. Individuals were compared to their own baseline (non-exposed) health status measures to eliminate variations in genetics and environmental factors. The REPEATED statement specifies the covariance structure of multivariate responses for GEE model fitting in the GENMOD procedure" (SAS 9.1 help

manual). The REPEATED option was used to a comment that multiple measures modes were obtained from each subject. PROC GENMOD was used with "type=exch" or exchangeable with the link function "link=log". Models were examined for auto-correlation since consecutive days might have correlated air quality measurements.

Similar to the methods 3.2.3, the assumption of regression model is that the dependent variable is normally distributed however the symptom index is heavily skewed to the left. The log and reciprocal transformations of the dependent variable were unsuccessfully attempted to adjust for skewness and kurtosis (Table 8). Finally, the logistic models were also examined where presence or absence of any symptoms (cough, wheeze, headache, stomachache, shortness of breath, sore, itchy, watery eyes, irritation of nose/sinus/throat, and other symptoms) was defined as the dependent variable. Same PROC GENMOD was used assuming binomial regression distribution "dist=binomial" with logistic regression function "link=logit".

PROC GENMOD does not compute the odds ratio. Odds ratios and corresponding confidence intervals were determined based on the following formula.

Point Estimate: $OR = EXP^{\text{parameter estimate from GENMOD}}$

Confidence Interval: $OR = EXP^{\text{parameter estimate +/- standard error from GENMOD}}$

The regression models for instrument measured and observed vog index were examined. The best predicted models to predict variation into lung function and symptoms were determined based on the statistical models (the high-value indicates the model might be more robust), p-value (the low-value indicates the model might be more robust), and

likelihood ratio chi-square (the higher chi-square value indicates that the model might be more robust). Similarly as described in the methods 3.3.3, the tables with results of statistical analysis (the instrument measured and observed vog) will be compared side-by-side.

Models were controlled for potential confounders such as: use of fast-acting and maintenance medication.

Since changes in respiratory health status or the physiological response to the environmental trigger might be hours or days, time series analysis allows for a range of lag (same day, 1, 2, 3 days lag) times between changes in air quality ($PM_{1.0}$, SO_2, and visual vog index were examined).

The relationship within: air quality measurements (SO_2, $PM_{1.0}$, and VVI) and lung function measurements (PEF_{AM-1} and $FEV1_{AM-1}$) and symptoms (cough, wheeze, headache, stomachache, shortness of breath, sore/itchy/watery eyes, irritation of nose/sinus/throat, and other symptoms) were also examined.

3.5 Hypotheses 5: individuals who believe that vog adversely affects their symptoms are more likely to have elevated daily self-reported symptoms during vog episodes (defined by instrument-measured and visually-observed vog) than individuals who do not believe that vog adversely affects their symptoms.

Previous research has shown positive relationships between the vog belief index and symptom belief index; both indexes derived from the comprehensive take-home questionnaire (REVE/HAPS, 2005). Michaud JP et al (2006) examined possible contributions of bioaerosols and smoke to impacts on public health. They derived indexes for exposure to bioaerosols (i.e. mold spores, dust mites, roach parts, pollens, and animal dander) and smoke from questionnaire data and compared them to lung function,

symptoms and asthma episode occurrences. They found that the daily diary symptoms index bore no significant ($p<0.05$) associations between the measures of symptoms and either bioaerosols or smoke exposure ($p=0.083$ and $p=0.094$ respectively). However, one's diagnoses with asthma were significant for current bioaerosols and one for smoke exposures (Michaud JP, Krupitsky D, 2006)

The research hypothesis 5 is a continuation of this investigation that some individuals inherently respond differently to vog exposure than other individuals. Comparisons of lung function measurements (from AM-1) and symptoms (from diaries) were made between subjects who believed that vog contributed to their symptoms and subjects who did not. Similar to hypotheses 1-4, regression models (dependent variable: lung function measurements and symptoms; independent variable: air quality measurements) for subjects who had a vog belief index higher than 0 were compared to the subjects' models with vog belief index zero. The 95% confidence intervals of the parameter estimates for these two samples were compared; significance tests were performed based on the overlap in these intervals.

3.5.1 Data Source: Instrument Air Quality.

The same methods applied as in sections 3.2.1 and 3.2.2.

3.5.2 Data Source: Visually Observed Vog.

The same methods as described in section 3.1.1.

3.5.3 Data Source: Lung Function Measurements.

The same methods as described in sections 3.3.4 and 3.3.5.

3.5.4 Data Source: Symptoms.

The same methods as described in section 3.3.3.

3.5.5 Data Source: Belief Response Vog Index.

This study used the same comprehensive 26 page questionnaire (Appendix A: Comprehensive Take Home Questionnaire) which contains data on the subjects health status, supplement and medication use, characteristics of the home environment for co-exposures such as bioaerosols and smoke. The questionnaire was given to the subjects to complete at "home" and mailed back in the provided stamped, self-addressed envelope or deposited in a sealed envelope at the HVNP Visitor Center. The subjects were reminded to complete the questionnaire during every training session; additional copies were provided if requested by the subjects. Only one comprehensive 26 page questionnaire for each subject was requested to be completed regardless of whether the subjects participated in the Spring, 2003 and/or Fall, 2003 study periods.

The belief response vog index was derived from the three questions and weighted accordingly. The maximum index is 6.0 and minimum is 0.0

Q31. Do any of the following trigger your asthma? Choice Vog.

Never = 0, Occasionally = 0.5 Often = 1.0 Always = 2.0

Q49. Identify the things which can start your asthma episode (check each that applies to your child).

Even though vog is not listed, if subjects checked [OTHER] and entered "vog" in the blank, it was scored as 2.0.

Q26. Do you have allergies?

If subjects chose OTHER PLEASE LIST and entered "vog", it was scored 2.0.

3.5.6 Data Analysis.

The data analysis methods were similar to the research hypothesis 3 (section 3.3.6). Air quality measurements ($PM_{1.0}$, SO_2, and VVI) were regressed on the self-reported symptoms index and lung function measurements (FEV1 and PEF). The vog belief variable was added to the regression models (both multiple regression models and multiple logistic regressions) to determine whether subjects who believed that vog contributed to their symptoms and the subjects who did not had difference responses. There are 3 possibilities:

1. Partial p-value <0.05 for a regression model would indicate that the vog belief variable is a potential confounder.
2. A change in the parameter estimates of a model, with and without the vog belief variable, by more than 10% would indicate that the variable is a potential effect modifier.

3. If none of the above described criteria were met, there is not enough evidence to reject (H_o), thus the individuals who believed and those who do not believe respond to worsened air quality in the same manner in this study.

In addition, the attributable Odds Ratios were computed for every symptom index and combined symptom index with 0, 1, 2, and 3 days lag to determine the risk difference.

$$OR_{attributable} = OR_{VBI>0} - OR_{VBI=0}$$

CHAPTER IV

RESULTS

4.1 Hypotheses 1: the observed vog measurements between the individual vog observers are in agreement with each other.

Five observers were instructed to individually record the visual vog index (VVI) daily (ranging 0-3) for each study period. The observers' response rate ranged from 33 to 91 days during the Spring 2003 study period and from 36 to 79 days during the Fall 2003 study period (Table 4). Most observers recorded the average day as less than "light haze" (VVI<1), with the exception of Observer 5 (average $VVI_{observer5}$= 1.04). Half of the observers recorded a maximum of "moderate haze" (VVI =2), whereas VVI can have a maximum value of 3 ("heavy haze"). Observer 5 (Spring 2003 period) recorded "heavy haze" (VVI = 3) for nine days (10%) (Table 9); however the majority of observers recorded "heavy haze" (VVI=3) for only 0 to 2 days during each study period. For the majority of days (61% for the Fall 2003 study period and 84% for the Spring 2003 study period) observers recorded no vog (VVI=0).

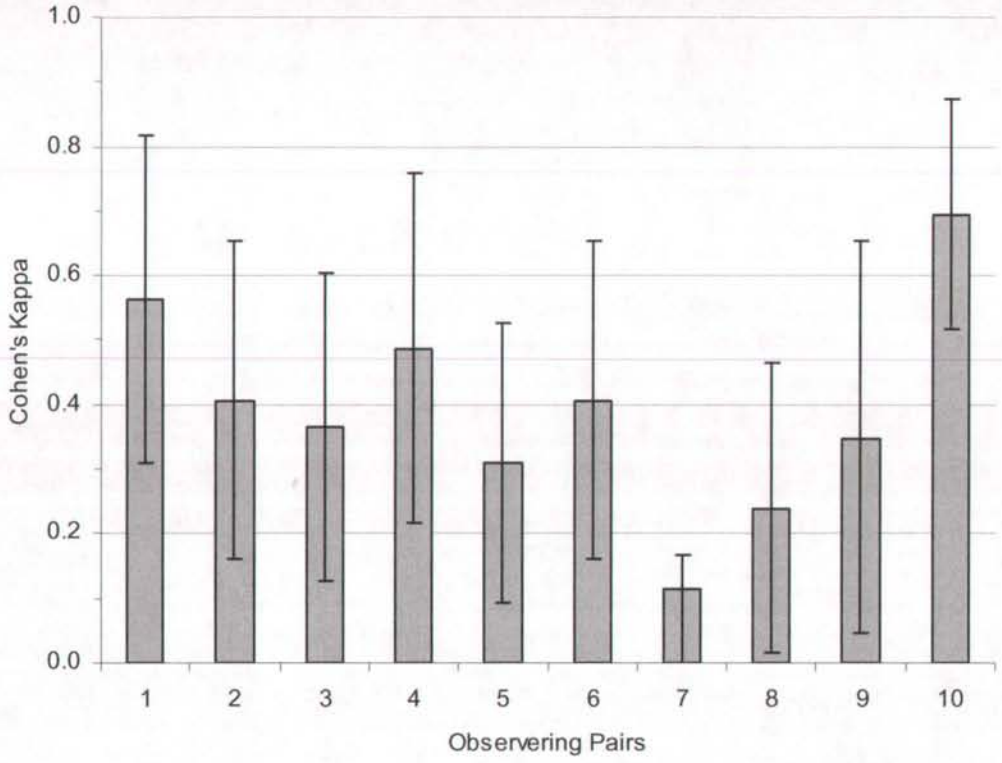
In fact, two out of five observers recorded a maximum value for VVI as 2 out of 3 during the entire Fall 2003 study period (Appendix B). The majority of observers (61%) reported a vog index of 0 (no vog) most of the time for Spring 2003 study period and Average(VVI=0) =84% for Fall 2003 study period. The second most common (20%) measurement of VVI was 1 "low hazy" for Spring 2003 study period and Average(VVI=1) =10% for Fall 2003 study period.

Table 9. Visual Vog Index (VVI) Frequency by Observer.

Observer	VVI=0	VVI=1	VVI=2	VVI=3	VVI (missing)
Spring 2003					
1	20 (61.00%)	8 (22.00%)	5 (15.00%)	0 (0.00%)	61
2	53 (79.00%)	6 (9.00%)	5 (7.00%)	3 (4.00%)	27
3	49 (80.00%)	4 (7.00%)	7 (11.00%)	1 (2.00%)	33
4	23 (53.00%)	8 (19.00%)	10 (23.00%)	2 (5.00%)	51
5	29 (32.00%)	38 (42.00%)	15 (16.00%)	9 (10.00%)	3
Fall 2003					
1	67 (85.00%)	6 (8.00%)	5 (6.00%)	1 (1.00%)	0
2	41 (87.00%)	6 (13.00%)	0 (0.00%)	0 (0.00%)	32
3	29 (81.00%)	5 (14.00%)	2 (6.00%)	0 (0.00%)	43
4	37 (84.00%)	4 (9.00%)	3 (6.00%)	0 (0.00%)	35
5	67 (85.00%)	6 (8.00%)	5 (6.00%)	1 (1.00%)	0

The average VVI was concluded based on the arithmetic averaging of available individual measurements from observers. The average VVI was higher during the Spring 2003 study period (Avg(VVI)= 0.75) than the Fall 2003 period (Avg(VVI)= 0.21) (Table 23). The VVI between each two observers and the average of the observers' reports were compared. The majority of the time, two observers assigned the same value for a given day (Appendix B). On average, "fair agreement" between two observers occurred during the Spring 2003 study period and "substantial agreement" occurred during the Fall 2003 study period; the average kappa for the Spring 2003 study period was almost twice as low (Avg(Kappa)=0.394) as the Fall 2003 study period (Avg(kappa)=0.694) (Table 10-11).

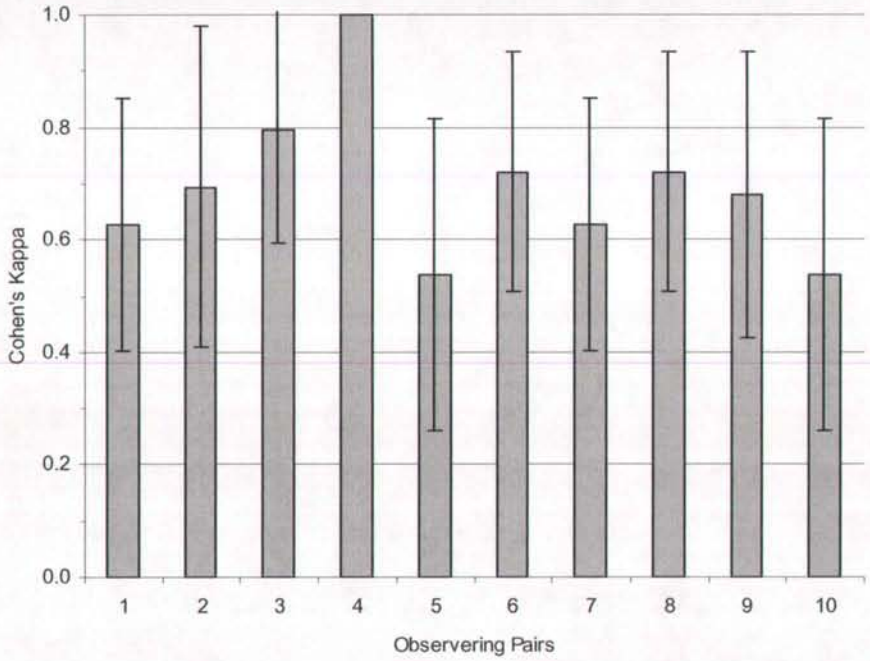
Table 10. Cohen's Kappa for Visual Vog Index, Spring 2003.



Observer	Observer 2	Observer 3	Observer 4	Observer 5	Average
Observer 1	0.487 (0.217 -0.757)*	0.348 (0.044-0.651)*	0.563 (0.309 -0.817)*	0.310 (0.095 -0.526)*	0.660 (0.449 - 0.872)*
Observer 2		0.695 (0.518 -0. 872)*	0.407 (0.162 -0.653)*	0.407 (0.162-0.653)*	0.610 (0.454 - 0.766)*
Observer 3			0.366 (0.127 -0.605)*	0.114 (-0.060 -0.290)	0.624 (0.443 - 0.805)*
Observer 4				0.239 (0.014 -0.464)*	0.091 (0.454 - 0.810)*
Observer 5					0.581 (0.452 - 0.710)*

* Test of H_0: Weighted Kappa = 0 (p-value<0.05).

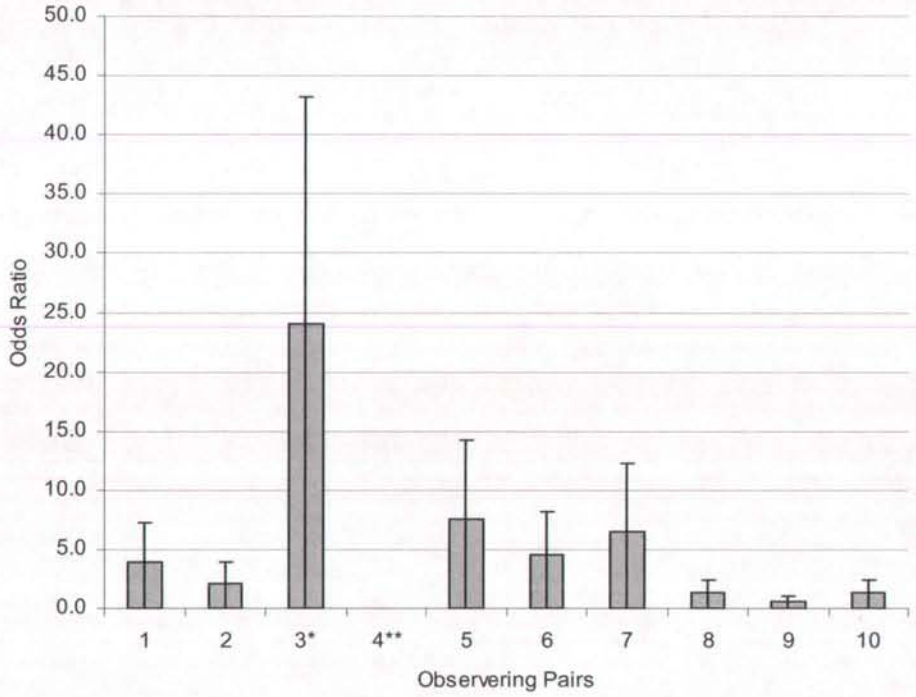
Table 11. Cohen's Kappa for Visual Vog Index, Fall 2003.



Observer	Observer 2	Observer 3	Observer 4	Observer 5	Average
Observer 1	0.537 (0.26-0.813)*	0.721 (0.507-0.935)*	0.628 (0.404-0.852)*	1.000 (1.00-1.00)*	0.734 (0.554-0.915)*
Observer 2		0.679 (0.425-0.932)*	0.693 (0.407-0.978)*	0.537 (0.26-0.813)*	0.646 (0.439-0.853)*
Observer 3			0.797 (0.554-1.00)*	0.721 (0.507-0.935)*	0.887 (0.673-1.00)*
Observer 4				0.628 (0.404-0.852)*	0.824 (0.668-0.98)*
Observer 5					0.734 (0.554-0.915)*

* Test of H_0: Weighted Kappa = 0 (p-value<0.05).

Table 12. Odds that One Observer Predicts Vog Recording of the Other (Logistic Regression Model), Spring 2003.

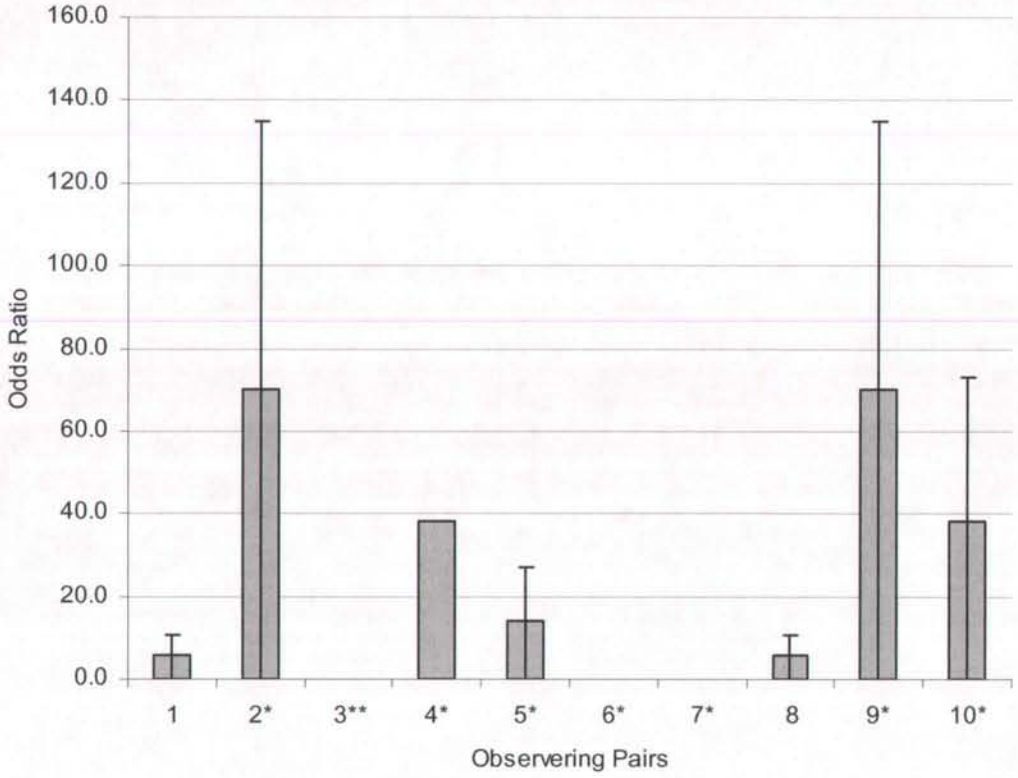


* Statistically significant (p-value<0.05).
** Odds Ratio (OR) cannot be predicted since one or more cells of the 2x2 table has value 0.

Dependent Variables	Independent variables			
	Observer 2	Observer 3	Observer 4	Observer 5
Observer 1	4.00 (0.77-20.92)**	2.14 (0.41-11.17)	∞	6.46 (0.69-60.54)
Observer 2		24 (4.83-119.31)	7.5 (0.79-71.23)	1.36 (0.37-4.97)
Observer 3			4.5 (0.78-26.13)	0.58 (0.16-2.13)
Observer 4				1.43 (0.42 - 4.91)

** The odds of vog reported vog for the Observer 1 is 4 times higher when Observer 2 reports reported of vog.
∞ Odds Ratio (OR) cannot be predicted since one or more cells of the 2x2 table has value 0.

Table 13. Odds that One Observer Predicts Vog Recording of the Other (Logistic Regression Model), Fall 2003.



** The odds of vog reported vog for the Observer 1 is 4 times higher when Observer 2 reports reported of vog.

∞ Odds Ratio (OR) cannot be predicted since one or more cells of the 2x2 table has value 0.

Dependent Variables	Independent variables			
	Observer 2	Observer 3	Observer 4	Observer 5
Observer 1	5.83 (0.95-35.99)**	70 (5.29-925.82)	38.4 (3.78-389.71)	∞
Observer 2		∞	14 (1.02-192.13)	5.83 (0.95-35.99)
Observer 3			∞	70.00 (5.29-925.82)
Observer 4				38.39 (3.78 -389 .47)

** The odds of vog reported buying the Observer 6 is 6.83 times higher when Observer 7 reports reported of vog.

∞ Odds Ratio (OR) cannot be predicted since one or more cells of the 2x2 table has value 0.

During Spring 2003 study period, observers 3 and 5 were the most likely to disagree (kappa=0.114 with 95% CI (-0.060-0.290)); Observer 3 was located in the Kilauea military Camp and Observer 5 was located at the HVNP Visitors Center. Whereas during Fall 2003 study period, observers 1 and 5 have Cohen's kappa=1; both observers were located in the Kilauea Military Camp (Table 10 and 11).

Results for logistic regression showed that the odds of an observer reporting a vog episode (VVI=0 vs. VVI≥1) is 35 times higher when another observer also reported a vog episode (VVI=0 vs. VVI≥1); the results were based on seven models (p-value<0.05) (Table 12 and 13) since for the three models the odds ratios were not possible to compute because at least one cell (B or C) was empty (Table 7).

4.2 Hypotheses 2: visually-observed vog and the instrument-measured vog (SO_2 and $PM_{1.0}$) for the same day are positively associated; during the voggy days, the daily SO_2 and $PM_{1.0}$ are higher than on non-voggy days, as assessed by the observers.

During the 2003 calendar year, daily average of sulfur dioxide was 32.5 ppb, ranging between 0 and 173 ppb (Table 24). The daily average of sulfur dioxide surpassed the National Ambient Air Quality Standard (NAAQS) of 140 ppb (24 hour average) three times: on 3/29/2003 173 ppb, on 6/2/2003 162 ppb, and on 3/5/2003 141 ppb (EPA, 2008). However, the annual daily average sulfur dioxide (SO_2) was 14 ppb which is lower than the NAAQS annual limit of 30 ppb.

The daily average $PM_{1.0}$ was 1.87 ug/m^3, at times peeking to as high as 7.85 ug/m^3 (Table 24); the NAAQS did not set standards for $PM_{1.0}$. They only set standards for $PM_{2.5}$ and PM_{10}.

Visual vog index (VVI) was obtained from five observers independently. The compliance varied throughout the week. Higher compliance was observed in the beginning of the week; on Monday the compliance was 85% whereas on weekends it was 36.5% (Table 14). On weekends and Mondays, the recorded VVI was slightly higher (not significantly so) compared to the rest of the week, whereas instrument measured vog were more or less the same throughout the week (Table 14). The results of analysis of variance (ANOVA) tests show that day of weekday is not a good predictor (p-value>0.05) of daily SO_2 (R^2= 0.00921), $PM_{1.0}$ (R^2 = 0.00926), and VVI (R^2 = 0.1723) (Table 15-16).

The observers generally assigned higher vog values for the Spring 2003 study period (VVI_{mean} = 0.62) compared to the Fall 2003 study period (VVI_{mean}=0.24) (Table 23); the average assigned vog value ranged from 0.37 to 1.04 for the Fall 2003 study period and from 0.23 to 0.25 for the Spring 2003 study periods. Only 2 days during the Fall, 2003 study period was the average VVI more than or equal to 2, which is in contrast to 15 days during the Spring, 2003, when the average VVI was more than or equal to 2. The VVI for both study periods was 0.44; 0.75 for the Spring 2003 study period and 0.21 for the Fall 2003 study period (Table 23).

The SO_2 measurements were slightly higher during the Spring study period compared to Fall (daily average SO_2: 25.11 ppb versus 15.72 ppb respectively); similarly, $PM_{1.0}$ was higher during the Spring 2003 study period compared to the Fall 2003 study period (3.08 ug/m^3 versus 0.81 ug/m^3). For the rest of the year, the daily average SO_2 was slightly lower than Fall and Spring study periods; however, daily average $PM_{1.0}$ remained similar to the Spring and Fall 2003 study periods combined (Table 23).

Table 14. Visual Vog Index by Weekday, 2003.

Weekday*	Number of observations	Average VVI	Lower 95% CI	Upper 95% CI	Compliance
Monday	24	0.73	0.33	1.12	85%
Tuesday	25	0.47	0.21	0.73	83%
Wednesday	26	0.35	0.13	0.56	83%
Thursday	25	0.34	0.12	0.55	78%
Friday	25	0.34	0.16	0.52	65%
Saturday	24	0.61	0.31	0.90	38%
Sunday	23	0.72	0.27	1.18	35%

*ANOVA test results: weekday is not a good predictor of VVI (F-test=1.53, p-value=0.1723, R^2=0.053).

Table 15. Daily Average Sulfur Dioxide (SO_2) by Weekday, 2003.

Weekday*	Number of observations	Average SO_2	Lower 95% CI	Upper 95% CI
Monday	26	14.17	5.68	22.66
Tuesday	25	19.92	6.33	33.52
Wednesday	24	23.64	12.78	34.49
Thursday	24	21.08	5.55	36.61
Friday	25	22.97	9.07	36.86
Saturday	25	21.33	5.09	37.58
Sunday	23	24.14	6.01	42.28

* Limited to days when daily average VVI is available.
** ANOVA test results: weekday is not a good predictor of VVI (F-test=0.026, p-value=0.999, R^2=0.00921).

Table 16. Daily Average Particulate matter ($PM_{1.0}$) by Weekday, 2003.

Weekday**	Number of Observations*	Average $PM_{1.0}$	Lower 95% CI	Upper 95% CI
Monday	21	1.54	0.90	2.18
Tuesday	22	1.85	1.26	2.43
Wednesday	23	1.92	1.20	2.64
Thursday	20	1.93	1.18	2.68
Friday	22	1.95	1.17	2.72
Saturday	21	2.08	1.20	2.95
Sunday	22	2.03	1.11	2.96

* Limited to days when daily average VVI is available.
** ANOVA test results: weekday is not a good predictor of VVI (F-test=0.022, p-value=0.9684, R^2=0.0.00926).

Air quality measurements (0, 1, 2, and 3 days lag) were examined for Pearson correlation. Sulfur dioxide was weakly correlated with $PM_{1.0}$ for the same day (r^2=0.37, p-value<0.01), and moderately correlated with the visual vog index (r^2= 0.44, p-value <0.01). $PM_{1.0}$ measurements were moderately and highly correlated with previous 1, 2, 3 day $PM_{1.0}$ (r^2 were 0.66, 0.50 and 0.64 respectively) whereas SO_2 measurements were weakly correlated with SO_2 1 lag day measurements (r^2 = 0.37, p-value<0.01), less correlated with SO_2 2 lag day measurements (r^2 = 0 .24, p-value<0.01) and even less correlated with SO_2 3 lag day (r^2 = 0.0092). The visual vog index is moderately correlated with the 1 lag day visual vog index (VVI) (r^2 = 0.66, p-value<0.05) and less so with consecutive days (Table 30)

Increases in average VVI coincided with increases in SO_2 and $PM_{1.0}$ for the same day. The rounded VVI by average SO_2 and $PM_{1.0}$ for the same day were examined (Table 17). The mean $PM_{1.0}$ significantly increased as the average VVI increased; VVI=0 corresponded to the average $PM_{1.0}$ 1.49 ug/m^3, VVI=1 corresponded to 2.31 ug/m^3, VVI=2 corresponded to 4.19 ug/m^3, and VVI=3 (not statistically significant) corresponded to 7.40 ug/m^3. Similarly, the mean SO_2 significantly increased as the average VVI increased; VVI=0 correspondent to the average SO_2 11.56 ppb, VVI=1 correspondent to 32.73 ppb, VVI=2 correspondent to 64.61 ppb, and VVI=3 (not statistically significant) correspondent to 38.85 ppb. However, there were very few days with (n = 4) average VVI=3; average $PM_{1.0}$ and SO_2 measurements were not statistically different during days with VVI=3 and VVI=2.

The results of simple linear aggression model showed that the daily average VVI is a fair predictor of both daily SO_2 (p-value<0.01, R^2 [variation explained by the model]

=0.23) and $PM_{1.0}$ (p-value<0.01, R^2=0.29) (Table 18-19). In contrast, daily $PM_{1.0}$ was not as good predictor as the average VVI in predicting daily SO_2 (p-value<0.01, R^2=0.15) although statically significant.

Table 17. Daily Average Particulate matter ($PM_{1.0}$) and Sulfur Dioxide (SO_2) by Visual Vog Index for the Same Day.

VVI**	Instrument Measured	N	Mean	Lower 95%	Upper 95%	Minimum	Maximum
0	$PM_{1.0}$*	107	1.49	1.23	1.76	0.01	6.89
1	$PM_{1.0}$*	32	2.31	1.78	2.84	0.21	5.58
2	$PM_{1.0}$*	11	4.19	2.92	5.46	1.96	7.85
3	$PM_{1.0}$	1	7.40	---	---	7.40	7.40
0	SO_2*	118	11.56	7.13	15.99	0.00	128.77
1	SO_2*	36	32.73	21.66	43.81	0.00	127.18
2	SO_2*	14	64.61	37.19	92.03	11.00	173.05
3	SO_2	4	38.85	-47.69	125.40	0.00	115.36

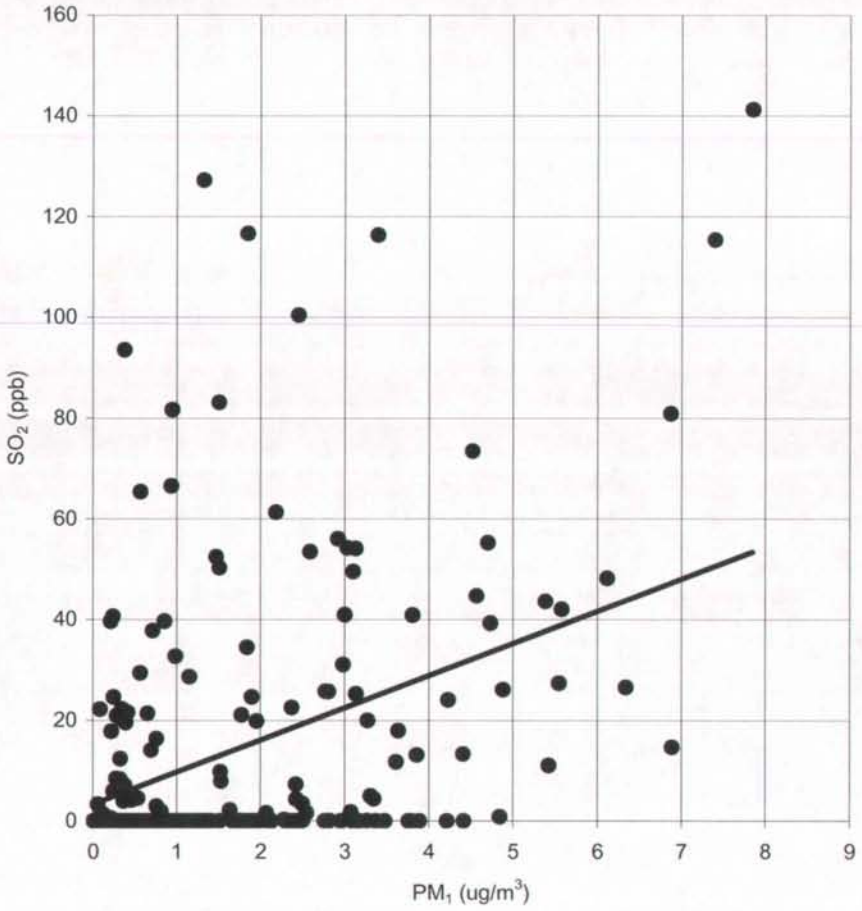
* Statistically significant (p-value<0.05).
** The VVI was roundup to the nearest whole number.

4.3 **Hypotheses 3: lung function measurements (FE.V1 and PEF) of the Hawai`i Volcanoes National Park workers are negatively associated with the visually observed vog; whereas, self-reported symptoms are positively associated.**

4.3.1 Exclusion Criteria.

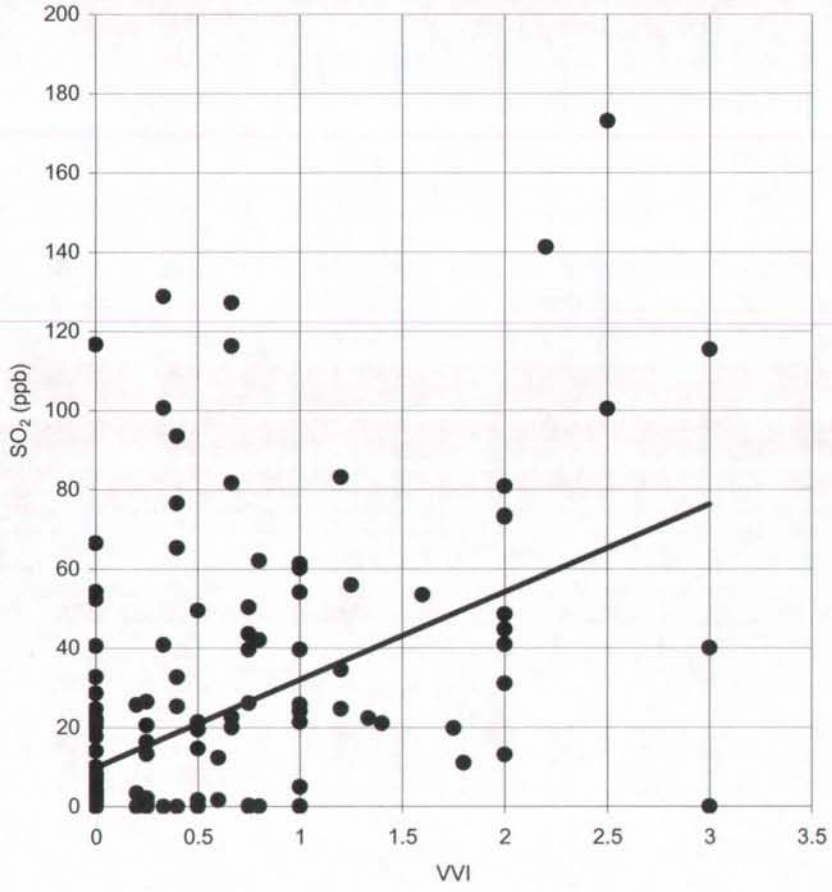
An average person completed 59 days of diaries and/or AM-1 use; some subjects completed as many as 94 days during each study period. The total number of observations before exclusion was 7,704 person*days.

Table 18. Linear Regression: Daily Average Particulate matter ($PM_{1.0}$) and Sulfur Dioxide (SO_2) for the Same Day.



Dependent variable	Independent variable	Parameter estimate	Standard Error	t-test	p-value	R^2
SO_2	PM_1	6.38	1.06	6.00	<.0001	0.15

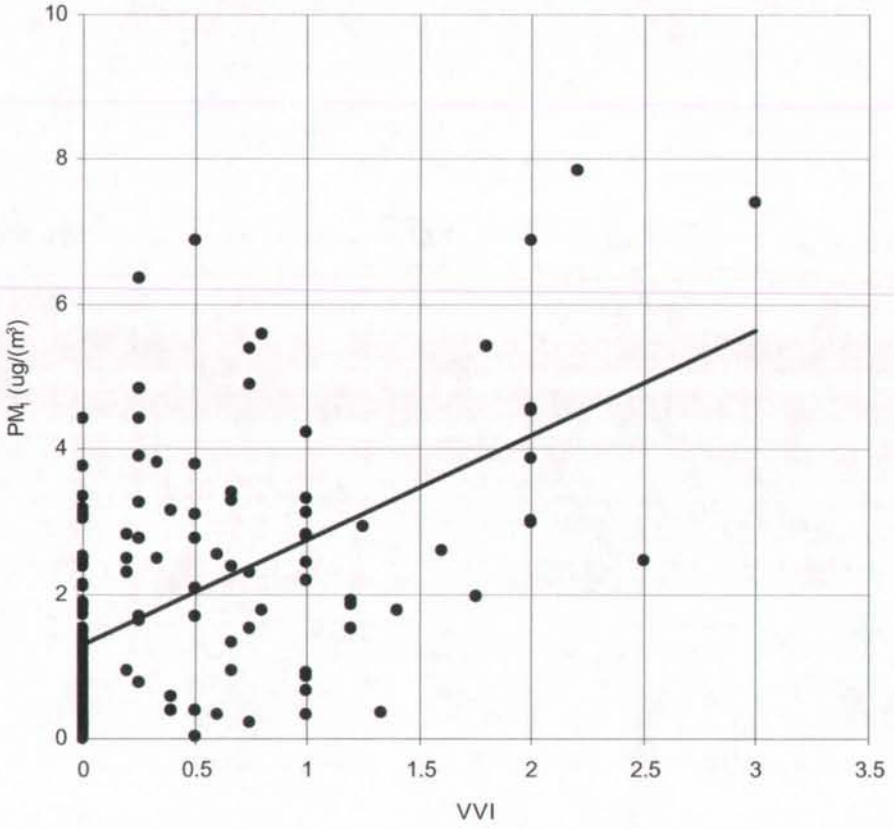
Table 19. Linear Regression: Daily Average Visual Vog Index (VVI) and Sulfur Dioxide (SO_2) for the Same Day.



Dependent variable	Independent variable	Parameter estimate	Standard Error	t-test	p-value	R^2
SO_2	VVI*	22.17	3.12	7.10	<.0001	0.23

* The actual value VVI was used in this model (the VVI was not roundup to the nearest whole number).

Table 20. Linear Regression: Daily Average Visual Vog Index (VVI) and Particulate matter ($PM_{1.0}$) for the Same Day.



Dependent variable	Independent variable	Parameter estimate	Standard Error	t-test	p-value	R^2
$PM_{1.0}$	VVI*	1.45	0.18	7.83	<.0001	0.29

* The actual value VVI was used in this model (the VVI was not roundup to the nearest whole number).

Some subjects were the Park's firefighters and were exposed to forest fires. Others left the islands or took vacations for prolonged periods of time (Table 21). The following is a list of factors that were defined as unusual exposure/compliance:

- subjects left the island of Hawai`i,
- absent from work more than 3 days,
- exposure to additional environmental factors such as laze, sulfur Springs, forest fire smoke, steam vents, direct contact with lava or exposure to secondhand smoke or paint,
- worked at or visited Chain Creator Road at any time of the day (diary exclusion criteria).

The most common reason for exclusions were exposure to forest fire (152 person-days), absence from work for more than three days (142 person-days), and exposure to lava (74 person - days) (Table 21). Thus, the day of the exposure and three following days were excluded from analysis (Table 22). After the exclusion 6,671 person days were included in the analysis.

Table 21. The Exclusion Criteria.

Reason for Exclusion Number of Person Days Exposures	Number of Person Days Exposures
Exposed to forest fire and lava	152
Absent from work for more than three consecutive days (vacation, day off, personal days, holidays)	142
Exposed to Lava	74
Expose to forest fire and smoke	50
Expose to forest fire and laze	42
Exposed to secondhand smoke	36
Unusual indoor/outdoor exposures such as indoor painting	35
Worked/Visited Chain of Craters Road	34
Exposed to Sulfur Springs and secondhand smoke	29
Exposed to forest fire	22
Expose to forest fire and secondhand smoke	18
Exposed to Lava and secondhand smoke	14
Exposed to Sulfur Springs	11
Left island	4
Exposed to unusual amount of dust	2

Table 22. AM-1 and Diary Exclusion and Inclusion Criteria for Consecutive Days after Unusual Exposure.

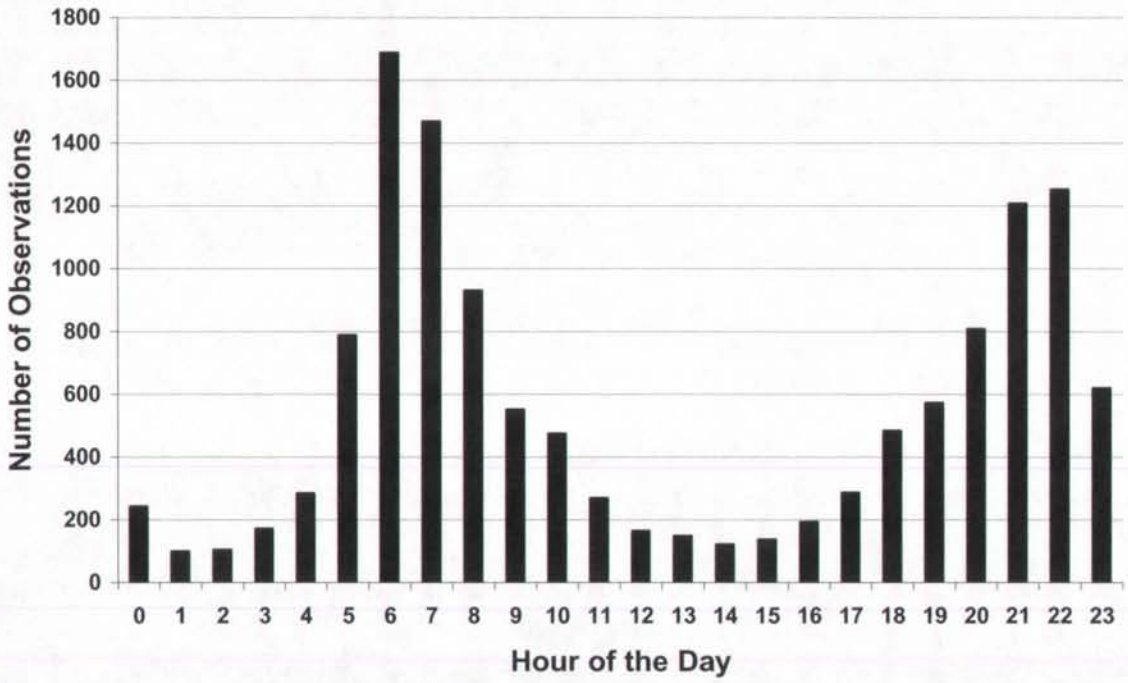
Numbered days after exposure	Included/excluded from analysis	Number of person days
Unknown	Included	1092
First day of the exposure	Excluded	574
Second day after exposure	Excluded	240
Third day after exposure	Excluded	219
Fourth day after exposure	Included	191
Fifth day after exposure	Included	160
Sixth day after exposure	Included	139
Seventh day after exposure	Included	111
Longer than seven days after exposure	Included	4978

$N_{\text{before exclusion}}$ =7,704 person*days; $N_{\text{after exclusion}}$ =6,671 person*days.

4.3.2 Descriptive Statistics.

The majority of subjects followed instructions, regularly and properly used the AM-1 and completed diaries daily. The majority of subjects used the AM-1 twice-a-day 6 a.m. - 8 a.m. in the morning and 8 p.m. - 10 p.m. in the evening. A slightly higher use of AM-1 use is observed in the morning than in the evening. Very few subjects used AM-1 devices late at night (1 a.m. - 3 a.m.) or during working hours (10 a.m. - 4 p.m.) (Figure 16).

Figure 16. Asthma Monitor 1 (AM-1) Compliance* by Hour of the Day.



* AM-1 compliance: personal AM-1 was used at least once between 12:01 a.m. to 11:59 p.m. that day. (N =5,581 person*days).

After the exclusion criteria listed above, on average, each subject completed around two months of continuous diary (mean = 59 days, standard deviation = 23 days) for each study period, however some subjects completed only one day and others 94 days (Figure

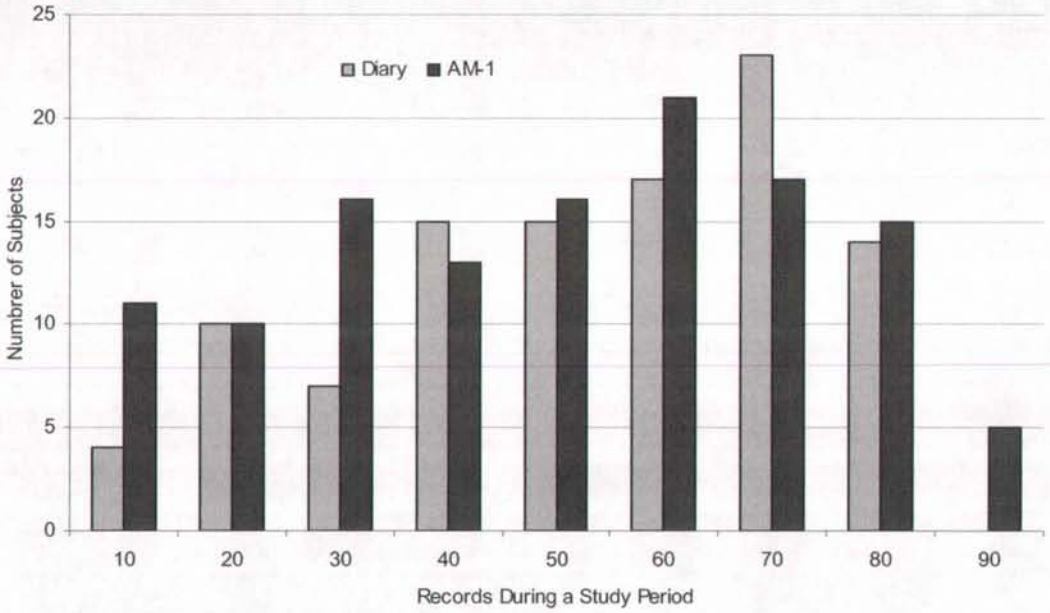
17-19). Two subjects decided not to use the AM-1 (and only agreed to complete diaries). Among subjects that used the AM-1, on average, each subject used his/her personal AM-1 for a month and a half (at least once a day) continuously (mean = 45 days, standard deviation = 24 days) for each study period; however, as the diaries compliance response rates varied, 8 subjects had less than one week of valid AM-1 data. At a given day, some subjects only completed diaries (n = 6), only used AM-1 (n =13), or completed both (n = 105); subjects that did not complete the AM-1 (more than 2 measurements) or diary (more than 2 measurements) were excluded from analysis. Overall, 5,579 person - days of diary data and 5,581 person - days of AM-1 data were analyzed. For more than twenty-five percent of the time (n = 3,891 person - days) subjects that used AM-1 devices did so both in the morning (a.m.) and the afternoon (p.m.) as instructed; 5,557 person - days were collected in the morning only and 4,849 person - days were collected in the afternoon/evening only.

The average age of subjects was 45 years old, ranging between 22 and 70 (standard deviation = 13.2). A little more than half of the participants were females (52%). The body weight ranged from 102 to 298 pounds, averaging 162 pounds (standard deviation = 36.1). The average height was 171 cm (standard deviation = 8.2), ranging between 147 cm to 195 cm. The average BMI was 24.9 kg/m^3 space (standard deviation = 8.8), ranging between 16.9 kg/m^3 and 35.2 kg/m^3 (not shown).

Table 23. Descriptive Statistics for Visual Vog Index, and Daily Average Particulate matter ($PM_{1.0}$) and Sulfur Dioxide (SO_2).

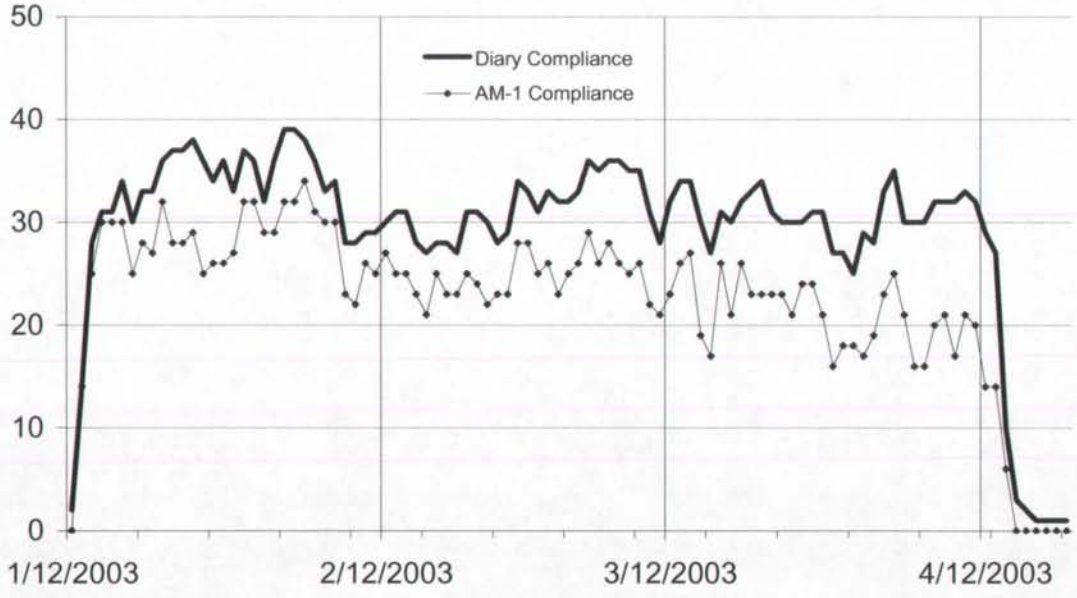
Period	Observer	N	Mean	Std Dev	Minimum	Maximum
Spring 2003	Person 1	33	0.55	0.75	0.00	2.00
	Person 2	67	0.37	0.81	0.00	3.00
	Person 3	61	0.34	0.75	0.00	3.00
	Person 4	43	0.79	0.97	0.00	3.00
	Person 5	91	1.04	0.94	0.00	3.00
	Average	93	0.75	0.79	0.00	3.00
	Daily $PM_{1.0}$	73	3.08	1.59	0.76	7.85
	Daily SO_2	94	25.11	36.03	0.00	173.05
Fall 2003	Person 1	79	0.24	0.62	0.00	3.00
	Person 2	47	0.26	0.67	0.00	2.00
	Person 3	36	0.25	0.55	0.00	2.00
	Person 4	44	0.23	0.57	0.00	2.00
	Person 5	79	0.24	0.62	0.00	3.00
	Average	79	0.21	0.49	0.00	2.50
	Daily $PM_{1.0}$	79	0.81	0.72	0.01	3.35
	Daily SO_2	79	15.72	28.67	0.00	127.18
Other times during 2003	Daily $PM_{1.0}$	63	1.50	1.37	0.03	6.12
	Daily SO_2	175	6.70	20.36	0.00	161.73

Figure 17. Diary** and Asthma Monitor 1 (AM-1)* Compliance Spring and Fall 2003.



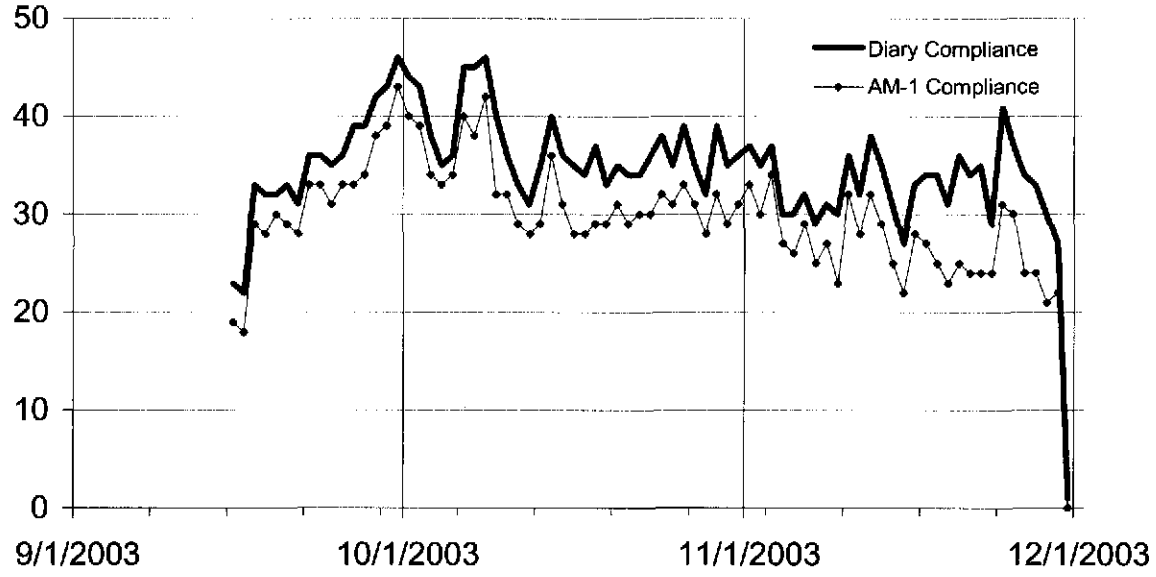
* AM-1 compliance: personal AM-1 was used at least once between 12:01 a.m. to 11:59 p.m. that day.
**diary compliance: diary day was partially or completely filled by a subject.

Figure 18. Diary** and Asthma Monitor 1 (AM-1)* Compliance by Date, Spring 2003.



** Diary compliance: diary day was partially or completely filled by a subject.
* AM-1 compliance: at least one AM-1 blow per person per day.
The graph is based on the after exclusion data.

Figure 19. Diary** and Asthma Monitor 1 (AM-1)* Compliance by Date, Fall 2003.



** Diary compliance: diary day was partially or completely filled by a subject.
* AM-1 compliance: at least one AM-1 blow per person per day.
The graph is based on the after exclusion data.

Only 1% of park employees reported taking fast acting asthma medication and 2.5% took asthma maintenance medication during a given day. Allergy medications were taken more often: 4% of park employees took allergy medication in the morning and 4% took it in the afternoon and evening during a given day. 1.4% of park employees took cough syrup during a given time. 12% of the park employees took their heart medication during a given day (Table 24). Medication use was not significant in these multiple regression and logistic models, thus it was excluded from the models.

Both unadjusted best efforts PEF and FEV1 values were slightly higher in the morning (485 L/M and 3.06 L) than afternoon/evening (482 L/M and 3.2 L). Nose irritation (19.2%) and coughing (15.5%) were the most common symptoms observed in the park; the mean indexes were 0.25 and 0.19 respectively. Headache (8.5%) and sore eyes

(11.1%) were moderately common symptoms (the mean indexes were 0.11 and 0.13 respectively). Only a small portion of park employees reported smoking during a given day (1.2%).

4.3.3 Asthma Monitor 1 Validation.

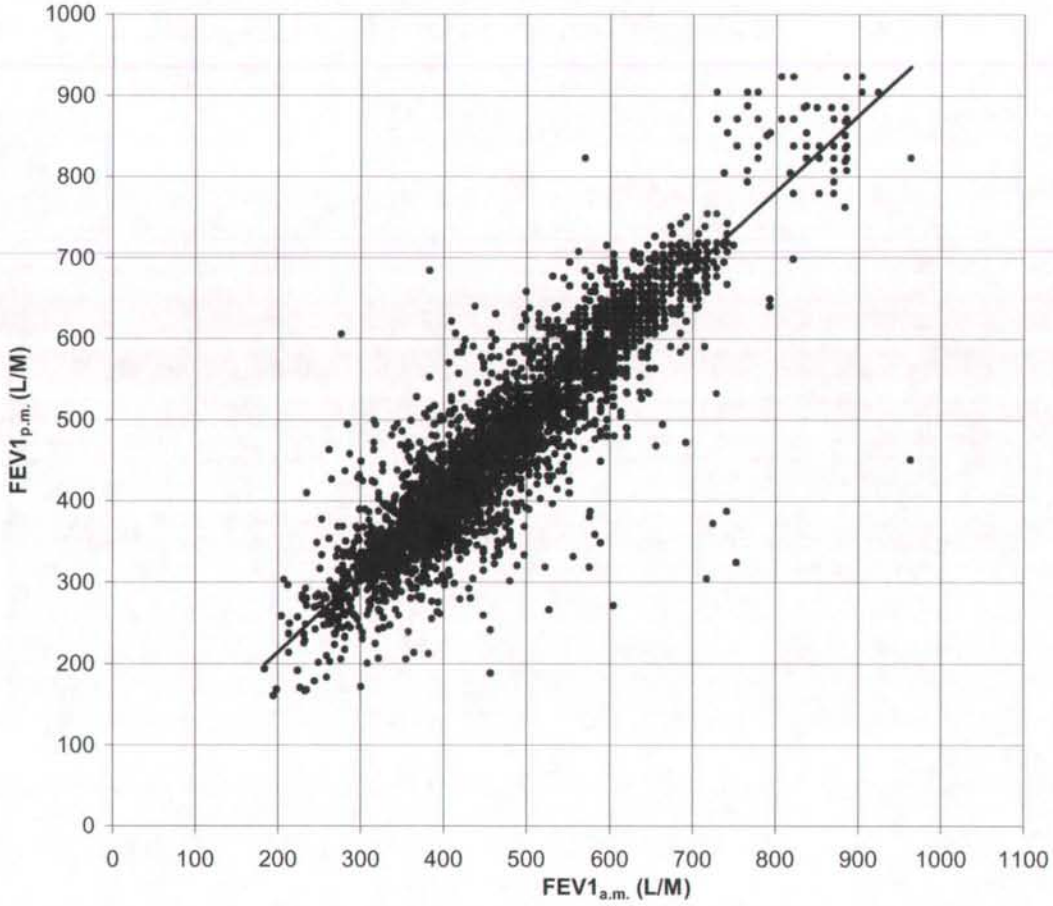
To evaluate the reliability of the AM-1 in the "home" settings, the lung function measurements (PEF and FEV1) for both Spiro-232 (observed the technician) and AM-1 measurements (at "home") were matched for the same day for an individual (n= 81). The PEF measurements were moderately correlated ($r^2 = 0.55$, $p<0.001$) and FEV1 measurements were highly correlated ($r^2= 0.82$, $p < 0.001$) (Table 27 and 31). On average, Spiro-232 measurements were slightly higher: 2.5% higher for PEF and 1.6% higher for FEV1 compared to AM-1 measurements (Table 25-31). The paired (two-sided) t-test did not detect a significant difference between AM-1 and Spiro-232 measurements (H_o:PEF_{AM-1}=$PEF_{Spiro-232}$, p-value = 0.24 & H_o: $FEV1_{AM-1}$= $FEV1_{Spiro-232}$, p-value = 0.12). Simple linear regressions have shown that $FEV1_{AM-1}$ is a good predictor of $FEV1_{Spiro-232}$ (p-value<0.0001, R^2=0.671) and PEF_{AM-1} is a moderate predictor of $PEF_{Spiro-232}$ (p-value<0.0001, R^2=0.304).

The results of linear regression models indicate that over 90% of evening $FEV1_{AM-1}$ variation could be explained by the morning $FEV1_{AM-1}$ measurements for the same individual; morning and evening $FEV1_{AM-1}$ measurements for the same individual were highly associated. Similarly, morning PEF_{AM-1} and evening PEF_{AM-1} were slightly less associated (R^2=0.85) (Table 25-29).

Table 24. Descriptive Statistics for Lung Function, Common Symptoms, Medication Use, and Air Quality.

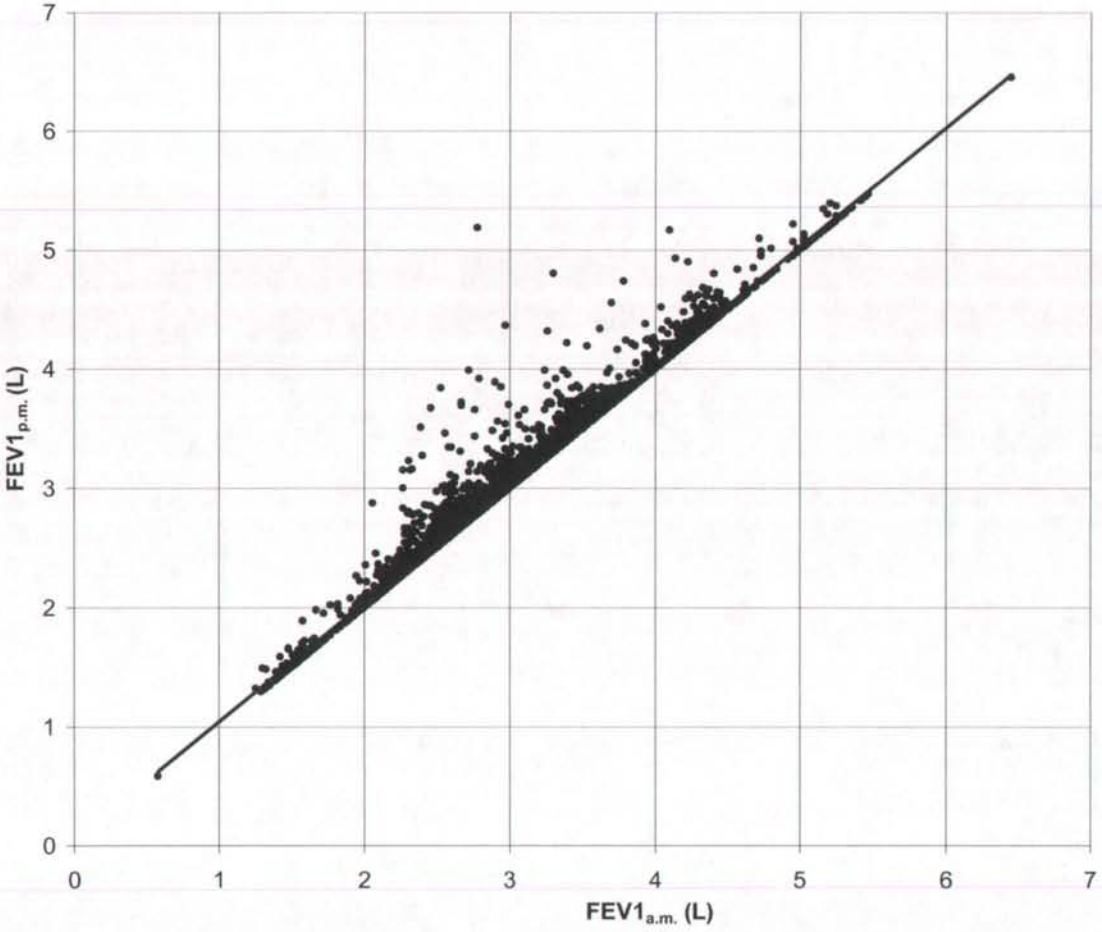
Variable	Mean	Std Dev	Minimum	Maximum
Lung Function Test				
Morning PEF (L/M) from AM-1	484.8	129.3	145.0	963.0
Morning FEV1 (L) from AM-1	3.064	0.701	0.580	6.450
Afternoon/Evening PEF (L/M) from AM-1	481.8	121.5	184.0	963.0
Afternoon/Evening FEV1 (L) from AM-1	3.017	0.686	1.320	5.390
Daily PEF (L/M) from AM-1	493.9	126.8	145.0	963.0
Daily FEV1 (L) from AM-1	3.100	0.693	0.580	6.450
Symptoms	1.841	1.666	0.010	7.848
Cough (scale: 0-3)	0.189	0.514	0.000	3.000
Wheeze (scale: 0-3)	0.046	0.259	0.000	3.000
Headache (scale: 0-3)	0.112	0.408	0.000	3.000
Stomachache (scale: 0-3)	0.028	0.192	0.000	3.000
Shortness of Breath (scale: 0-3)	0.063	0.295	0.000	3.000
Sore, Itchy, Watery Eyes (scale: 0-3)	0.135	0.403	0.000	3.000
Irritation of Nose/Sinus/Throat (scale: 0-3)	0.246	0.549	0.000	3.000
Other Symptoms (scale: 0-3)	0.017	0.150	0.000	3.000
Flu, Cold, Bronchitis	6.6 %			
Average Symptoms	0.104	0.214	0.000	2.625
Smoking Status	1.2%			
Medication Use				
Fast Relief Asthma Medication	1.1%			
Fast Relief Asthma Medication Use in the Morning	0.3%			
Fast Relief Asthma Medication Use in the Afternoon/Evening	0.5%			
Maintenance Asthma Medication Use	2.5%			
Maintenance Asthma Medication Use in the Morning	1.6%			
Maintenance Asthma Medication Use in the Afternoon/Evening	1.2%			
Allergy Medication Use	8.0%			
Allergy Medication Use in the Morning	4.0%			
Allergy Medication Use in the Afternoon/Evening	4.1%			
Cough Syrup Use	1.4%			
Cough Syrup Use in the Morning	0.7%			
Cough Syrup Use in the Afternoon/Evening	0.8%			
Heart Medication Use	11.9%			
Heart Medication Use in the Morning	8.9%			
Heart Medication Use in the Afternoon/Evening	4.7%			
Other Medication Use	3.4%			
Other Medication Use in the Morning	1.9%			
Other Medication Use in the Afternoon/Evening	1.3%			
Air Quality				
Particulate matter (ug/m^3)	1.841	1.666	0.010	7.848
Sulfur Dioxide (ppb)	20.735	32.623	0.000	173.045
Visual Vog Index (scale: 0-3)	0.449	0.742	0.000	3.000

Table 25, Within Person Daily Variation between Morning (A.M.) and Afternoon/Evening (P.M.) in Asthma Monitor 1 (AM-1) PEF Measurements for the Same Day.



Dependent variable	Independent variable	Parameter estimate	Standard Error	t-test	p-value	R^2
$PEF_{p.m.}$	$PEF_{a.m.}$	0.895	0.007	135.26	<.0001	0.848

Table 26. Within Person Daily Variation between Morning (A.M.) and Afternoon/Evening (P.M.) in Asthma Monitor 1 (AM-1) FEV1 Measurements for the Same Day.

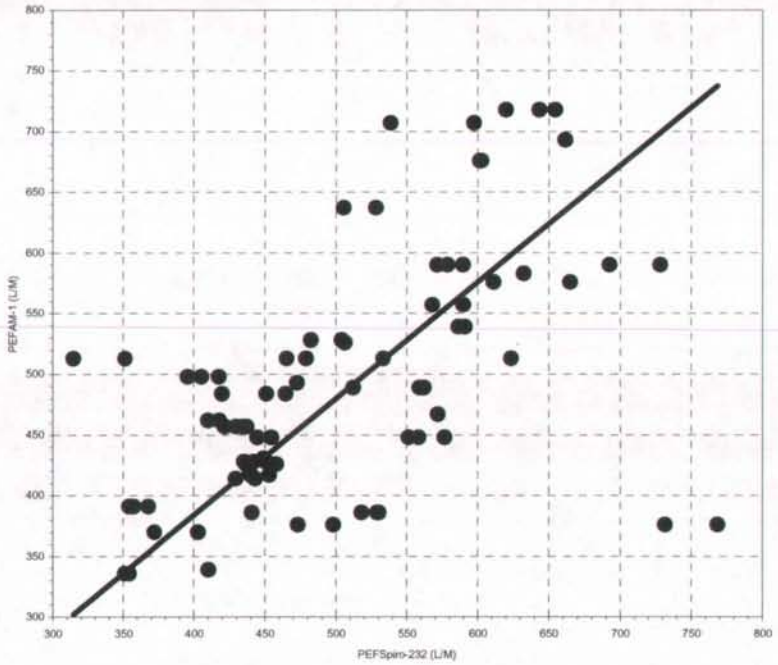


Dependent variable	Independent variable	Parameter estimate	Standard Error	t-test	p-value	R^2
$FEV1_{p.m.}$	$FEV1_{a.m.}$	0.952	0.00551	172.98	<.0001	0.901

4.3.4 Pearson Correlation.

The reported symptoms index and lung function were examined for Pearson correlations; among lung functions, correlation ranged from moderately to high. Moderate significant correlations are observed between different lung functions (PEF and FEV1) for the same part of the day (a.m. and p.m.) (Table 29). The correlation was much higher ($r^2 = 0.95$ for FEV1, $r^2 = 0.92$ for PEF) for the same lung function for the different parts of the day (a.m. and pm) (p - value <0.001). The symptom indexes (cough, wheeze, headache, stomachache, shortness of breath, sore/itchy/watery eyes, irritation of nose/sinus/throat, and other symptoms) were weakly to moderately ($p<0.0001$) correlated. The highest correlations were served between the nose irritation index and cough index ($r^2= 0.52$, $p<0.001$) and the nose irritation index and eye irritation index ($r^2= 0.42$, $p<0.001$). The weakest correlations between symptoms were the stomach ache index and the eye irritation index ($r^2= 0.15$, $p<0.001$) and the nose irritation index ($r^2= 0.13$, $p<0.001$). Although the correlation between lung function and symptoms were weak (r^2 range [-0.17: 0.0056]), most of the correlations were negative (40 out of 42) and significant at the alpha level 0.05 (38 out of 42).

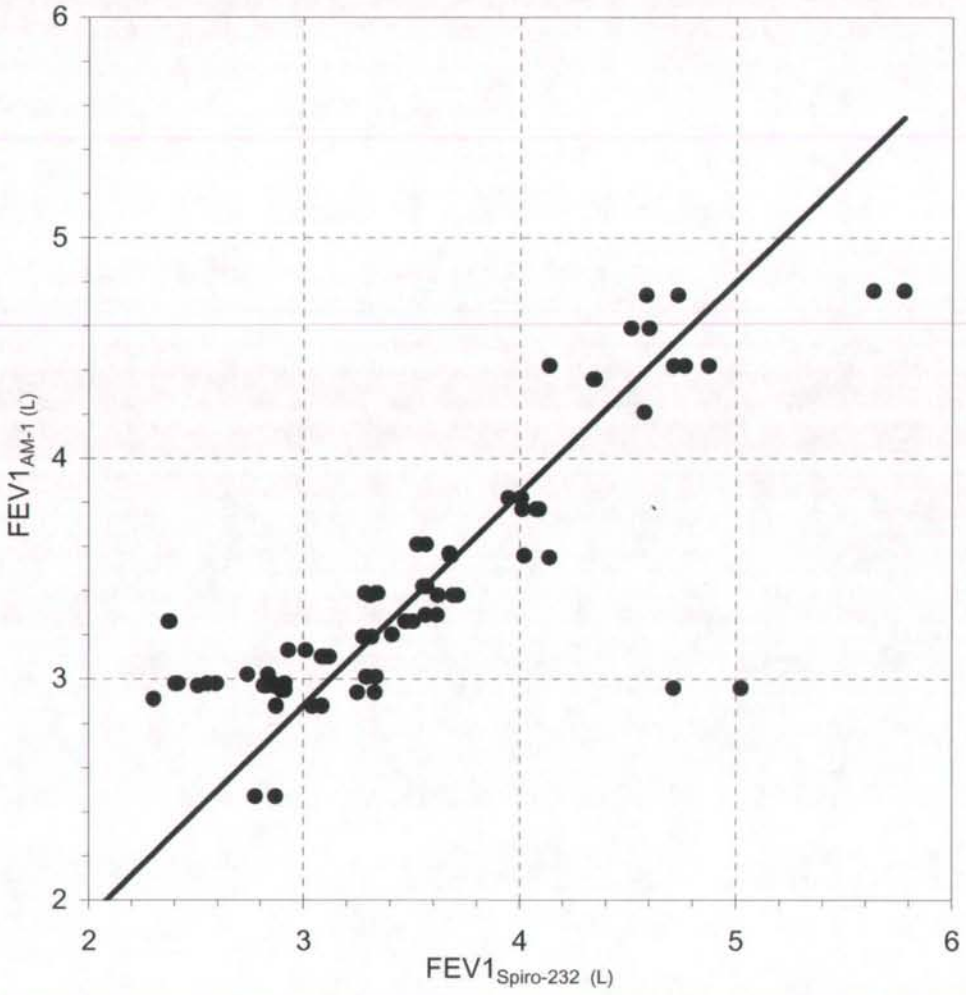
Table 27. Within Person Daily Variation in PEF between AM-1 (Taken Home) and Full Effort Spirometry (Administered by a Technician) for the Same Day.



Dependent Variable	Independent Variable	Parameter Estimate	Standard Error	t-test	p-value	R^2
$PEF_{Spiro-320}$	PEF_{AM-1}	0.553	0.094	5.870	<.0001	0.3035

Variable	Mean	Std Dev	Minimum	Maximum
PEF (L/M) from AM-1	493	99	336	718
PEF (L/M) from Spiro-232	505	99	315	769

Table 28. Within Person Daily Variation in FEV1 between AM-1 (Taken Home) and Full Effort Spirometry (Monitored by a Technician) for the Same Day.



Dependent Variable	Independent Variable	Parameter Estimate	Standard Error	t-test	p-value	R^2
$FEV1_{Spiro-320}$	$FEV1_{AM-1}$	1.128	0.088	12.81	<.0001	0.6707

Variable	Mean	Std Dev	Minimum	Maximum
FEV1 (L) from AM-1	3.41	0.57	2.47	4.76
FEV1 (L) from Spiro-232	3.49	0.78	1.97	5.78

Table 29. Pearson Correlation for Lung Function (FEV1 and PEF) & Symptoms for the Same Day.

Variables		Morning PEF (L/M)	Morning FEV1 (L)	Afternoon/Evening PEF (L/M)	Afternoon/Evening FEV1 (L)	Daily PEF (L/M)	Daily FEV1 (L)	Cough	Wheeze	Headache	Stomachache	Shortness of Breath	Sore, Itchy, Watery Eyes	Irritation of Nose/Sinus/
Average Symptoms	r^2	-0.149	-0.136	-0.162	-0.136	-0.155	-0.136	0.706	0.554	0.571	0.376	0.651	0.660	0.755
	p	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Irritation of Nose/Sinus/Throat	r^2	-0.149	-0.116	-0.145	-0.102	-0.143	-0.110	0.523	0.257	0.276	0.134	0.288	0.425	
	p	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	
Sore, Itchy, Watery Eyes	r^2	-0.067	-0.056	-0.075	-0.058	-0.070	-0.057	0.268	0.236	0.343	0.153	0.373		
	p	<.0001	0.001	<.0001	0.001	<.0001	0.000	<.0001	<.0001	<.0001	<.0001	<.0001		
Shortness of Breath	r^2	-0.034	-0.085	-0.067	-0.103	-0.048	-0.095	0.399	0.508	0.276	0.219			
	p	0.032	<.0001	<.0001	<.0001	0.001	<.0001	<.0001	<.0001	<.0001	<.0001			
Stomachache	r^2	-0.040	-0.047	-0.031	-0.039	-0.043	-0.047	0.153	0.204	0.289				
	p	0.013	0.003	0.072	0.022	0.004	0.002	<.0001	<.0001	<.0001				
Headache	r^2	-0.056	0.003	-0.051	-0.002	-0.057	0.006	0.158	0.215					
	p	0.000	0.872	0.003	0.910	0.000	0.689	<.0001	<.0001					
Wheeze	r^2	-0.032	-0.024	-0.041	-0.034	-0.039	-0.031	0.327						
	p	0.044	0.137	0.017	0.044	0.009	0.040	<.0001						
Cough	r^2	-0.150	-0.171	-0.156	-0.152	-0.157	-0.168							
	p	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001							
Daily FEV1 (L)	r^2	0.557	0.988	0.532	0.979	0.563								
	p	<.0001	<.0001	<.0001	<.0001	<.0001								
Daily PEF (L/M)	r^2	0.976	0.578	0.976	0.538									
	p	<.0001	<.0001	<.0001	<.0001									
Afternoon/Evening FEV1 (L)	r^2	0.520	0.949	0.539										
	p	<.0001	<.0001	<.0001										
Afternoon/Evening PEF (L/M)	r^2	0.921	0.545											
	p	<.0001	<.0001											
Morning FEV1 (L)	r^2	0.575												
	p	<.0001												

Table 30. Pearson Correlation for Air Quality (PM_1, SO_2, and VVI) with 0, 1, 2, 3 Days Lag*.

Variables	VVI (0-3) with 3 days lag	VVI (0-3) with 2 days lag	VVI (0-3) with 1 days lag	VVI (0-3) with 0 days lag	$PM_{1.0}$ (ug/m^3) with 3 days lag	$PM_{1.0}$ (ug/m^3) with 2 days lag	$PM_{1.0}$ (ug/m^3) with 1 days lag	$PM_{1.0}$ (ug/m^3) with 0 days lag	SO_2 (ppb) with 3 days lag	SO_2 (ppb) with 2 days lag	SO_2 (ppb) with 1 days lag
SO_2 (ppb) with 0 days lag	0.059	0.200	0.330	0.443	0.187	0.270	0.335	0.370	0.092	0.238	0.368
SO_2 (ppb) with 1 days lag	0.202	0.336	0.445	0.195	0.272	0.339	0.385	0.219	0.238	0.372	
SO_2 (ppb) with 2 days lag	0.330	0.442	0.195	0.143	0.335	0.379	0.217	0.236	0.365		
SO_2 (ppb) with 3 days lag	0.452	0.200	0.152	0.073	0.404	0.229	0.248	0.201			
$PM_{1.0}$ (ug/m^3) with 0 days lag	0.234	0.357	0.538	0.504	0.641	0.502	0.656				
$PM_{1.0}$ (ug/m^3) with 1 days lag	0.359	0.548	0.507	0.385	0.489	0.643					
$PM_{1.0}$ (ug/m^3) with 2 days lag	0.549	0.505	0.387	0.417	0.628						
$PM_{1.0}$ (ug/m^3) with 3 days lag	0.501	0.386	0.425	0.322							
VVI (0-3) with 0 days lag	0.067	0.205	0.495								
VVI (0-3) with 1 days lag	0.208	0.505									
VVI (0-3) with 2 days lag	0.494										

* All correlations were statistically significant (p-value<0.05).

4.3.5 Test of Hypotheses 3: Multiple Regression Models.

The visual vog index (VVI) did not seem to be associated with either $FEV1_{AM-1}$ or PEF_{AM-1} (Table 43) after adjusting for the individual. From eight models examined (0, 1, 2, and 3 days lag), none indicated a significant association between lung function measurement and VVI. For six out of eight models, the non-significant positive associations (β_1 or regression coefficient) between VVI and lung functions were observed (Table 31).

In contrast, symptoms index was significantly associated with VVI after adjusting for the individual for the same day, 1, 2, and 3 days lag. The highest strengths of association (β_1) were observed with one and two days lag; for every unit increase in VVI, the symptoms index (0-3) increased by 0.12 units. Same day daily average VVI index was slightly lower β_1; for every unit increase in VVI (for the same day), the symptoms index (0-3) increased by 0.113 units (Table 31).

4.3.6 Test of Hypotheses 3: Multiple Logistic Models.

Similar to the multiple regression models, the statistically significant associations (p-value<0.05) were observed between the symptoms binomial index (Y/N) and VVI for models examined (same day, 1, 2, and 3 days lag) (Table 32). The strongest association was observed with two days lag; the odds of having symptoms during a given day is 1.15 times higher for each unit increase in VVI after adjusting for the individual. This strength of association, odds ratio (OR), is very similar for the 1 and 2 days lag ($OR_{VVI\ 1\ days\ lag}$ = 1.144 and ($OR_{VVI\ 2\ days\ lag}$ = 1.142) (Table 32, Figures 19-20).

Table 31. Air Quality and Lung Function Measurement Multiple Regression Models.

Dependnt Variable	Independent Variable	Estimate	95% Confidence Interval		Z-score	p-value
			Lower	Higher		
$FEV1_{AM-1}$	VVI (0-3) with 0 days lag	0.00190	-0.00090	0.00480	1.33	0.18
$FEV1_{AM}$	VVI (0-3) with 1 days lag	0.00260	-0.00030	0.00540	1.77	0.08
$FEV1_{AM}$	VVI (0-3) with 2 days lag	0.00200	-0.00070	0.00480	1.44	0.15
$FEV1_{AM}$	VVI (0-3) with 3 days lag	-0.00050	-0.00280	0.00180	-0.42	0.67
$FEV1_{AM}$	SO_2 (ppb) with 0 days lag	0.00000	0.00000	0.00010	1.37	0.17
$FEV1_{AM}$	SO_2 (ppb) with 1 days lag	0.00010	0.00000	0.00010	2.54	0.01
$FEV1_{AM}$	SO_2 (ppb) with 2 days lag	0.00000	-0.00010	0.00000	-0.74	0.46
$FEV1_{AM}$	SO_2 (ppb) with 3 days lag	0.00000	0.00000	0.00010	1.07	0.28
$FEV1_{AM}$	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.00010	-0.00160	0.00170	0.07	0.95
$FEV1_{AM}$	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.00110	-0.00060	0.00290	1.25	0.21
$FEV1_{AM}$	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.00010	-0.00140	0.00160	0.14	0.89
$FEV1_{AM}$	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.00080	-0.00070	0.00230	1.04	0.30
PEF_{AM-1}	VVI (0-3) with 0 days lag	-0.00130	-0.00530	0.00280	-0.62	0.54
PEF_{AM}	VVI (0-3) with 1 days lag	0.00050	-0.00320	0.00420	0.27	0.78
PEF_{AM}	VVI (0-3) with 2 days lag	-0.00030	-0.00380	0.00330	-0.15	0.88
PEF_{AM}	VVI (0-3) with 3 days lag	0.00090	-0.00260	0.00430	0.48	0.63
PEF_{AM}	SO_2 (ppb) with 0 days lag	0.00010	0.00000	0.00020	1.11	0.27
PEF_{AM}	SO_2 (ppb) with 1 days lag	0.00010	0.00000	0.00020	2.40	0.02
PEF_{AM}	SO_2 (ppb) with 2 days lag	-0.00010	-0.00020	0.00000	-2.26	0.02
PEF_{AM}	SO_2 (ppb) with 3 days lag	0.00010	0.00000	0.00020	2.62	0.01
PEF_{AM}	$PM_{1.0}$ (ug/m^3) with 0 days lag	-0.00070	-0.00320	0.00180	-0.56	0.57
PEF_{AM}	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.00160	-0.00080	0.00400	1.31	0.19
PEF_{AM}	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.00000	-0.00220	0.00230	0.04	0.97
PEF_{AM}	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.00100	-0.00120	0.00320	0.92	0.36

Figure 20. Air quality and Symptoms Multiple Logistic Regression Models.

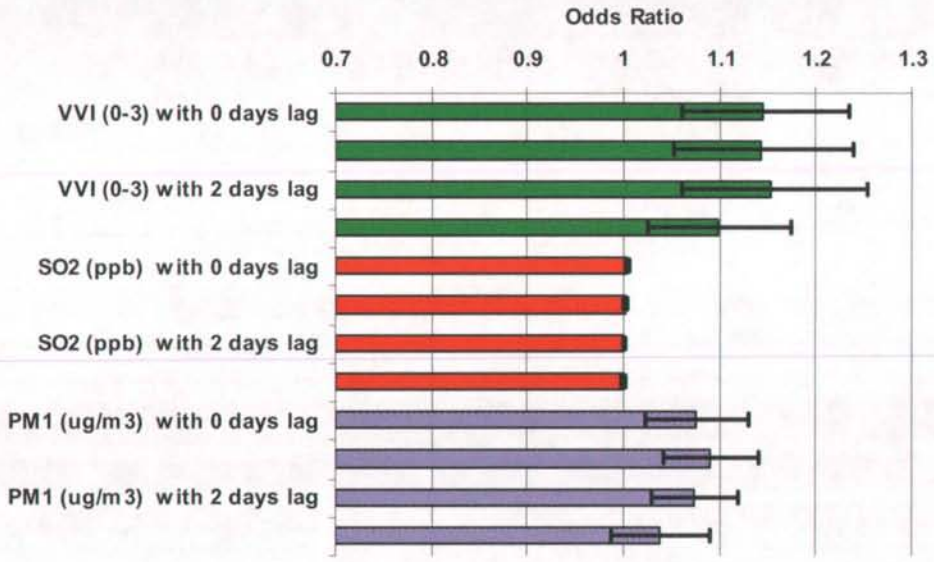


Figure 21. Air quality and Cough Multiple Logistic Regression Models.

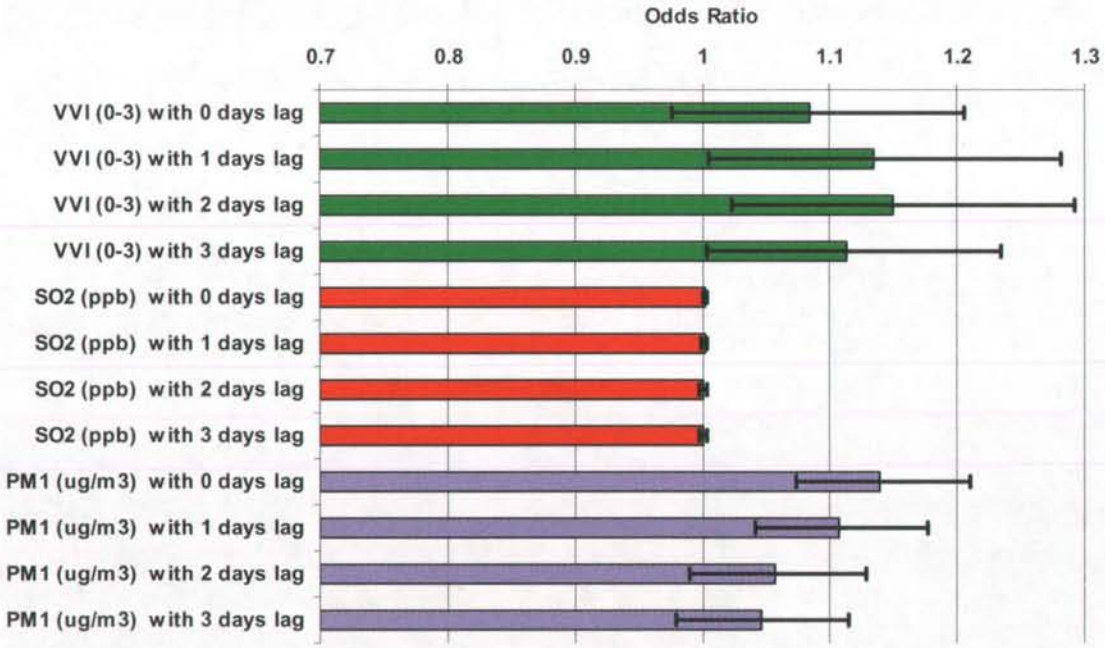


Table 31. Air quality and Symptoms Multiple Linear Regression Models*.

Dependent	Independent Variable	Estimate	95% Confidence Limits		p-value
			Lower	Higher	
Symptoms Index (0-3)	VVI (0-3) with 0 days lag	0.113	0.042	0.184	0.002
Symptoms Index (0-3)	VVI (0-3) with 1 days lag	0.127	0.044	0.211	0.003
Symptoms Index (0-3)	VVI (0-3) with 2 days lag	0.127	0.053	0.202	0.001
Symptoms Index (0-3)	VVI (0-3) with 3 days lag	0.089	0.024	0.153	0.007
Symptoms Index (0-3)	SO_2 (ppb) with 0 days lag	0.003	0.001	0.005	0.001
Symptoms Index (0-3)	SO_2 (ppb) with 1 days lag	0.002	0.001	0.004	0.007
Symptoms Index (0-3)	SO_2 (ppb) with 2 days lag	0.001	-0.001	0.003	0.149
Symptoms Index (0-3)	SO_2 (ppb) with 3 days lag	0.001	-0.001	0.002	0.594
Symptoms Index (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.073	0.022	0.124	0.005
Symptoms Index (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.094	0.047	0.140	<.0001
Symptoms Index (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.084	0.038	0.129	0.000
Symptoms Index (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.037	-0.017	0.091	0.179
Cough (0-3)	VVI (0-3) with 0 days lag	0.056	-0.039	0.150	0.248
Cough (0-3)	VVI (0-3) with 1 days lag	0.091	-0.028	0.211	0.135
Cough (0-3)	VVI (0-3) with 2 days lag	0.112	-0.007	0.230	0.064
Cough (0-3)	VVI (0-3) with 3 days lag	0.114	0.010	0.217	0.031
Cough (0-3)	SO_2 (ppb) with 0 days lag	0.001	-0.001	0.004	0.205
Cough (0-3)	SO_2 (ppb) with 1 days lag	0.001	-0.002	0.003	0.499
Cough (0-3)	SO_2 (ppb) with 2 days lag	0.001	-0.002	0.003	0.474
Cough (0-3)	SO_2 (ppb) with 3 days lag	0.001	-0.002	0.003	0.475
Cough (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.109	0.051	0.168	0.000
Cough (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.075	0.013	0.138	0.018
Cough (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.041	-0.024	0.105	0.216
Cough (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.060	-0.009	0.130	0.090
Wheeze (0-3)	VVI (0-3) with 0 days lag	0.158	0.007	0.308	0.041
Wheeze (0-3)	VVI (0-3) with 1 days lag	0.137	-0.026	0.300	0.099
Wheeze (0-3)	VVI (0-3) with 2 days lag	0.198	0.048	0.347	0.010
Wheeze (0-3)	VVI (0-3) with 3 days lag	0.148	0.021	0.275	0.022
Wheeze (0-3)	SO_2 (ppb) with 0 days lag	0.003	-0.001	0.006	0.147
Wheeze (0-3)	SO_2 (ppb) with 1 days lag	0.003	0.000	0.006	0.031
Wheeze (0-3)	SO_2 (ppb) with 2 days lag	0.003	-0.002	0.007	0.208
Wheeze (0-3)	SO_2 (ppb) with 3 days lag	0.000	-0.004	0.004	0.959
Wheeze (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.035	-0.073	0.144	0.523
Wheeze (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.115	-0.003	0.233	0.056
Wheeze (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.128	0.038	0.218	0.005
Wheeze (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.035	-0.069	0.139	0.510

* no transformations were preformed (Table 8).

Table 31. (Continued) Air quality and Symptoms Multiple Linear Regression Models.

Dependent	Independent Variable	Estim.	95% Confidence Limits		p-value
			Lower	Higher	
Headache (0-3)	VVI (0-3) with 0 days lag	0.135	-0.031	0.302	0.111
Headache (0-3)	VVI (0-3) with 1 days lag	0.149	-0.035	0.332	0.113
Headache (0-3)	VVI (0-3) with 2 days lag	0.218	0.086	0.350	0.001
Headache (0-3)	VVI (0-3) with 3 days lag	0.179	0.063	0.296	0.003
Headache (0-3)	SO_2 (ppb) with 0 days lag	0.004	0.001	0.008	0.019
Headache (0-3)	SO_2 (ppb) with 1 days lag	0.003	0.000	0.005	0.050
Headache (0-3)	SO_2 (ppb) with 2 days lag	0.001	-0.001	0.004	0.376
Headache (0-3)	SO_2 (ppb) with 3 days lag	0.000	-0.003	0.003	0.899
Headache (0-3)	$PM_{1.0}$(ug/m^3) with 0 days lag	0.064	-0.018	0.146	0.126
Headache (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.138	0.057	0.218	0.001
Headache (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.131	0.078	0.184	<.0001
Headache (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.026	-0.059	0.111	0.546
Stomachache (0-3)	VVI (0-3) with 0 days lag	0.134	-0.105	0.374	0.273
Stomachache (0-3)	VVI (0-3) with 1 days lag	0.153	-0.069	0.374	0.177
Stomachache (0-3)	VVI (0-3) with 2 days lag	0.109	-0.122	0.341	0.355
Stomachache (0-3)	VVI (0-3) with 3 days lag	0.097	-0.149	0.343	0.439
Stomachache (0-3)	SO_2 (ppb) with 0 days lag	0.002	-0.003	0.007	0.438
Stomachache (0-3)	SO_2 (ppb) with 1 days lag	0.002	-0.004	0.008	0.554
Stomachache (0-3)	SO_2 (ppb) with 2 days lag	-0.001	-0.008	0.006	0.725
Stomachache (0-3)	SO_2 (ppb) with 3 days lag	-0.002	-0.008	0.005	0.669
Stomachache (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.082	-0.068	0.232	0.283
Stomachache (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.120	-0.034	0.274	0.126
Stomachache (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.134	0.001	0.267	0.048
Stomachache (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.026	-0.152	0.204	0.774
Shortness of Breath (0-3)	VVI (0-3) with 0 days lag	0.091	-0.078	0.260	0.293
Shortness of Breath (0-3)	VVI (0-3) with 1 days lag	0.107	-0.030	0.244	0.125
Shortness of Breath (0-3)	VVI (0-3) with 2 days lag	0.111	-0.103	0.325	0.311
Shortness of Breath (0-3)	VVI (0-3) with 3 days lag	0.123	-0.091	0.337	0.259
Shortness of Breath (0-3)	SO_2 (ppb) with 0 days lag	0.003	0.000	0.007	0.040
Shortness of Breath (0-3)	SO_2 (ppb) with 1 days lag	0.002	-0.001	0.005	0.216
Shortness of Breath (0-3)	SO_2 (ppb) with 2 days lag	0.002	-0.004	0.008	0.448
Shortness of Breath (0-3)	SO_2 (ppb) with 3 days lag	-0.001	-0.006	0.005	0.747
Shortness of Breath (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.033	-0.097	0.164	0.619
Shortness of Breath (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.102	-0.027	0.231	0.120
Shortness of Breath (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.121	-0.008	0.250	0.066
Shortness of Breath (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	-0.010	-0.105	0.086	0.846

* no transformations were preformed (Table 8).

Table 31. (Continued) Air quality and Symptoms Multiple Linear Regression Models.

Dependent	Independent Variable	Estimate	95% Confidence Limits		p-value
			Lower	Higher	
Sore, Itchy and Watery eyes (0-3)	VVI (0-3) with 0 days lag	0.163	0.056	0.271	0.003
Sore, Itchy and Watery eyes (0-3)	VVI (0-3) with 1 days lag	0.218	0.097	0.338	0.000
Sore, Itchy and Watery eyes (0-3)	VVI (0-3) with 2 days lag	0.160	0.057	0.263	0.002
Sore, Itchy and Watery eyes (0-3)	VVI (0-3) with 3 days lag	0.052	-0.041	0.145	0.274
Sore, Itchy and Watery eyes (0-3)	SO_2 (ppb) with 0 days lag	0.006	0.003	0.008	<.0001
Sore, Itchy and Watery eyes (0-3)	SO_2 (ppb) with 1 days lag	0.004	0.002	0.007	0.000
Sore, Itchy and Watery eyes (0-3)	SO_2 (ppb) with 2 days lag	0.002	0.000	0.005	0.046
Sore, Itchy and Watery eyes (0-3)	SO_2 (ppb) with 3 days lag	0.002	0.000	0.004	0.062
Sore, Itchy and Watery eyes (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.121	0.062	0.180	<.0001
Sore, Itchy and Watery eyes (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.131	0.078	0.184	<.0001
Sore, Itchy and Watery eyes (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.113	0.053	0.173	0.000
Sore, Itchy and Watery eyes (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.081	0.009	0.152	0.027
Eye Irritation (0-3)	VVI (0-3) with 0 days lag	0.095	0.008	0.182	0.032
Eye Irritation (0-3)	VVI (0-3) with 1 days lag	0.092	-0.002	0.186	0.056
Eye Irritation (0-3)	VVI (0-3) with 2 days lag	0.092	0.012	0.173	0.025
Eye Irritation (0-3)	VVI (0-3) with 3 days lag	0.052	-0.013	0.118	0.118
Eye Irritation (0-3)	SO_2 (ppb) with 0 days lag	0.003	0.001	0.005	0.006
Eye Irritation (0-3)	SO_2 (ppb) with 1 days lag	0.001	-0.001	0.003	0.179
Eye Irritation (0-3)	SO_2 (ppb) with 2 days lag	0.001	-0.001	0.003	0.287
Eye Irritation (0-3)	SO_2 (ppb) with 3 days lag	0.001	-0.001	0.002	0.620
Eye Irritation (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.043	-0.013	0.098	0.129
Eye Irritation (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.062	0.013	0.112	0.014
Eye Irritation (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.049	-0.005	0.102	0.073
Eye Irritation (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.023	-0.032	0.077	0.412
Other Symptoms (0-3)	VVI (0-3) with 0 days lag	0.283	-0.055	0.621	0.101
Other Symptoms (0-3)	VVI (0-3) with 1 days lag	0.130	-0.058	0.317	0.176
Other Symptoms (0-3)	VVI (0-3) with 2 days lag	-0.141	-0.482	0.199	0.416
Other Symptoms (0-3)	VVI (0-3) with 3 days lag	-0.174	-0.457	0.110	0.230
Other Symptoms (0-3)	SO_2 (ppb) with 0 days lag	0.001	-0.004	0.006	0.665
Other Symptoms (0-3)	SO_2 (ppb) with 1 days lag	0.002	-0.002	0.006	0.380
Other Symptoms (0-3)	SO_2 (ppb) with 2 days lag	-0.003	-0.012	0.006	0.498
Other Symptoms (0-3)	SO_2 (ppb) with 3 days lag	-0.004	-0.013	0.006	0.419
Other Symptoms (0-3)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.035	-0.162	0.233	0.727
Other Symptoms (0-3)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.025	-0.106	0.157	0.706
Other Symptoms (0-3)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.096	-0.074	0.267	0.268
Other Symptoms (0-3)	$PM_{1.0}$ (ug/m^3) with 3 days lag	-0.016	-0.158	0.126	0.827

* no transformations were preformed (Table 8).

Table 32. Air quality and Symptoms Multiple Logistic Regression Models.

Dependent	Independent Variable	Odds Ratio	95% Confidence Limits		p-value
			Lower	Higher	
Symptoms Index (Y/N)	VVI (0-3) with 0 days lag	1.144	1.060	1.236	0.001
Symptoms Index (Y/N)	VVI (0-3) with 1 days lag	1.142	1.052	1.240	0.002
Symptoms Index (Y/N)	VVI (0-3) with 2 days lag	1.153	1.060	1.253	0.001
Symptoms Index (Y/N)	VVI (0-3) with 3 days lag	1.098	1.026	1.174	0.007
Symptoms Index (Y/N)	SO_2 (ppb) with 0 days lag	1.004	1.002	1.006	0.001
Symptoms Index (Y/N)	SO_2 (ppb) with 1 days lag	1.002	1.000	1.004	0.019
Symptoms Index (Y/N)	SO_2 (ppb) with 2 days lag	1.001	0.999	1.003	0.459
Symptoms Index (Y/N)	SO_2 (ppb) with 3 days lag	1.000	0.998	1.002	0.946
Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.075	1.024	1.130	0.004
Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.091	1.043	1.141	0.000
Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.073	1.029	1.119	0.001
Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.038	0.987	1.091	0.144
Cough (Y/N)	VVI (0-3) with 0 days lag	1.085	0.977	1.206	0.129
Cough (Y/N)	VVI (0-3) with 1 days lag	1.135	1.005	1.282	0.042
Cough (Y/N)	VVI (0-3) with 2 days lag	1.150	1.023	1.293	0.020
Cough (Y/N)	VVI (0-3) with 3 days lag	1.113	1.004	1.235	0.042
Cough (Y/N)	SO_2 (ppb) with 0 days lag	1.002	1.000	1.004	0.102
Cough (Y/N)	SO_2 (ppb) with 1 days lag	1.002	0.999	1.004	0.229
Cough (Y/N)	SO_2 (ppb) with 2 days lag	1.001	0.998	1.004	0.550
Cough (Y/N)	SO_2 (ppb) with 3 days lag	1.001	0.998	1.004	0.646
Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.139	1.073	1.210	<.0001
Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.107	1.042	1.177	0.001
Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.057	0.990	1.128	0.097
Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.046	0.980	1.115	0.175
Wheeze (Y/N)	VVI (0-3) with 0 days lag	1.198	1.033	1.388	0.017
Wheeze (Y/N)	VVI (0-3) with 1 days lag	1.153	0.988	1.345	0.070
Wheeze (Y/N)	VVI (0-3) with 2 days lag	1.254	1.094	1.437	0.001
Wheeze (Y/N)	VVI (0-3) with 3 days lag	1.166	1.025	1.327	0.020
Wheeze (Y/N)	SO_2 (ppb) with 0 days lag	1.003	0.999	1.008	0.116
Wheeze (Y/N)	SO_2 (ppb) with 1 days lag	1.003	1.000	1.006	0.044
Wheeze (Y/N)	SO_2 (ppb) with 2 days lag	1.002	0.998	1.007	0.339
Wheeze (Y/N)	SO_2 (ppb) with 3 days lag	1.000	0.996	1.004	0.881
Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.061	0.934	1.205	0.364
Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.105	0.994	1.229	0.065
Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.134	1.019	1.261	0.021
Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.065	0.948	1.197	0.285

Table 32. (Continued) Air quality and Symptoms Multiple Logistic Regression Models.

Dependent	Independent Variable	Odds Ratio	95% Confidence Limits		p-value
			Lower	Higher	
Headache (Y/N)	VVI (0-3) with 0 days lag	1.202	1.029	1.405	0.021
Headache (Y/N)	VVI (0-3) with 1 days lag	1.169	0.993	1.377	0.061
Headache (Y/N)	VVI (0-3) with 2 days lag	1.211	1.074	1.364	0.002
Headache (Y/N)	VVI (0-3) with 3 days lag	1.188	1.050	1.343	0.006
Headache (Y/N)	SO_2 (ppb) with 0 days lag	1.006	1.002	1.009	0.001
Headache (Y/N)	SO_2 (ppb) with 1 days lag	1.003	1.000	1.006	0.028
Headache (Y/N)	SO_2 (ppb) with 2 days lag	1.001	0.999	1.004	0.411
Headache (Y/N)	SO_2 (ppb) with 3 days lag	1.001	0.998	1.004	0.591
Headache (Y/N)	$PM_{1.0}(ug/m^3)$ with 0 days lag	1.083	1.004	1.168	0.040
Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.143	1.058	1.235	0.001
Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.133	1.076	1.194	<.0001
Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.036	0.956	1.122	0.390
Stomachache (Y/N)	VVI (0-3) with 0 days lag	1.140	0.902	1.441	0.272
Stomachache (Y/N)	VVI (0-3) with 1 days lag	1.184	0.954	1.471	0.125
Stomachache (Y/N)	VVI (0-3) with 2 days lag	1.150	0.919	1.438	0.221
Stomachache (Y/N)	VVI (0-3) with 3 days lag	1.069	0.844	1.353	0.579
Stomachache (Y/N)	SO_2 (ppb) with 0 days lag	1.002	0.997	1.007	0.409
Stomachache (Y/N)	SO_2 (ppb) with 1 days lag	1.002	0.996	1.007	0.502
Stomachache (Y/N)	SO_2 (ppb) with 2 days lag	0.999	0.992	1.005	0.700
Stomachache (Y/N)	SO_2 (ppb) with 3 days lag	0.998	0.990	1.005	0.496
Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.080	0.939	1.243	0.279
Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.113	0.943	1.314	0.205
Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.133	1.001	1.284	0.049
Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.002	0.848	1.184	0.979
Shortness of Breath (Y/N)	VVI (0-3) with 0 days lag	1.109	0.927	1.327	0.256
Shortness of Breath (Y/N)	VVI (0-3) with 1 days lag	1.199	1.016	1.416	0.032
Shortness of Breath (Y/N)	VVI (0-3) with 2 days lag	1.166	0.979	1.389	0.085
Shortness of Breath (Y/N)	VVI (0-3) with 3 days lag	1.087	0.888	1.330	0.420
Shortness of Breath (Y/N)	SO_2 (ppb) with 0 days lag	1.004	1.000	1.008	0.029
Shortness of Breath (Y/N)	SO_2 (ppb) with 1 days lag	1.003	1.000	1.007	0.047
Shortness of Breath (Y/N)	SO_2 (ppb) with 2 days lag	1.002	0.998	1.007	0.288
Shortness of Breath (Y/N)	SO_2 (ppb) with 3 days lag	1.000	0.995	1.004	0.853
Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.075	0.957	1.208	0.221
Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.121	0.989	1.271	0.074
Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.122	1.004	1.254	0.043
Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.005	0.910	1.110	0.923

Individual symptoms such as cough, wheezing, sore eyes, nose irritation, and headache were statistically significantly associated with VVI in three out of four models (for every symptom) (Table 31, Figure 20-21). Shortness of breath was statistically significantly associated with VVI with one day lag and borderline associated with 2 days lag (p-value=0.086). Whereas symptoms such as stomachache and other symptoms were not found to be associated with VVI in any of models.

The average odds ratio between the individual symptoms and VVI (same day, 1, 2, and 3 days lag) were the highest for sore eyes, wheezing, and headache ($OR_{mean\ sore\ eyes}$ =1.202, $OR_{mean\ wheeze}$ =1.193, and $OR_{mean\ headache}$ =1.193). Whereas, shortness of breath, headache, and cough had intermediate average Odds Ratios ($OR_{mean\ shortness\ of\ breath}$ =1.140, $OR_{mean\ stomachache}$ =1.136, and $OR_{mean\ cough}$ =1.12). And finally, nose irritation and other symptoms had the lowest OR ($OR_{mean\ nose\ irritation}$ =1.099, and $OR_{mean\ other\ symptoms}$ =1.065)

The maximum OR for the individual symptom and VVI were sore eyes with VVI 1 day lag (OR= 1.306), wheeze with VVI 2 days lag (OR = 1.254), headache with VVI 2 days lag (OR = 1.216), cough with VVI 2 days lag (OR = 1.150), and nose irritation with VVI 2 days lag (OR= 1.127).

4.4 Hypotheses 4: the visually-observed vog is as good a predictor of reduced lung function and self-reported symptoms as instrument-measured vog (SO_2 and $PM_{1.0}$).

Time series graph (Figure 22) suggest that during the days with high SO_2, sum of symptoms, PM_1, VVI also appear to be higher; for example, March 10th , March 29th , and October 28th

The regression models for instrument-measured and observed vog index were examined. The best models to predict variation in lung function and symptoms were

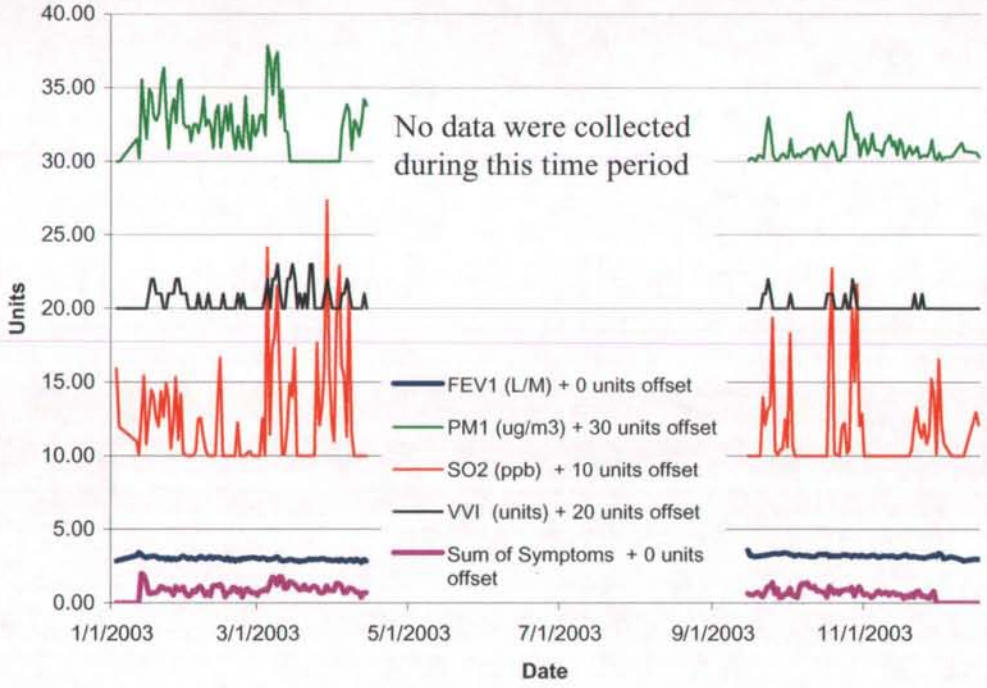
determined based on the statistical models (the high-value indicates the model might be more robust), p-value (the low-volume indicates the model might be more robust), and likelihood ratio chi-square (the higher chi-square value indicates that the model might be more robust). Similarly as described in the methods 3.2.3, the tables with results of statistical analysis (Table 33-34) were compared side-by-side.

4.4.1 Test of Hypotheses 4: Multiple Regression Models.

Similar to the results in sections 3.3.5 and 3.3.6, the instrument measured vog ($PM_{1.0}$ and SO_2) did not seem to be associated with either $FEV1_{AM-1}$ or PEF_{AM-1} (Table 33) after adjusting for the individual. From 16 models examined (0, 1, 2, and 3 days lag), none indicated a significant negative association between lung function measurement and VVI; the positive significant association was observed in 3 models. For only 3 out of 16 models, the non-significant negative association (β_1 or regression coefficient) between VVI and lung functions was observed.

In contrast, symptoms index was significantly positively associated with $PM_{1.0}$ (all four models), SO_2 (same day and 2 days lag) and VVI (all four models) after adjusting for the individual. The average adjusted test statistics (average adjusted p-value) for VVI was 3.05 (p - value = 0.0033), for SO_2 was 2.02 (p - value = 0.188) and for $PM_{1.0}$ was 2.92 (p - value = 0.046).

Figure 22. PEF Measurements, $PM_{1.0}$, SO_2, VVI and Sum of Symptoms Time Series.



This strength of association (β_1) varied between air quality measurements and symptoms (Table 31). During days with heavy vog:

- The maximum daily $PM_{1.0}$ (7.848 ug/m^3), the expected increase in the symptoms index is by 0.57 units for $PM_{1.0}$ with 0 days lag, 74% for $PM_{1.0}$ with 1 day lag, and 0.66 units for $PM_{1.0}$ with 2 days lag compared to non-voggy days (0 ug/m^3).
- The maximum daily SO_2 (173.045 ppb), the expected increase in the symptoms index is by 0.52 for SO_2 with 0 days lag and 0.35 for SO_2 with 1 day lag compared to non-voggy days (0 ppb).

- the maximum daily VVI (3 units), the expected increase in the symptoms index is by 34% for VVI with 0 days lag, 38% for VVI with 1 day lag, 38% for VVI with 2 days lag, and 27% for VVI with 3 days lag compared to non-voggy days (0 units).

4.4.2 Test of Hypotheses 4: Multiple Logistic Models.

Similar to the multiple regression models, the statistically significant associations (p-value<0.05) were observed between the symptoms binomial index and SO_2, $PM_{1.0}$ and VVI for models examined (same day, 1, 2, and 3 days lag) (Table 32). For visual vog index, the strongest association was observed for VVI with 2 days lag; the odds of having symptoms during a given day is 1.15 times higher for each unit increase in VVI after adjusting for the individual. The odds ratio (OR) were very similar for the 1 and 2 days lag ($OR_{VVI\ 1\ days\ lag}$ = 1.144, p-value=0.001 and ($OR_{VVI\ 2\ days\ lag}$ = 1.142, p-value=0.019). For the daily SO_2, the highest significant associations (between SO_2 and symptoms index) were observed during this same day ($OR_{SO2\ 0\ days\ lag}$ =1.004, p-value=0.001) and followed by 1 day lag, (OR=1.002, p-value=0.019); the odds ratios declined even further with 2 days lag ($OR_{SO2\ 2\ days\ lag}$ = 1.001, p-value=.459) and 3 days lag ($OR_{SO2\ 2\ days\ lag}$ = 1.00, p-value= 0.946). In contrast, the daily $PM_{1.0}$ had the highest odds ratio with a 1 day lag ($OR_{PM1.0\ 1\ days\ lag}$ = 1.091, p-value<0.001) with slightly lower odds ratio with 0 ($OR_{SO2\ 2\ days\ lag}$ = 1.075, p-value=0.004) and 2 days lag ($OR_{SO2\ 2\ days\ lag}$ = 1.073, p-value=0.001).

This strength of association (OR) varied between air quality measurements and symptoms (Table 32). During heavy voggy days:

- during the maximum daily $PM_{1.0}$ (7.848 ug/m^3), the odds of having any symptoms is almost twice as high (OR=1.981) one day later than after non-voggy day (0 ug/m^3).
- during the maximum daily SO_2 (173.045 ppb), the odds of having any symptoms is almost twice as high (OR=1.981) during the same day than after non-voggy day (0 ppb).
- during the maximum daily VVI one (3 units), the odds of having any symptoms is more than 1 1/2 times higher (OR=1.533) two days later than after a non-voggy day (0 units).

Individual symptom headache was statistically associated with $PM_{1.0}$ (OR= 1.083), 1 (OR= 1.143, p-value=0.040), and 2 (OR = 1.133, p-value<0.001) days lag. Symptoms such as cough, nose irritation, and sore eyes were statistically associated with $PM_{1.0}$ in 50% of the models. And symptoms such as stomachache and shortness of breath were statistically associated with $PM_{1.0}$ in only 1 model out of 4.

Individual symptoms such as cough, wheezing, sore eyes, nose irritation, and headache were statistically significantly associated with VVI in three out of four models (for every symptom). Shortness of breath was statistically significantly associated with VVI with one day lag and borderline associated with 2 days lag (p-value=0.086), whereas symptoms such as stomachache and other symptoms were not found to be associated with VVI in any of the models.

Headache, shortness of breath and sore eyes and nose irritation symptoms were statistically associated with the daily SO_2 with 0 and 1 day lag (50% of the models). Individual Symptoms such as cough, wheeze, sore eyes, nose irritation, headache, and

shortness of breath had 16 out of 24 logistic regression models (6 individual symptoms * 4 possible lags), 13 out of 24 models were significant for $PM_{1.0}$, and only 9 out of 24 models were significant with daily SO_2.

4.5 Hypotheses 5: individuals who believe that vog adversely affects their symptoms are more likely to have elevated daily self-reported symptoms during vog episodes (defined by instrument-measured and visually-observed vog) than individuals who do not believe that vog adversely affects their symptoms.

4.5.1 Descriptive Statistics.

Forty five comprehensive completed questionnaires were received at least once during two study periods; only one questionnaire was required per person regardless of whether they participated in Spring or Fall study periods or both (Attachment A). Since 45 subjects participated in both Spring 2003 and Fall 2003 study periods, the vog belief index was available for 51 subjects (41% response rate).

The majority of participants (82%) did not believe that vog is responsible for exacerbation of their allergies and/or asthma (belief vog index (BVI)=0); two subjects (4%) believed that vog is moderately associated with their health condition (BVI =0.5; and six (13%) believed that vog is strongly associated with their symptoms (BVI $\geq$1). Thus, eight individuals (18%) believed that vog is associated with their elevated symptoms.

4.5.2 Test of Hypotheses 5: Multiple Regression Models.

Similar to the section 4.3.5, multiple regressions were modeled to predict the lung function measurement (FEV1 and PEF) and symptom indexes with air quality measurements (SO_2, $PM_{1.0}$, and VVI) where (1) subjects that did complete the

comprehensive questionnaire being treated as missing, (2) subjects that did not believe that vog associated with elevated asthma/allergy symptoms (BVI =0), and (3) subjects that believe that vog associated with elevated asthma/allergy symptoms (BVI >0) (Table 34).

The model with the highest attributable slope between (1) the combined symptoms index and 0 days lag visual vog index (VVI) ($\beta_{BVI=0} - \beta_{BVI>0}$=0.18), (2) the combined symptoms index and 0 day lag SO_2 ($\beta_{BVI=0} - \beta_{BVI>0}$=0.0024), and (3) the combined symptoms index and 0 day lag SO_2 ($\beta_{BVI=0} - \beta_{BVI>0}$=0.160); however, these models as well as most models were not statistically significant.

Table 33. Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Missing	Symptoms Index (Y/N)	VVI (0-3) with 0 days lag	1.23257	0.95294	1.35459	1.12142	<.0001	
No	Symptoms Index (Y/N)	VVI (0-3) with 0 days lag	1.05940	0.93725	1.20286	0.93295	0.37380	
Yes	Symptoms Index (Y/N)	VVI (0-3) with 0 days lag	0.93838	0.88568	1.19053	0.73971	0.60040	-0.12102
Missing	Symptoms Index (Y/N)	VVI (0-3) with 1 days lag	1.22642	0.94980	1.35676	1.10871	<.0001	
No	Symptoms Index (Y/N)	VVI (0-3) with 1 days lag	0.99800	0.93230	1.14499	0.86988	0.97760	
Yes	Symptoms Index (Y/N)	VVI (0-3) with 1 days lag	1.08850	0.85959	1.46419	0.80921	0.57520	0.09050
Missing	Symptoms Index (Y/N)	VVI (0-3) with 2 days lag	1.15327	0.95380	1.26541	1.05117	0.00260	
No	Symptoms Index (Y/N)	VVI (0-3) with 2 days lag	1.09812	0.91119	1.31758	0.91521	0.31410	
Yes	Symptoms Index (Y/N)	VVI (0-3) with 2 days lag	1.34205	0.84383	1.87180	0.96223	0.08310	0.24393
Missing	Symptoms Index (Y/N)	VVI (0-3) with 3 days lag	1.08415	0.96204	1.16964	1.00491	0.03690	
No	Symptoms Index (Y/N)	VVI (0-3) with 3 days lag	1.05211	0.92090	1.23652	0.89512	0.53790	
Yes	Symptoms Index (Y/N)	VVI (0-3) with 3 days lag	1.34017	0.92784	1.55209	1.15720	<.0001	0.28806
Missing	Symptoms Index (Y/N)	SO_2 (ppb) with 0 days lag	1.00562	0.99850	1.00854	1.00260	0.00020	
No	Symptoms Index (Y/N)	SO_2 (ppb) with 0 days lag	1.00290	0.99840	1.00602	0.99980	0.06470	
Yes	Symptoms Index (Y/N)	SO_2 (ppb) with 0 days lag	0.99591	0.99720	1.00130	0.99045	0.13930	-0.00700
Missing	Symptoms Index (Y/N)	SO_2 (ppb) with 1 days lag	1.00351	0.99870	1.00612	1.00090	0.00800	
No	Symptoms Index (Y/N)	SO_2 (ppb) with 1 days lag	1.00020	0.99880	1.00250	0.99780	0.89910	
Yes	Symptoms Index (Y/N)	SO_2 (ppb) with 1 days lag	1.00030	0.99780	1.00461	0.99601	0.88710	0.00010
Missing	Symptoms Index (Y/N)	SO_2 (ppb) with 2 days lag	1.00090	0.99860	1.00371	0.99810	0.52920	
No	Symptoms Index (Y/N)	SO_2 (ppb) with 2 days lag	1.00170	0.99830	1.00501	0.99840	0.32410	
Yes	Symptoms Index (Y/N)	SO_2 (ppb) with 2 days lag	0.99770	0.99800	1.00170	0.99382	0.25670	-0.00400
Missing	Symptoms Index (Y/N)	SO_2 (ppb) with 3 days lag	0.99970	0.99870	1.00220	0.99710	0.80980	
No	Symptoms Index (Y/N)	SO_2 (ppb) with 3 days lag	1.00130	0.99840	1.00441	0.99830	0.39320	
Yes	Symptoms Index (Y/N)	SO_2 (ppb) with 3 days lag	0.99850	0.99850	1.00140	0.99561	0.31420	-0.00280
Missing	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.11360	0.97054	1.18093	1.05012	0.00030	
No	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.05601	0.95275	1.16125	0.96041	0.26030	
Yes	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.90366	0.92386	1.05548	0.77368	0.20100	-0.15235
Missing	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.11438	0.97035	1.18199	1.05054	0.00030	
No	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.06418	0.96377	1.14396	0.98995	0.09150	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.01949	0.92008	1.20033	0.86597	0.81630	-0.04469
Missing	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.07853	0.97365	1.13644	1.02347	0.00470	
No	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.06003	0.95897	1.15085	0.97648	0.16390	
Yes	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.08015	0.92941	1.24670	0.93576	0.29260	0.02012
Missing	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.05085	0.97103	1.11316	0.99213	0.09110	
No	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.01461	0.94026	1.14477	0.89915	0.81420	
Yes	Symptoms Index (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.01147	0.95171	1.11449	0.91787	0.81860	-0.00314
Missing	Cough (Y/N)	VVI (0-3) with 0 days lag	1.07842	0.92533	1.25546	0.92635	0.33020	
No	Cough (Y/N)	VVI (0-3) with 0 days lag	1.09615	0.90547	1.33162	0.90231	0.35510	
Yes	Cough (Y/N)	VVI (0-3) with 0 days lag	1.08665	0.97103	1.15108	1.02583	0.00470	-0.00950
Missing	Cough (Y/N)	VVI (0-3) with 1 days lag	1.13974	0.92063	1.34031	0.96909	0.11390	
No	Cough (Y/N)	VVI (0-3) with 1 days lag	1.09286	0.88206	1.39766	0.85462	0.47910	
Yes	Cough (Y/N)	VVI (0-3) with 1 days lag	1.19148	0.88188	1.52455	0.93128	0.16350	0.09862
Missing	Cough (Y/N)	VVI (0-3) with 2 days lag	1.10407	0.92598	1.28377	0.94952	0.19820	
No	Cough (Y/N)	VVI (0-3) with 2 days lag	1.18294	0.88479	1.50366	0.93062	0.16980	
Yes	Cough (Y/N)	VVI (0-3) with 2 days lag	1.27011	0.83644	1.80219	0.89503	0.18060	0.08717
Missing	Cough (Y/N)	VVI (0-3) with 3 days lag	1.07864	0.93885	1.22055	0.95313	0.23030	
No	Cough (Y/N)	VVI (0-3) with 3 days lag	1.13746	0.88091	1.45849	0.88719	0.30970	
Yes	Cough (Y/N)	VVI (0-3) with 3 days lag	1.19006	0.90801	1.43778	0.98501	0.07130	0.05259
Missing	Cough (Y/N)	SO_2 (ppb) with 0 days lag	1.00310	0.99820	1.00662	0.99960	0.08560	
No	Cough (Y/N)	SO_2 (ppb) with 0 days lag	1.00040	0.99840	1.00361	0.99720	0.79900	
Yes	Cough (Y/N)	SO_2 (ppb) with 0 days lag	1.00070	0.99870	1.00331	0.99810	0.58610	0.00030
Missing	Cough (Y/N)	SO_2 (ppb) with 1 days lag	1.00170	0.99780	1.00592	0.99740	0.44610	
No	Cough (Y/N)	SO_2 (ppb) with 1 days lag	1.00220	0.99830	1.00552	0.99890	0.18970	
Yes	Cough (Y/N)	SO_2 (ppb) with 1 days lag	1.00030	0.99870	1.00280	0.99780	0.82540	-0.00190
Missing	Cough (Y/N)	SO_2 (ppb) with 2 days lag	1.00010	0.99780	1.00451	0.99571	0.95260	
No	Cough (Y/N)	SO_2 (ppb) with 2 days lag	1.00250	0.99820	1.00602	0.99890	0.17160	
Yes	Cough (Y/N)	SO_2 (ppb) with 2 days lag	1.00000	0.99840	1.00310	0.99690	0.99670	-0.00250
Missing	Cough (Y/N)	SO_2 (ppb) with 3 days lag	1.00000	0.99770	1.00461	0.99551	0.99000	
No	Cough (Y/N)	SO_2 (ppb) with 3 days lag	1.00240	0.99790	1.00662	0.99820	0.26580	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Cough (Y/N)	SO_2 (ppb) with 3 days lag	0.99920	0.99910	1.00090	0.99750	0.34990	-0.00320
Missing	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.16044	0.96156	1.25320	1.07466	0.00010	
No	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.14465	0.94857	1.26947	1.03210	0.01050	
Yes	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.01694	0.96310	1.09472	0.94478	0.65400	-0.12771
Missing	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.09450	0.95695	1.19303	1.00411	0.04010	
No	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.15662	0.95849	1.25696	1.06428	0.00060	
Yes	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.05148	0.92265	1.23121	0.89808	0.53250	-0.10514
Missing	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.06184	0.95542	1.16102	0.97113	0.18810	
No	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.05454	0.93913	1.19268	0.93230	0.39840	
Yes	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.03759	0.95399	1.13792	0.94611	0.43270	-0.01695
Missing	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.03376	0.96705	1.10396	0.96802	0.32210	
No	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.07616	0.92136	1.26364	0.91659	0.36990	
Yes	Cough (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.03345	0.95485	1.13134	0.94403	0.47650	-0.04271
Missing	Wheeze (Y/N)	VVI (0-3) with 0 days lag	1.21994	0.90411	1.48646	1.00120	0.04860	
No	Wheeze (Y/N)	VVI (0-3) with 0 days lag	1.21799	0.87249	1.59106	0.93230	0.14820	
Yes	Wheeze (Y/N)	VVI (0-3) with 0 days lag	1.13678	0.86114	1.52394	0.84798	0.39120	-0.08121
Missing	Wheeze (Y/N)	VVI (0-3) with 1 days lag	1.10197	0.90168	1.34986	0.89960	0.34840	
No	Wheeze (Y/N)	VVI (0-3) with 1 days lag	1.21082	0.81922	1.78979	0.81906	0.33750	
Yes	Wheeze (Y/N)	VVI (0-3) with 1 days lag	1.16848	0.90032	1.43548	0.95113	0.13800	-0.04235
Missing	Wheeze (Y/N)	VVI (0-3) with 2 days lag	1.31864	0.91265	1.57728	1.10241	0.00250	
No	Wheeze (Y/N)	VVI (0-3) with 2 days lag	1.08796	0.86019	1.46141	0.80986	0.57570	
Yes	Wheeze (Y/N)	VVI (0-3) with 2 days lag	1.27227	0.87643	1.64757	0.98246	0.06790	0.18431
Missing	Wheeze (Y/N)	VVI (0-3) with 3 days lag	1.21155	0.91787	1.43319	1.02419	0.02520	
No	Wheeze (Y/N)	VVI (0-3) with 3 days lag	1.10705	0.81873	1.63837	0.74804	0.61110	
Yes	Wheeze (Y/N)	VVI (0-3) with 3 days lag	1.12975	0.95552	1.23516	1.03345	0.00730	0.02270
Missing	Wheeze (Y/N)	SO_2 (ppb) with 0 days lag	1.00813	0.99730	1.01339	1.00290	0.00230	
No	Wheeze (Y/N)	SO_2 (ppb) with 0 days lag	0.99740	0.99581	1.00572	0.98916	0.53650	
Yes	Wheeze (Y/N)	SO_2 (ppb) with 0 days lag	0.99980	0.99880	1.00220	0.99740	0.89240	0.00240
Missing	Wheeze (Y/N)	SO_2 (ppb) with 1 days lag	1.00632	0.99800	1.01025	1.00250	0.00130	
No	Wheeze (Y/N)	SO_2 (ppb) with 1 days lag	0.99372	0.99491	1.00371	0.98373	0.21620	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Wheeze (Y/N)	SO_2 (ppb) with 1 days lag	1.00431	0.99860	1.00702	1.00160	0.00200	0.01059
Missing	Wheeze (Y/N)	SO_2 (ppb) with 2 days lag	1.00642	0.99730	1.01187	1.00100	0.01960	
No	Wheeze (Y/N)	SO_2 (ppb) with 2 days lag	0.99810	0.99591	1.00612	0.99015	0.64190	
Yes	Wheeze (Y/N)	SO_2 (ppb) with 2 days lag	0.99770	0.99900	0.99970	0.99581	0.02140	-0.00040
Missing	Wheeze (Y/N)	SO_2 (ppb) with 3 days lag	1.00321	0.99730	1.00844	0.99790	0.23680	
No	Wheeze (Y/N)	SO_2 (ppb) with 3 days lag	0.99690	0.99511	1.00642	0.98748	0.52140	
Yes	Wheeze (Y/N)	SO_2 (ppb) with 3 days lag	0.99890	0.99830	1.00230	0.99551	0.51640	0.00200
Missing	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.11661	0.93062	1.28570	0.96977	0.12510	
No	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.11427	0.88082	1.42889	0.86892	0.39400	
Yes	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.90095	0.94422	1.00833	0.80501	0.06930	-0.21332
Missing	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.11728	0.92413	1.30408	0.95724	0.15980	
No	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.10517	0.90819	1.33469	0.91512	0.29870	
Yes	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.07358	0.88825	1.35446	0.85104	0.54910	-0.03159
Missing	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.20190	0.91934	1.41737	1.01918	0.02890	
No	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.11896	0.88950	1.40762	0.88950	0.33710	
Yes	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.03728	0.97638	1.08709	0.98965	0.12680	-0.08168
Missing	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.13281	0.93072	1.30395	0.98413	0.08230	
No	Wheeze (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.03593	0.85942	1.39417	0.76966	0.81600	
Yes	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.96041	0.93118	1.10440	0.83519	0.57080	-0.07553
Missing	Headache (Y/N)	VVI (0-3) with 0 days lag	1.29888	0.92146	1.52470	1.10650	0.00140	
No	Headache (Y/N)	VVI (0-3) with 0 days lag	1.15558	0.83293	1.65334	0.80759	0.42900	
Yes	Headache (Y/N)	VVI (0-3) with 0 days lag	0.91686	0.80308	1.40917	0.59655	0.69230	-0.23872
Missing	Headache (Y/N)	VVI (0-3) with 1 days lag	1.25583	0.91649	1.48989	1.05855	0.00900	
No	Headache (Y/N)	VVI (0-3) with 1 days lag	1.14077	0.84611	1.58281	0.82218	0.43060	
Yes	Headache (Y/N)	VVI (0-3) with 1 days lag	0.90638	0.79828	1.40973	0.58281	0.66280	-0.23439
Missing	Headache (Y/N)	VVI (0-3) with 2 days lag	1.12693	0.91952	1.32830	0.95609	0.15430	
No	Headache (Y/N)	VVI (0-3) with 2 days lag	1.32843	0.91028	1.59712	1.10484	0.00250	
Yes	Headache (Y/N)	VVI (0-3) with 2 days lag	1.40242	0.90674	1.69893	1.15766	0.00050	0.07399
Missing	Headache (Y/N)	VVI (0-3) with 3 days lag	1.11539	0.92367	1.30330	0.95456	0.16910	
No	Headache (Y/N)	VVI (0-3) with 3 days lag	1.16672	0.88728	1.47506	0.92284	0.19740	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Headache (Y/N)	VVI (0-3) with 3 days lag	1.49197	0.85470	2.02932	1.09680	0.01080	0.32525
Missing	Headache (Y/N)	SO_2 (ppb) with 0 days lag	1.00854	0.99810	1.01227	1.00481	<.0001	
No	Headache (Y/N)	SO_2 (ppb) with 0 days lag	1.00441	0.99700	1.01025	0.99850	0.14240	
Yes	Headache (Y/N)	SO_2 (ppb) with 0 days lag	0.99392	0.99671	1.00030	0.98758	0.06080	-0.01049
Missing	Headache (Y/N)	SO_2 (ppb) with 1 days lag	1.00501	0.99840	1.00823	1.00180	0.00220	
No	Headache (Y/N)	SO_2 (ppb) with 1 days lag	1.00140	0.99651	1.00823	0.99452	0.69210	
Yes	Headache (Y/N)	SO_2 (ppb) with 1 days lag	0.99820	0.99671	1.00461	0.99183	0.58190	-0.00320
Missing	Headache (Y/N)	SO_2 (ppb) with 2 days lag	1.00120	0.99850	1.00421	0.99810	0.45060	
No	Headache (Y/N)	SO_2 (ppb) with 2 days lag	1.00391	0.99690	1.01005	0.99780	0.21290	
Yes	Headache (Y/N)	SO_2 (ppb) with 2 days lag	0.99740	0.99780	1.00160	0.99312	0.22640	-0.00650
Missing	Headache (Y/N)	SO_2 (ppb) with 3 days lag	1.00130	0.99810	1.00511	0.99750	0.49190	
No	Headache (Y/N)	SO_2 (ppb) with 3 days lag	1.00260	0.99690	1.00864	0.99661	0.40300	
Yes	Headache (Y/N)	SO_2 (ppb) with 3 days lag	0.99700	0.99740	1.00210	0.99193	0.25480	-0.00560
Missing	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.07821	0.95542	1.17892	0.98600	0.09870	
No	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.13349	0.91065	1.36179	0.94337	0.18100	
Yes	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.01816	0.96948	1.08199	0.95810	0.56160	-0.11533
Missing	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.15200	0.95361	1.26440	1.04949	0.00290	
No	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.10716	0.90285	1.35270	0.90620	0.31910	
Yes	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.13304	0.94139	1.27558	1.00652	0.03870	0.02587
Missing	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.09724	0.97025	1.16428	1.03417	0.00210	
Yes	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.24545	0.93885	1.40959	1.10054	0.00050	0.07908
Missing	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.06396	0.96069	1.15085	0.98364	0.12170	
No	Headache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.03666	0.89889	1.27749	0.84114	0.73580	
Yes	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.89360	0.90285	1.09188	0.73140	0.27120	-0.14306
Missing	Stomachache (Y/N)	VVI (0-3) with 0 days lag	1.16544	0.87845	1.50245	0.90402	0.23740	
No	Stomachache (Y/N)	VVI (0-3) with 0 days lag	1.10705	0.73646	2.01617	0.60787	0.73950	
Yes	Stomachache (Y/N)	VVI (0-3) with 0 days lag	1.16067	0.69406	2.37453	0.56739	0.68320	0.05362
Missing	Stomachache (Y/N)	VVI (0-3) with 1 days lag	1.17680	0.90014	1.44629	0.95753	0.12170	
No	Stomachache (Y/N)	VVI (0-3) with 1 days lag	0.99850	0.71049	1.95111	0.51094	0.99640	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Stomachache (Y/N)	VVI (0-3) with 1 days lag	1.51786	0.70307	3.02769	0.76094	0.23630	0.51936
Missing	Stomachache (Y/N)	VVI (0-3) with 2 days lag	1.04718	0.89208	1.30983	0.83728	0.68620	
No	Stomachache (Y/N)	VVI (0-3) with 2 days lag	1.20732	0.73867	2.18606	0.66684	0.53390	
Yes	Stomachache (Y/N)	VVI (0-3) with 2 days lag	1.61204	0.78907	2.56485	1.01319	0.04390	0.40472
Missing	Stomachache (Y/N)	VVI (0-3) with 3 days lag	0.94838	0.86424	1.26213	0.71255	0.71610	
No	Stomachache (Y/N)	VVI (0-3) with 3 days lag	1.33016	0.80260	2.04664	0.86450	0.19440	
Yes	Stomachache (Y/N)	VVI (0-3) with 3 days lag	1.36165	0.81767	2.02021	0.91778	0.12510	0.03149
Missing	Stomachache (Y/N)	SO_2 (ppb) with 0 days lag	1.00020	0.99770	1.00481	0.99571	0.92050	
No	Stomachache (Y/N)	SO_2 (ppb) with 0 days lag	1.00481	0.99442	1.01593	0.99382	0.39450	
Yes	Stomachache (Y/N)	SO_2 (ppb) with 0 days lag	1.00622	0.99402	1.01806	0.99442	0.30390	0.00141
Missing	Stomachache (Y/N)	SO_2 (ppb) with 1 days lag	0.99770	0.99760	1.00240	0.99312	0.33920	
No	Stomachache (Y/N)	SO_2 (ppb) with 1 days lag	1.00451	0.99402	1.01633	0.99273	0.45780	
Yes	Stomachache (Y/N)	SO_2 (ppb) with 1 days lag	1.01319	0.99342	1.02644	1.00010	0.04890	0.00868
Missing	Stomachache (Y/N)	SO_2 (ppb) with 2 days lag	0.99750	0.99621	1.00491	0.99005	0.50290	
No	Stomachache (Y/N)	SO_2 (ppb) with 2 days lag	0.99940	0.99164	1.01593	0.98314	0.94110	
Yes	Stomachache (Y/N)	SO_2 (ppb) with 2 days lag	1.00431	0.99402	1.01613	0.99263	0.46740	0.00491
Missing	Stomachache (Y/N)	SO_2 (ppb) with 3 days lag	0.99521	0.99551	1.00411	0.98639	0.29510	
No	Stomachache (Y/N)	SO_2 (ppb) with 3 days lag	0.99900	0.99233	1.01430	0.98393	0.89500	
Yes	Stomachache (Y/N)	SO_2 (ppb) with 3 days lag	1.00541	0.99571	1.01390	0.99710	0.20290	0.00641
Missing	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.00985	0.95113	1.11416	0.91530	0.84510	
No	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.10396	0.81522	1.64773	0.73963	0.62850	
Yes	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.39166	0.86632	1.84356	1.05064	0.02120	0.28771
Missing	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.98511	0.92858	1.13917	0.85189	0.83970	
No	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.18105	0.88497	1.50065	0.92960	0.17310	
Yes	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.64263	0.79002	2.60726	1.03500	0.03520	0.46159
Missing	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.99611	0.96060	1.07788	0.92063	0.92350	
No	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.27813	0.87871	1.64674	0.99193	0.05780	
No	Stomachache (Y/N)	SO_2 (ppb) with 3 days lag	0.99900	0.99233	1.01430	0.98393	0.89500	
Yes	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.49765	0.83753	2.11975	1.05813	0.02270	0.21952

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Missing	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.90692	0.93211	1.04091	0.79018	0.16480	
No	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.08709	0.79184	1.71790	0.68798	0.72050	
Yes	Stomachache (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.33897	0.88117	1.71566	1.04509	0.02100	0.25188
Missing	Shortness of Breath (Y/N)	VVI (0-3) with 0 days lag	1.22507	0.85453	1.66696	0.90032	0.19650	
No	Shortness of Breath (Y/N)	VVI (0-3) with 0 days lag	1.12378	0.92802	1.30109	0.97064	0.11840	
Yes	Shortness of Breath (Y/N)	VVI (0-3) with 0 days lag	0.95332	0.94261	1.07026	0.84908	0.41800	-0.17046
Missing	Shortness of Breath (Y/N)	VVI (0-3) with 1 days lag	1.33776	0.88816	1.68809	1.06024	0.01420	
No	Shortness of Breath (Y/N)	VVI (0-3) with 1 days lag	1.23244	0.95628	1.34528	1.12896	<.0001	
Yes	Shortness of Breath (Y/N)	VVI (0-3) with 1 days lag	1.01511	0.90411	1.23689	0.83302	0.88200	-0.21733
Missing	Shortness of Breath (Y/N)	VVI (0-3) with 2 days lag	1.16439	0.86745	1.53864	0.88117	0.28440	
No	Shortness of Breath (Y/N)	VVI (0-3) with 2 days lag	1.15373	0.86243	1.54188	0.86329	0.33370	
Yes	Shortness of Breath (Y/N)	VVI (0-3) with 2 days lag	1.17457	0.85830	1.58487	0.87058	0.29240	0.02084
Missing	Shortness of Breath (Y/N)	VVI (0-3) with 3 days lag	1.12987	0.88409	1.43864	0.88745	0.32180	
No	Shortness of Breath (Y/N)	VVI (0-3) with 3 days lag	1.02235	0.81759	1.51695	0.68894	0.91270	
Yes	Shortness of Breath (Y/N)	VVI (0-3) with 3 days lag	1.07251	0.81726	1.59281	0.72217	0.72860	0.05016
Missing	Shortness of Breath (Y/N)	SO_2 (ppb) with 0 days lag	1.00783	0.99710	1.01359	1.00210	0.00750	
No	Shortness of Breath (Y/N)	SO_2 (ppb) with 0 days lag	1.00250	0.99820	1.00602	0.99900	0.16720	
Yes	Shortness of Breath (Y/N)	SO_2 (ppb) with 0 days lag	0.99960	0.99920	1.00110	0.99800	0.59750	-0.00290
Missing	Shortness of Breath (Y/N)	SO_2 (ppb) with 1 days lag	1.00642	0.99720	1.01197	1.00100	0.02120	
No	Shortness of Breath (Y/N)	SO_2 (ppb) with 1 days lag	0.99860	0.99780	1.00290	0.99422	0.51690	
Yes	Shortness of Breath (Y/N)	SO_2 (ppb) with 1 days lag	1.00230	0.99870	1.00491	0.99970	0.07910	0.00370
Missing	Shortness of Breath (Y/N)	SO_2 (ppb) with 2 days lag	1.00481	0.99681	1.01116	0.99860	0.13110	
No	Shortness of Breath (Y/N)	SO_2 (ppb) with 2 days lag	0.99970	0.99641	1.00672	0.99273	0.93200	
Yes	Shortness of Breath (Y/N)	SO_2 (ppb) with 2 days lag	1.00060	0.99720	1.00602	0.99521	0.82520	0.00090
Missing	Shortness of Breath (Y/N)	SO_2 (ppb) with 3 days lag	1.00290	0.99740	1.00803	0.99780	0.26330	
No	Shortness of Breath (Y/N)	SO_2 (ppb) with 3 days lag	0.99870	0.99591	1.00672	0.99074	0.74640	
Yes	Shortness of Breath (Y/N)	SO_2 (ppb) with 3 days lag	0.99531	0.99720	1.00080	0.98975	0.09460	-0.00339
Missing	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.21349	0.93894	1.37300	1.07262	0.00210	
No	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.05612	0.94677	1.17551	0.94885	0.31780	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.86260	0.94819	0.95743	0.77717	0.00550	-0.19351
Missing	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.22091	0.93510	1.39236	1.07047	0.00290	
No	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.07208	0.93941	1.21179	0.94847	0.26550	
Yes	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.99900	0.85916	1.34501	0.74193	0.99450	-0.07308
Missing	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.15754	0.92293	1.35459	0.98916	0.06820	
No	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.98778	0.88418	1.25747	0.77600	0.92070	
Yes	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.16230	0.87459	1.51135	0.89395	0.26150	0.17452
Missing	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.01288	0.92737	1.17422	0.87372	0.86510	
No	Shortness of Breath (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.97395	0.87941	1.25282	0.75715	0.83720	
Yes	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.00170	0.92682	1.16253	0.86304	0.98250	0.02776
Missing	Sore, Itchy Eye (Y/N)	VVI (0-3) with 0 days lag	1.29576	0.93641	1.47359	1.13928	<.0001	
No	Sore, Itchy Eye (Y/N)	VVI (0-3) with 0 days lag	1.02347	0.88338	1.30513	0.80260	0.85180	
Yes	Sore, Itchy Eye (Y/N)	VVI (0-3) with 0 days lag	1.15108	0.90647	1.39529	0.94961	0.15180	0.12761
Missing	Sore, Itchy Eye (Y/N)	VVI (0-3) with 1 days lag	1.35880	0.93389	1.55379	1.18827	<.0001	
No	Sore, Itchy Eye (Y/N)	VVI (0-3) with 1 days lag	1.15569	0.82638	1.67934	0.79533	0.44790	
Yes	Sore, Itchy Eye (Y/N)	VVI (0-3) with 1 days lag	1.26655	0.89601	1.57067	1.02122	0.03140	0.11086
Missing	Sore, Itchy Eye (Y/N)	VVI (0-3) with 2 days lag	1.14752	0.93463	1.30996	1.00511	0.04190	
No	Sore, Itchy Eye (Y/N)	VVI (0-3) with 2 days lag	1.22753	0.87415	1.59776	0.94308	0.12750	
Yes	Sore, Itchy Eye (Y/N)	VVI (0-3) with 2 days lag	1.50697	0.87757	1.94644	1.16672	0.00170	0.27944
Missing	Sore, Itchy Eye (Y/N)	VVI (0-3) with 3 days lag	1.04164	0.94630	1.16067	0.93491	0.45930	
No	Sore, Itchy Eye (Y/N)	VVI (0-3) with 3 days lag	1.06695	0.90348	1.30187	0.87442	0.52320	
Yes	Sore, Itchy Eye (Y/N)	VVI (0-3) with 3 days lag	1.15893	0.79644	1.81068	0.74186	0.51690	0.09199
Missing	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 0 days lag	1.00803	0.99820	1.01167	1.00441	<.0001	
No	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 0 days lag	1.00572	0.99770	1.01025	1.00130	0.01120	
Yes	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 0 days lag	1.00100	0.99541	1.00995	0.99203	0.83110	-0.00472
Missing	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 1 days lag	1.00612	0.99840	1.00934	1.00290	0.00020	
No	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 1 days lag	1.00060	0.99800	1.00461	0.99661	0.76140	
Yes	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 1 days lag	1.00361	0.99611	1.01126	0.99611	0.34480	0.00301
Missing	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 2 days lag	1.00280	0.99850	1.00582	0.99990	0.06140	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
No	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 2 days lag	1.00030	0.99740	1.00541	0.99521	0.90540	
Yes	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 2 days lag	1.00200	0.99730	1.00723	0.99671	0.46180	0.00170
Missing	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 3 days lag	1.00220	0.99850	1.00511	0.99930	0.13020	
No	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 3 days lag	1.00220	0.99790	1.00632	0.99820	0.28150	
Yes	Sore, Itchy Eye (Y/N)	SO_2 (ppb) with 3 days lag	0.99830	0.99810	1.00210	0.99452	0.38410	-0.00390
Missing	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.18187	0.96348	1.27138	1.09867	<.0001	
No	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.08654	0.93286	1.24520	0.94819	0.23240	
Yes	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.05390	0.94365	1.18069	0.94073	0.36490	-0.03264
Missing	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.16509	0.96754	1.24284	1.09210	<.0001	
No	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.13496	0.94829	1.25961	1.02276	0.01710	
Yes	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.04613	0.92580	1.21677	0.89951	0.55800	-0.08883
Missing	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.11316	0.96464	1.19459	1.03728	0.00290	
No	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.16404	0.92450	1.35757	0.99810	0.05290	
Yes	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.11093	0.91934	1.31010	0.94205	0.21100	-0.05311
Missing	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.08361	0.95753	1.17986	0.99521	0.06450	
No	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.08015	0.92487	1.25885	0.92682	0.32390	
Yes	Sore, Itchy Eye (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.04519	0.94393	1.17035	0.93351	0.44330	-0.03496
Missing	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 0 days lag	1.18768	0.94753	1.31983	1.06865	0.00140	
No	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 0 days lag	1.08632	0.94318	1.21847	0.96851	0.15730	
Yes	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 0 days lag	0.77345	0.89315	0.96512	0.61984	0.02300	-0.31288
Missing	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 1 days lag	1.19399	0.94290	1.33977	1.06407	0.00250	
No	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 1 days lag	1.01979	0.92830	1.17986	0.88144	0.79220	
Yes	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 1 days lag	0.84764	0.88878	1.06801	0.67274	0.16090	-0.17215
Missing	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 2 days lag	1.18436	0.94838	1.31390	1.06759	0.00140	
No	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 2 days lag	1.05054	0.92090	1.23467	0.89395	0.54920	
Yes	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 2 days lag	1.00431	0.94374	1.12502	0.89655	0.94030	-0.04623
Missing	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 3 days lag	1.08491	0.96281	1.16848	1.00733	0.03120	
No	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 3 days lag	0.98373	0.92672	1.14191	0.84747	0.82920	
Yes	Iritat.of Nose/Sinus/Throat	VVI (0-3) with 3 days lag	1.12053	0.92081	1.31706	0.95332	0.16760	0.13679

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Missing	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 0 days lag	1.00582	0.99850	1.00874	1.00280	0.00010	
No	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 0 days lag	1.00461	0.99840	1.00783	1.00140	0.00530	
Yes	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 0 days lag	0.99740	0.99651	1.00431	0.99064	0.45880	-0.00721
Missing	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 1 days lag	1.00401	0.99840	1.00713	1.00090	0.01150	
No	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 1 days lag	1.00040	0.99850	1.00321	0.99750	0.81000	
Yes	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 1 days lag	0.99870	0.99830	1.00210	0.99541	0.46570	-0.00170
Missing	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 2 days lag	1.00321	0.99850	1.00612	1.00020	0.03790	
No	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 2 days lag	1.00110	0.99840	1.00421	0.99800	0.50230	
Yes	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 2 days lag	0.99521	0.99780	0.99960	0.99094	0.03120	-0.00589
Missing	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 3 days lag	1.00200	0.99870	1.00461	0.99950	0.11470	
No	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 3 days lag	1.00080	0.99840	1.00391	0.99770	0.62020	
Yes	Iritat.of Nose/Sinus/Throat	SO_2 (ppb) with 3 days lag	0.99591	0.99760	1.00060	0.99124	0.08420	-0.00489
Missing	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.09955	0.96918	1.16906	1.03427	0.00240	
No	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.08058	0.95542	1.18175	0.98807	0.08960	
Yes	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.76315	0.94167	0.85856	0.67834	<.0001	-0.31743
Missing	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.13917	0.96406	1.22397	1.06035	0.00040	
No	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.06652	0.96397	1.14614	0.99253	0.07930	
Yes	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.83494	0.94120	0.94016	0.74149	0.00290	-0.23158
Missing	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.09615	0.96454	1.17657	1.02122	0.01100	
No	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.05802	0.95504	1.15766	0.96686	0.22020	
Yes	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.95313	0.94999	1.05390	0.86200	0.34920	-0.10489
Missing	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.05570	0.96841	1.12423	0.99124	0.09160	
No	Iritat.of Nose/Sinus/Throat	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.03873	0.95151	1.14511	0.94224	0.44510	
Yes	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.91001	0.94658	1.01329	0.81726	0.08550	-0.12872
Missing	Other Symptoms (Y/N)	VVI (0-3) with 0 days lag	1.18922	0.88418	1.51377	0.93417	0.15930	
No	Other Symptoms (Y/N)	VVI (0-3) with 0 days lag	1.25070	0.79422	1.96443	0.79628	0.33160	
Yes	Other Symptoms (Y/N)	VVI (0-3) with 0 days lag	1.57680	0.88559	2.00071	1.24272	0.00020	0.32611
Missing	Other Symptoms (Y/N)	VVI (0-3) with 1 days lag	1.18554	0.88188	1.51664	0.92672	0.17560	
No	Other Symptoms (Y/N)	VVI (0-3) with 1 days lag	0.96262	0.81310	1.44398	0.64172	0.85400	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
					Lower	Higher		
Yes	Other Symptoms (Y/N)	VVI (0-3) with 1 days lag	1.37396	0.77756	2.25016	0.83904	0.20670	0.41135
Missing	Other Symptoms (Y/N)	VVI (0-3) with 2 days lag	0.91284	0.82456	1.33229	0.62544	0.63630	
No	Other Symptoms (Y/N)	VVI (0-3) with 2 days lag	0.45530	0.39507	2.81061	0.07376	0.39690	
Yes	Other Symptoms (Y/N)	VVI (0-3) with 2 days lag	1.28454	0.79128	2.03236	0.81196	0.28460	0.82924
Missing	Other Symptoms (Y/N)	VVI (0-3) with 3 days lag	0.96909	0.90874	1.16906	0.80324	0.74270	
No	Other Symptoms (Y/N)	VVI (0-3) with 3 days lag	0.23653	0.37704	1.60015	0.03496	0.13940	
Yes	Other Symptoms (Y/N)	VVI (0-3) with 3 days lag	1.29253	0.70427	2.56973	0.65012	0.46430	1.05600
Missing	Other Symptoms (Y/N)	SO_2 (ppb) with 0 days lag	1.00310	0.99870	1.00582	1.00050	0.01860	
No	Other Symptoms (Y/N)	SO_2 (ppb) with 0 days lag	1.01076	0.99471	1.02132	1.00040	0.04160	
Yes	Other Symptoms (Y/N)	SO_2 (ppb) with 0 days lag	0.99183	0.99651	0.99870	0.98511	0.01960	-0.01892
Missing	Other Symptoms (Y/N)	SO_2 (ppb) with 1 days lag	1.00351	0.99710	1.00924	0.99790	0.21560	
No	Other Symptoms (Y/N)	SO_2 (ppb) with 1 days lag	0.98285	0.98906	1.00431	0.96185	0.11660	
Yes	Other Symptoms (Y/N)	SO_2 (ppb) with 1 days lag	1.00582	0.99920	1.00733	1.00431	<.0001	0.02297
Missing	Other Symptoms (Y/N)	SO_2 (ppb) with 2 days lag	1.00010	0.99561	1.00884	0.99154	0.97610	
No	Other Symptoms (Y/N)	SO_2 (ppb) with 2 days lag	0.99243	0.99362	1.00501	0.98000	0.23580	
Yes	Other Symptoms (Y/N)	SO_2 (ppb) with 2 days lag	0.99551	0.99203	1.01126	0.98010	0.57690	0.00308
Missing	Other Symptoms (Y/N)	SO_2 (ppb) with 3 days lag	1.00321	0.99601	1.01096	0.99541	0.42420	
No	Other Symptoms (Y/N)	SO_2 (ppb) with 3 days lag	0.97961	0.99064	0.99780	0.96175	0.02810	
Yes	Other Symptoms (Y/N)	SO_2 (ppb) with 3 days lag	0.99273	0.99382	1.00481	0.98069	0.23800	0.01312
Missing	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.12682	0.95935	1.22214	1.03884	0.00400	
No	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	1.26137	0.88311	1.60946	0.98857	0.06180	
Yes	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.80204	0.64701	1.88288	0.34161	0.61240	-0.45933
Missing	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.96300	0.91156	1.15465	0.80316	0.68350	
No	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.04896	0.89440	1.30539	0.84291	0.66850	
Yes	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 1 days lag	1.20707	0.91567	1.43462	1.01552	0.03280	0.15811
Missing	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.07004	0.89199	1.33884	0.85522	0.55370	
No	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.10871	0.88692	1.40270	0.87643	0.38960	
Yes	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 2 days lag	1.37713	0.90747	1.66579	1.13860	0.00100	0.26841
Missing	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.03159	0.91558	1.22630	0.86788	0.72410	

Table 33. (Continued) Air quality and Symptoms Multiple Logistic Models - Attributable OR.

Vog Belief Index	Dependent Variable	Independent Variable	Odds Ratio	Standard Error	95% Confidence Interval		p-value	Attributable Odds Ratio
No	Other Symptoms (Y/N)	$PM_{1.0}$ (ug/m^3) with 3 days lag	1.02102	0.86797	1.34743	0.77360	0.88340	

Table 34. Air quality and Symptoms Multiple Models - βVBI=Yes - βVBI=No.

Independent Variable	Dependent Variable	Independent Variable	Estimate	Standard Error	95% Confidence Interval		p-value	$\beta_{VBI=Yes} - \beta_{VBI=No}$
					Lower	Higher		
Missing	$FEV1_{AM-1}$	VVI (0-3) with 0 days lag	0.002	0.002	-0.001	0.005	0.210	
No	$FEV1_{AM-1}$	VVI (0-3) with 0 days lag	0.002	0.003	-0.005	0.008	0.571	
Yes	$FEV1_{AM-1}$	VVI (0-3) with 0 days lag	0.000	0.004	-0.008	0.008	0.997	-0.002
Missing	$FEV1_{AM-1}$	VVI (0-3) with 1 days lag	0.003	0.002	0.000	0.007	0.081	
No	$FEV1_{AM-1}$	VVI (0-3) with 1 days lag	0.002	0.003	-0.004	0.007	0.559	
Yes	$FEV1_{AM-1}$	VVI (0-3) with 1 days lag	-0.002	0.002	-0.006	0.002	0.288	-0.004
Missing	$FEV1_{AM-1}$	VVI (0-3) with 2 days lag	0.002	0.002	-0.001	0.006	0.231	
No	$FEV1_{AM-1}$	VVI (0-3) with 2 days lag	0.002	0.002	-0.003	0.007	0.364	
Yes	$FEV1_{AM-1}$	VVI (0-3) with 2 days lag	-0.002	0.001	-0.003	-0.001	0.004	-0.004
Missing	$FEV1_{AM-1}$	VVI (0-3) with 3 days lag	0.000	0.001	-0.003	0.002	0.763	
No	$FEV1_{AM-1}$	VVI (0-3) with 3 days lag	-0.001	0.003	-0.007	0.005	0.716	
Yes	$FEV1_{AM-1}$	VVI (0-3) with 3 days lag	0.002	0.003	-0.005	0.008	0.615	0.003
Missing	$FEV1_{AM-1}$	SO_2 (ppb) with 0 days lag	0.000	0.000	0.000	0.000	0.176	
No	$FEV1_{AM-1}$	SO_2 (ppb) with 0 days lag	0.000	0.000	0.000	0.000	0.545	
Yes	$FEV1_{AM-1}$	SO_2 (ppb) with 0 days lag	0.000	0.000	0.000	0.000	0.605	0.000
Missing	$FEV1_{AM-1}$	SO_2 (ppb) with 1 days lag	0.000	0.000	0.000	0.000	0.008	
No	$FEV1_{AM-1}$	SO_2 (ppb) with 1 days lag	0.000	0.000	0.000	0.000	0.412	
Yes	$FEV1_{AM-1}$	SO_2 (ppb) with 1 days lag	0.000	0.000	0.000	0.000	0.259	0.000
Missing	$FEV1_{AM-1}$	SO_2 (ppb) with 2 days lag	0.000	0.000	0.000	0.000	0.956	
No	$FEV1_{AM-1}$	SO_2 (ppb) with 2 days lag	0.000	0.000	0.000	0.000	0.238	
Yes	$FEV1_{AM-1}$	SO_2 (ppb) with 2 days lag	0.000	0.000	0.000	0.000	0.868	0.000
Missing	$FEV1_{AM-1}$	SO_2 (ppb) with 3 days lag	0.000	0.000	0.000	0.000	0.534	
No	$FEV1_{AM-1}$	SO_2 (ppb) with 3 days lag	0.000	0.000	0.000	0.000	0.631	
Yes	$FEV1_{AM-1}$	SO_2 (ppb) with 3 days lag	0.000	0.000	0.000	0.001	0.048	0.000
Missing	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.001	0.001	-0.001	0.003	0.358	
No	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 0 days lag	-0.002	0.002	-0.006	0.002	0.249	
Yes	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.001	0.001	-0.001	0.004	0.411	0.003
Missing	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.001	0.001	-0.001	0.003	0.206	
No	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.001	0.002	-0.004	0.006	0.674	
Yes	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.000	0.003	-0.005	0.005	0.967	-0.001

Table 34. (Continued) Air quality and Symptoms Multiple Models - βVBI=Yes - βVBI=No.

Independent Variable	Dependent Variable	Independent Variable	Estimate	Standard Error	95% Confidence Interval		p-value	$\beta_{VBI=Yes} - \beta_{VBI=No}$
					Lower	Higher		
Missing	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.001	0.001	-0.001	0.003	0.195	
No	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 2 days lag	-0.003	0.002	-0.007	0.001	0.120	
Yes	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.004	0.001	0.003	0.005	<.0001	0.008
Missing	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.001	0.001	-0.001	0.003	0.212	
No	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.000	0.002	-0.004	0.004	0.935	
Yes	$FEV1_{AM-1}$	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.003	0.004	-0.004	0.011	0.354	0.004
Missing	PEF_{AM-1}	VVI (0-3) with 0 days lag	0.000	0.002	-0.004	0.005	0.978	
No	PEF_{AM-1}	VVI (0-3) with 0 days lag	-0.004	0.005	-0.014	0.005	0.390	
Yes	PEF_{AM-1}	VVI (0-3) with 0 days lag	-0.008	0.002	-0.012	-0.004	<.0001	-0.004
Missing	PEF_{AM-1}	VVI (0-3) with 1 days lag	0.002	0.002	-0.003	0.006	0.430	
No	PEF_{AM-1}	VVI (0-3) with 1 days lag	-0.002	0.004	-0.009	0.006	0.701	
Yes	PEF_{AM-1}	VVI (0-3) with 1 days lag	-0.014	0.003	-0.021	-0.008	<.0001	-0.013
Missing	PEF_{AM-1}	VVI (0-3) with 2 days lag	0.001	0.002	-0.003	0.004	0.712	
No	PEF_{AM-1}	VVI (0-3) with 2 days lag	-0.002	0.005	-0.011	0.007	0.668	
Yes	PEF_{AM-1}	VVI (0-3) with 2 days lag	-0.011	0.001	-0.013	-0.008	<.0001	-0.009
Missing	PEF_{AM-1}	VVI (0-3) with 3 days lag	0.003	0.002	-0.001	0.007	0.192	
No	PEF_{AM-1}	VVI (0-3) with 3 days lag	-0.003	0.004	-0.011	0.004	0.378	
Yes	PEF_{AM-1}	VVI (0-3) with 3 days lag	-0.006	0.002	-0.010	-0.002	0.001	-0.003
Missing	PEF_{AM-1}	SO_2 (ppb) with 0 days lag	0.000	0.000	0.000	0.000	0.292	
No	PEF_{AM-1}	SO_2 (ppb) with 0 days lag	0.000	0.000	0.000	0.000	0.628	
Yes	PEF_{AM-1}	SO_2 (ppb) with 0 days lag	0.000	0.000	0.000	0.000	0.249	0.000
Missing	PEF_{AM-1}	SO_2 (ppb) with 1 days lag	0.000	0.000	0.000	0.000	0.034	
No	PEF_{AM-1}	SO_2 (ppb) with 1 days lag	0.000	0.000	0.000	0.000	0.183	
Yes	PEF_{AM-1}	SO_2 (ppb) with 1 days lag	0.000	0.000	0.000	0.000	0.063	0.000
Missing	PEF_{AM-1}	SO_2 (ppb) with 2 days lag	0.000	0.000	0.000	0.000	0.051	
No	PEF_{AM-1}	SO_2 (ppb) with 2 days lag	0.000	0.000	0.000	0.000	0.361	
Yes	PEF_{AM-1}	SO_2 (ppb) with 2 days lag	0.000	0.000	-0.001	0.000	<.0001	0.000
Missing	PEF_{AM-1}	SO_2 (ppb) with 3 days lag	0.000	0.000	0.000	0.000	0.022	
No	PEF_{AM-1}	SO_2 (ppb) with 3 days lag	0.000	0.000	0.000	0.000	0.187	
Yes	PEF_{AM-1}	SO_2 (ppb) with 3 days lag	0.000	0.000	0.000	0.000	0.823	0.000

Table 34. (Continued) Air quality and Symptoms Multiple Models - $\beta_{VBI=Yes}$ - $\beta_{VBI=No.}$

Independent Variable	Dependent Variable	Independent Variable	Estimate	Standard Error	95% Confidence Interval		p-value	$\beta_{VBI=Yes}$ - $\beta_{VBI=No}$
					Lower	Higher		
Missing	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.000	0.002	-0.003	0.003	0.989	
No	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 0 days lag	-0.003	0.003	-0.008	0.002	0.204	
Yes	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 0 days lag	0.004	0.002	0.000	0.007	0.026	0.007
Missing	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.002	0.001	0.000	0.005	0.093	
No	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 1 days lag	0.000	0.003	-0.006	0.006	0.984	
Yes	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 1 days lag	-0.003	0.004	-0.012	0.006	0.507	-0.003
Missing	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.001	0.001	-0.001	0.004	0.301	
No	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 2 days lag	-0.004	0.002	-0.009	0.000	0.069	
Yes	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 2 days lag	0.003	0.002	-0.002	0.007	0.274	0.007
Missing	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 3 days lag	0.002	0.001	0.000	0.005	0.083	
No	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 3 days lag	-0.002	0.003	-0.007	0.003	0.466	
Yes	PEF_{AM-1}	$PM_{1.0}$ (ug/m^3) with 3 days lag	-0.004	0.003	-0.009	0.002	0.163	-0.002

4.5.3 Multiple Logistic Models.

Similar to section 4.3.6, multiple logistic regression were modeled to predict each symptom and combined symptom index with air quality measurements (SO_2, $PM_{1.0}$, and VVI) by (1) subjects that did complete the comprehensive questionnaire were treated as missing, (2) subjects that did not believe that vog was associated with elevated asthma/allergy symptoms (BVI =0), and (3) subjects that believe that vog was associated with elevated asthma/allergy symptoms (BVI >0) (Table 34).

The model with the highest attributable OR between (1) the combined symptoms index and 3 days lag the visual vog index (VVI) ($OR_{attributable}$ =0.288), (2) the combined symptoms index and 1 day lag SO_2 ($OR_{attributable}$ =0.0001), and (3) the combined symptoms index and 2 days lag SO_2 ($OR_{attributable}$ = 0.020). The models were not statistically significant beyond by chance.

CHAPTER V

DISCUSSION

5.1 Hypotheses 1: The observed vog measurements between the individual vog observers are in agreement with each other.

The observers were in "good" agreement with each other; the vog observers provided from fair to moderate inter-rater reliability of vog based on both the Cohan's kappa and logistic regression. However, the author recommends that the visual vog assessment should be conducted by multiple individuals in different locations for the following reasons: (1) an individual observer will not be able to provide 100% compliance, (2) multiple observers will provide better understanding in the vog conditions throughout the location, and (3) data from multiple observers provided quality assurance. In addition, the visual vog assessment is prone to the following biases: (1) relative humidity, during days with high relative humidity, SO_2 and SO_3 gases are more likely to hydrate to H_2SO_3 and H_2SO_4, which are components of visual vog, than during less humid days; (2) light intensity might influence the perception of the observers on the intensity of the vog; (3) angle between Sun, vog and the observer might change one's perception of vog; and (4) vog assessment is a subjective tool that might vary between individuals.

5.2 Hypotheses 2: visually-observed vog and instrument-measured vog (SO_2 and $PM_{1.0}$) for the same day are positively associated; during the voggy days, the daily SO_2 and $PM_{1.0}$ are higher than on non-voggy days, as assessed by the observers.

Visually-observed vog and instrument-measured vog (SO_2 and $PM_{1.0}$) for the same day are positively associated (p-value<0.05; during the voggy days, the daily SO_2 and $PM_{1.0}$ are statistically significantly higher than on non-voggy days, as assessed by the observers. The VVI was more highly correlated between instrument-measured air quality than instrument-measured air quality measurements within (SO_2 and $PM_{1.0}$).

Whereas the nephelometer and the sulfur dioxide monitor are very precise and accurate instruments (this study used SO^2 Monitor with precision of less than 1% or 1 ppb and the nephelometer with precision of 1 ug/m^3) these instruments can only provide a point space measurement; the Hawai`i Volcanoes National Park occupies 209,695 acres. Installing multiple monitors throughout the park might be cost prohibitive and require regular maintenance. In contrast, the visual assessment could be performed with limited funding and cover large geographic areas.

5.3 Hypotheses 3: lung function measurements (FEV1 and PEF) of the Hawai`i Volcanoes National Park workers are negatively associated with visually-observed vog; whereas, self-reported symptoms are positively associated.

This study is the only one to find that visual vog was a useful and statistically significant predictor of self-reported symptoms in the Hawaii Volcano National park workers. Lung function measurements (FEV1 and PEF) were not associated with the visually observed vog at alpha=0.05. The detailed discussion could be found in section 5.4 (next).

5.4 Hypotheses 4: visually-observed vog is as good a predictor of reduced lung function and self-reported symptoms as instrument-measured vog (SO_2 and $PM_{1.0}$).

This is one of the very few prospective cohort studies that examined the effects of vog on the HVNP workers and found the relationship between vog and daily symptoms (Michaud JP et al, 2005). This study found that visually-observed vog (VVI), $PM_{1.0}$ and SO_2 are statistically significantly associated with cough, wheeze, headache, shortness of breath, sore/itchy/watery eyes, and irritation of nose/sinus/throat. Increases in sulfur dioxide were associated with an immediate (0 days lag) effect on symptoms; during maximum SO_2 days of the period of study ($SO_{2\ max}$ = 173 ppb) the odds of having symptoms increased by two fold for the same day compared to days with the lowest SO_2 measurement ($SO_{2\ min}$= 0 ppb). The greatest relationship between $PM_{1.0}$ and symptoms is delayed by one day; one day after the maximum $PM_{1.0}$ ($PM_{1.0}$ max = 7.85 um/m^3), the odds of having symptoms increase by 1.5 times compared to days with the lowest $PM_{1.0}$ measurement ($PM_{1.0\ min}$= 0 ppb). In contrast, the relationship between visual vog index (VVI) and symptoms seem to be greatest two days after exposure; two days after "heavy haze" (VVI=3) the odds of having symptoms increase by 1.53 compared to "clear" days (VVI = 0). The odds of developing symptoms were lower at 75th percentile of the air quality compared to the 1st percentile for: SO_2 at 15.5 ppb with 0 day lag OR=1.064, $PM_{1.0}$ at 2.58 ug/m^3 with one day lag OR= 1.09 and VVI at 1 unit with two days lag OR=1.14. This suggests that physiological response to the visual vog might be different than SO_2 and $PM_{1.0}$ based on the delay in response observed above. Also, the results suggest that the physiological response (self-reported symptoms) to SO_2 might just last for a few days (at the level of SO_2 reached during this study) whereas $PM_{1.0}$ and VVI might have a more prolonged effect. Sulfur dioxide was mildly associated with the consequent day SO_2

(r^2=0.368) which was very similar to $PM_{1.0}$ (r^2=0.368) and VVI (r^2=0.494) *(autocorrelation)*.

In 2008, asthma treatment guidelines issued by the National Heart, Lung and Blood Institute's National Asthma Education and Prevention Program (NAEPP) provided the first comprehensive update in 10 years of clinical guidelines for the diagnosis and management of asthma. The new asthma guidelines stress new approaches for monitoring asthma, focusing on symptoms and control rather than lung function measurements. In addition, these new guidelines provide new recommendations on medications for patients, and new advice for controlling environmental factors that can cause asthma symptoms.

From 24 models that examined the relationship between air quality and lung function, only two models have p-value <0.05, both of which have positive association (β_1 or regression coefficient); more than one model is expected to have p-value <0.05 by chance. Neither VVI, SO_2, nor $PM_{1.0}$ seem to have any effect on lung function measurements (FEV1 and PEF) at the levels observed during this study. However, when a new vent became active in the Halema`uma`u Crater, the levels of SO_2 and $PM_{1.0}$ were at least doubled (USGS, 2008). Lung function measurements were effort-based, thus they have wide interpersonal variation even within 10 minute intervals. Similarly, previous studies have found very weak or no association between air quality measurements and lung function measurements. Previous studies found that an average day with elevated SO_2 might contribute to decreasing the lung function measurements by as much as 1-2%; a larger sample size is required to detect such a small decrease. This study sampled 13,062 person-day observations (n=72). The total population of workers in the park is 750 (or

270,000 person-day measurements possible for the duration of 3 month for 2 time periods for both morning and evening).

Only limited demographic information was collected for the study since individuals were compared to themselves in the regression models; this study design allows control of potential confounders such as age, gender, height, weight, genetics, social or economic status without collecting such data . The participants' ages were determined based on the date of birth provided at the time of their enrollment and the date of enrollment. The derived age was rounded to the nearest whole number. During the Spring 2003 study period, the average age of participants was 47 years old and during the Fall 2003 time period was 48 years old. According to the U.S. Census 2000, for Hawai`i State, the average age for an adult is 45.64 years old (U.S. Census, 2000). Since the workers in the park have higher education and might have started their career later, the average age group of the sample is representative to the state.

Park rangers in the Hawai`i Volcanoes National Park were intermittently exposed to high levels of volcanic gases, chiefly SO_2 and HCI, in the course of their daily work. Michaud et al (2006) found that ambient SO_2 concentrations exceeded U.S. occupational limits at several sites of high exposure (0.8 and 1.7 ppm along a trail, 5.0 ppm in a car park, 4.1 ppm at a vent source, and 1.2 ppm about 1 m from a volcanic vent). Thus it was essential to exclude individual person-days and consecutive 3 days when subjects were exposed to unusual and high exposures since these exposes could be 10 to 100 times higher than the SO_2 park's average.

In the addition to the strengths of the study, it has its potential limitations. If participating subjects volunteered because of higher response to vog than nonparticipating

subjects, the associations between vog and symptoms/lung function will be biased (self-selection bias). In this case, the "true" measure of association for all HVNP employees would be lower (closer to null) than was found in the study. The HVNP is the most popular national park in Hawai`i (1.7 million visitors in 2007); the employees were very preoccupied with daily duties. During recruitment meetings, the subjects were predominately concerned with the extra responsibilities associated with their participating in the project. Only the subjects that could dedicate 10-30 minutes daily participated in the study, which might be less likely to be associated with the one's sensitivity to vog.

The HVNP workers might be less sensitive to vog than other portions of island residents since individuals that were extremely sensitive to vog will not be able to work in the park (health worker effect bias). In that case, results of this study should be carefully interpreted when applying these findings to the rest of Hawai`i Island residents and almost 1.5 million HVNP visitors per year. The "true" measure of association between vog and symptoms/lung function measurements should be higher (away from null) for the Hawai`i Island residents than the Park workers.

Subjects that share their AM-1 with other family members might knowingly or unknowingly cause non-differential misclassification bias (information bias); other family members might perform better or worse peak flow than the subject and did not depend on vog measurements (SO_2, PM_1, and VVI). In that case, the parameter estimate should be biased towards the null. During regular training, the subjects were continually reminded that their AM-1 is "for your lips only". In addition, the best effort was made in the exclusion criteria to remove implausible and extreme outliers for the given individual from analysis.

If subjects completed diaries (median = 53 days) more often when any symptoms were present, this might lead to the differential information bias. In that case, the true prominent estimate will be lower than predicted by the model. However, the diary booklets (consisting of 19 diary pages) were very often completed continuously without days missing. The missing diary days usually occurred when subjects failed to start the new diary or stopped in the middle of the diary and failed to continue. This pattern of missing data could be better explained by busy employee schedules and attrition rather than selected patterns by the subjects. In addition, the fact that the study found that the visual vog index had the strongest relationship with symptoms with 2 days delay and not for the same day, suggests that the bias might be less significant.

Neither rescue asthma medication, maintenance asthma medication, allergy medication, cough syrup, nor heart medicine were significant when added to the multiple logistics regression and multiple regression models, thus medication use variables were excluded from the final models. This could be explained by the low (allergy, asthma, cough, and heart) medication use prevalence. Majority (94.4%) of subjects did not take asthma medication. Asthma medication was only taken on 186 person-days, from which, maintenance asthma medication was taken on 138 person-days and fast acting asthma medication was taken on 59 person-days. The adults current asthma prevalence for the Island of Hawai`i is around 8.7 (95% CI [7.0-10.8]); one third of all adults with asthma took their medication in the past 30 days; or approximately 3% of the residents of Hawai`i Island took their asthma medication in the past 30 days (Hawai`i Behavioral Risk Factor Surveillance System, HBRFSS 2000-2003). Eight of 124 subjects-study period (6%) took asthma medication at least once during study periods, which appears to be almost twice as

high as HBRFSS's estimates. The findings of elevated medication use by the HVNP employees were complicated by:

(1) the difference in methods for data collection between the study and HBRFSS; this study definition of asthma medication use is broader than HBRFSS; in that case, the asthma medication use for HVNP employees would appear to be higher than HBRFSS.

(2) this study has the healthy worker effect bias, the HVNP employees were healthier than general population; in that case, lower asthma medication use is expected for the HVNP employees.

(3) the study's subjects were self-selected (self-selection bias), the subjects that were using asthma medication might be more likely to enroll into this study than nonparticipants; in that case, higher medication use is expected, as people with higher education tend to control their asthma better, seek nonemergency medical care, and take asthma medication more often than a lower educated population; in that case, the asthma medication use for HVNP employees would appear to be higher than general population (Krupitsky, D et al, 2006).

The study did not have enough subjects with asthma to conduct further investigation, nor was it this study's main objective. Future studies should examine the relationship between vog and asthma medication use for adults who have this disease. The diary validity appears to be higher for adults than children (Michaud, 2003, Mar, 2004).

Hawai`i State Department of Health (DOH), Clean Air Branch (CAB) has been developing a similar vog index scale that will incorporate visual vog and $PM_{2.5}$. This index does not follow the federal reference or federal equivalent of methods for the air quality

data collection and will not be used to compare to the National Ambient Air Quality Standards. No previous studies have been done examining the relationship between the DOH derived visual vog index and the health effects. The main goal in developing the DOH vog index would be to collect with visual haze. Although this study is not using the same index that is being developed by the Hawai`i DOH, this study might be an example of how the Hawai`i DOH might study the relationship between its visual vog index and human health in the future.

5.5 **Hypotheses 5: individuals who believe that vog adversely affects their symptoms are more likely to have elevated daily self-reported symptoms during vog episodes (defined by instrument-measured and visually-observed vog) than individuals who do not believe that vog adversely affects their symptoms.**

One's beliefs that vog causes asthma and allergies did not seem to have a significant influence on one's response to vog in terms of self-reported symptoms and lung function measurements (PEF and FEV1).

Results from multiple linear regression models have shown that models with the highest attributable slope between (1) the combined symptoms index and 0 days lag visual vog index (VVI) ($\beta_{BVI=0} - \beta_{BVI>0}$=0.18), (2) the combined symptoms index and 0 day lag SO_2 ($\beta_{BVI=0} - \beta_{BVI>0}$=0.0024), and (3) the combined symptoms index and 0 day lag SO_2 ($\beta_{BVI=0} - \beta_{BVI>0}$=0.160) (not statistically significant). Other models were not statistically significant beyond chance.

Forty five comprehensive completed questionnaires were received at least once during two study periods thus the vog belief index was available for those subjects only (41% response rate). The majority of participants (82%) did not believe that vog is responsible for exacerbation of their allergies and/or asthma; only eight individuals

believed that vog is associated with their elevated symptoms. The small sample size could explain the lack of statistically significant associations between those who believed that vog adversely affects their symptoms and those who did not.

5.6 **Summary.**

Visual vog observers can provide reliable data which are correlated with data from SO_2 and $PM_{1.0}$ monitors. Visually observed vog, $PM_{1.0}$ and SO_2 are statistically significantly associated with cough, wheeze, headache, shortness of breath, sore/itchy/watery eyes, and irritation of nose/sinus/throat. Visually observed vog is as useful a tool of predicting self-reported symptoms as SO_2 and $PM_{1.0}$ monitors. A network of visual observers can provide a useful assessment of the HVNP. The maximum response to vog ranged from same day to 2 days after the exposure depending on the measurement (VVI, SO_2, and $PM_{1.0}$), which suggests that the relationships between air quality measurements maybe not clear. This study did not find lung function measurements (PEF and FEV1) to be significantly associated with vog. One's belief that vog is related to asthma/allergies did not seem to affect one's response to vog.

Appendix A: Comprehensive Take Home Questionnaire.

REVE
2003 Questionnaire

* These questions ask about your health and home for the past 6-12 months. *
** Please fill in the bubble to mark your answer, and fill in blanks where needed. **

*** All information will be kept private and confidential. ***

Your name _____/_____/_____
Last First
Middle

Today's date ____/____/____ **Your Birthday** ___/___/____
mo day yr mo day yr

You are: ___ Male **Sex** **Place of work** _____ **Work**
___ Female

Please fill in the bubble for correct answer
(for example)
Do you live in Hawai'i?

O No
O Yes

1 **Do you live at more than one home? Q1 livemorethanonehome**
O No
O Yes

2a **Please print the HOME address where you spend the most time over the past 6 months**

_____

_____
City

_____
State and Zip Code

2b **If you have a P.O. Box, please print it here:**

P. O. Box _____ City_____ State_____ Zip _____

3 **What is the phone number for the HOME listed in Question #2a?**
(___) _____

In the same way questions about 'your home' are taken to mean 'your home' where they spent the most time in the past 6 months.

5a **What type of home do you live in?**

O A house (not connected to other homes) **Q5a house**

O A building with 2-4 attached apartments, town houses, condos, a duplex or a triplex.

Q5a 2-4attachedapartments

O A building with 5-10 attached apartments, town houses, condos, etc.

Q5a 5-10attachedapartments

O A building with more than 10 attached apartments, town houses, condos, etc.

Q5a morethan10apartments

O A mobile home or trailer **Q5a mobilehome**

O Other (explain) _____ **Q5a other**

5b **Is your home mostly _____? (choose the best answer below)**

O Post and pier with wood floors **Q5b post&pier**

O Pole house with wood floors **Q5b polehouse**

O Concrete slab floors **Q5b concreteslab**

O A mix of wood floors and slab **Q5b mixwood**

6 **Have you had problems with asthma during the last 6 months? Q6 yn**

O No

O Yes

7 **Does your home have a kitchen stove, range, or oven that uses GAS? Q7 yn**

O No (go to question #8).

O Yes. **If Yes,** how is it lit? Mark all that apply below.

O Electronic ignition (it goes, "click, click, poof!") **Q7 Electronic**

O Continuous pilot light (without a match; it goes, "ssss, whoosh!") **Q7 PilotLight**

O No pilot light (with a match; it goes "ssss, whoosh!") **Q7 NoPilotLight**

O Sometimes we use a match. **Q7 Match**

O Camp stove propane. **Q7 CampStovePropane**

O Camp stove white gas. **Q7 CampStoveWhiteGas**

O Don't know how it is lit. **Q7 DNK**

8 **Does your family ever use any of the following air conditioning at home?**

Mark all that apply.

O No (go to question # 9a) **Q8 yn**

O Yes. **If Yes,** what is the main kind of air conditioning that is used?

O Room (box that sticks out of window or wall) **Q8 room**

O Central (vents in the room) **Q8 central**

O Swamp/desert/evaporative cooler **Q8 swampdesertevaporativecooler**

O Don't know what kind it is **Q8 dnk**

9a **Do you use a humidifier in your home?**

O No (go on to question # 10a) **Q9a yn**

O Yes. **If Yes,** please check all that apply

O Your room? **Q9a yourroom**

O Other room(s)? **Q9a otherroom** _____ _____

O The humidifier is the kind that makes a fine mist you can see (eg. spray nozzle or ultra sonic) **Q9a humidifierfinemistyoucansee**

O The humidifier heats the water *hot* and makes 'steam '. **Q9a humidifierheatsthewater**

O Don't know what kind of humidifier it is. **Q9a dnk**

9b **How often is the humidifier used? Q9b rarely**

O Rarely **O** Often **O** Regularly **O** Only when I have symptoms

Q9b rarely Q9b often Q9b regualarly Q9b whenihavesymptoms

10a **Do you use a 'negative ion' generator or ozone generator in your home?**

O No (go on to question # 11) **Q10a yn**

O Yes. **If Yes,** please check all that apply

O is it in your room? **Q10a yourroom**

O are any in other room(s)? **Q10aotherroom** _____ _____

Manufacturer: **Q10amanufacturer** model: **Q10amodel**

O don't know what kind of ozone or 'negative ion' generator it is **Q10adnk**.

(**Please note:** ***Ozone Generators can be Harmful to Your Health !!*** **Please consult your doctor**)

10b **How often is the ozone or 'negative ion' generator used?**

O rarely **O** often **O** regularly **O** only when I have symptoms

Q10brarely QO10boften QO10bregularly Q10bwhenihavesymptoms

11 **Do you use a HEPA Air Filter in your home?**

O No (go on to question # 12a) **Q11yn**

O Yes. **If Yes,** how often?

Q11rarely Q11often Q11regularly 11whenihavesymptoms

O do you close windows when you use the air filter **Q11closewindowusetheairfilter**

O are there any HEPA filter in other room(s) ? Which rooms? **Q11hepafilterinotherroom** _____

12a **Does your home have heating?**

O No (Go on to question # 13a) **Q12ayn**

O Yes. **If Yes**, what is the main fuel used to heat it? (Check all that apply.)

O gas (you may be able to see a blue flame or pilot light in the unit) **Q12agas**

O electricity (you may be able to see a red-hot glowing wire in the unit) **Q12aelectricity**

O bottled, tank or LP gas (a tank outside that a truck may fill with gas) **Q12abottledtank**

O firewood **QS12afirewood**

O other (explain) **Q12aother**

O don't know how it is heated **Q12adnk**

12b **Does your family use a wood burning fireplace for heating?**

O No **QS12byn**

O Yes

O Don't know **Q12bdnk**

12c **Does your family ever use the kitchen stove or oven to heat the house or take the chill off in the morning?**

O No (go to question # 13a) **Q12cyn**

O Yes. **If Yes,** is it

O gas **Q12cgas**

O electric **Q12celectric**

O camp stove **Q12ccampstove**

O Don't know **Q12cdnk**

13a **In the rooms without carpets are there any large rugs or grass mats or tatami or lauhala mats?**

O No (go to question # 13b) **Q13ayn**

O Yes. **If Yes,** which rooms? Mark all that apply.

O Whole house (excluding kitchen and bath) **Q13awholehouse**

O Your bedroom **Q13ayourbedroom**

O Other bedrooms **Q3aotherbedrooms**

O Other rooms **Q3aotherrooms**

13b **Does your home have wall-to-wall carpeting in any room?**

O No (go on to question #13c) **QB13byn**

O Yes. **If Yes,** which rooms? (Mark all that apply)

O Whole house (excluding kitchen and bath) **QB13bwholehouse**

O Your bedroom **QB13byourbedroom**

O Other bedrooms **Q13botherbedrooms**

O Other rooms **Q13botherrooms**

13c **Do any rooms have carpets over concrete slabs?**

O No (go to question # 14) **Q3cyn**

O Yes. **If Yes,** which rooms? (Mark all that apply)

O Whole house (except kitchen and bath) **QB13cwholehouse**

O bedroom **QB13cmybedroom**

O Other bedrooms **Q13cotherbedrooms**

O Other rooms **Q13cotherrooms**

14 **Has your home had any water flooding/leaking in the last year?**

O No (go to question # 15a) **Q14yn**

O Yes. **If Yes,** did it flood any carpeted areas?

O No **Q14no**

O Just a little **Q14justalittle**

O Some **Q14some**

O A lot **Q14alot**

O Don't know if it flooded carpeted areas. **Q14dnk**

15a **Has there been mold or mildew on the walls, ceilings, or floors in your home in the past year?**

O No (Go on to Question # 15b) **Q15ayn**

O Yes. **If Yes,** was/is it

O just a little **Q15ajustalittle**

O some **Q15asome**

O a lot **Q15aalot**

O Don't know **Q15adnk**

15b **Has there been a musty odor in your home in the past year?**

O No (Go on to Question # 16) **Q15byn**

O Yes. **If Yes,** was/is it

O hardly ever **Q15bhardlyever**

O sometimes **Q15bsometimes**

O often **Q15boften**

O Don't know Q15bdnk

16a **About how far from work is your home?**

O 1-3 miles **Q16a1-3miles**

O 4-8 miles **Q16a4-8miles**

O 9-30 **Q16a9-30miles**

O more than 30 miles **Q16amorethan30miles**

16b **How do you usually get to work?**

O walk **Q16bwalk**

O bicycle **Q16bbicycle**

O car or bus **Q16bcarorbus**

17a **Does anyone smoke cigarettes, pipes, or cigars at home?**

O No (go on to question # 19) **Q17ayn**

O Yes. **If Yes,** where do they smoke?

O Inside home **Q17ainsidehome**

O Outside home **Q17aoutsidehome**

O Both **Q17aboth**

17b **Do they smoke at home?**

O No **Q17byn**

O Yes

18a **About how many times a day does someone smoke in your home?**

O None **Q18anone**

O Less than once a day **Q18alessthanonceaday**

O 1 smokes/day **Q18a1**

O 2 smokes/day**2smokes/day**

O 3-4 smokes/day **Q18a3-4smokes/day**

O More than 4 smokes/day **Q18amorethan4smokes/day**

18b **How many people smoke inside your home on a daily basis?**

O 1 **Q18b1**

O 2 **Q18b2**

O 3 **Q18b3**

O 4 **Q18b4**

O 5 **Q18b5**

O 6 or more **Q18b6ormore**

19 **How many times do you smoke per week?**

O None **Q19none**

O 1-2 **Q191 (1-2 adult)**

O 3-4 **Q192-10 (3-4 Adult)**

O 4-20 **Q1910-20 (>4 adult)**

O More than 20 **Q19morethan20 (no adult)**

20 **Does your family have any pets?** (include pets that are kept outdoors)

O No (go on to question # 21) **Q20yn**

O Yes. **If Yes,** what kind? (Mark all that apply)

O Cats. How many? _____ Choose one: **Cats-Combined -- Q20catshowmany**

O Kept indoors only **Q20keptindoor**

O Kept outdoors only **Q20keptoutdoor**

O Kept both indoors and outdoors **Q20keptboth**

O Dogs. How many? _____ Choose one: **Q20keptoutdoor -- Q20dogshowmany**

O Kept indoors only **Q20keptindoor**

O Kept outdoors only **Q20keptoutdoor**

O Kept both indoors and outdoors **Q20keptbothdoor**

O Rabbits. How many? _____ Choose one: **Q20keptboth-- Q20rabbithowmany**

O Kept indoors only **Q20keptindoor**

O Kept outdoors only **Q20outdoor**

O Kept both indoors and outdoors **Q20keptboth**

O Guinea pigs. How many? _____ **Q20guineapighowmany**

O Mice/rats. How many? _____ **Q20micerathowmany**

O Birds. How many? _____ **Q20birdshowmany**

O Lizards/turtles. How many? _____ **Q20lizardturtlehowmany**

O Fish Q20fish

O Horses Q20horses

O Other (please explain) _____ **Q20other**

21 **In the past 6 months, have you had any of the following PESTS in your home?**

O No. (go on to question # 22) **Q21yn**

O Yes. **If Yes,** what kind? (Mark all that apply)

O Rats/mice **Q21ratsmice**

O Cockroaches **Q21cockroaches**

O Ants **Q21ants**

O Spiders **Q21spiders**

O Termites **Q21termites**

O Gecko **Q21gecko**

O Other _____ **Q21other**

22 **Has your home been tented (fumigated) in the past two years?**

O No (Go on to Question # 16) **Q22yn**

O Yes. **If Yes, What month and year was it tented?**

_____ **Q22ifyesexplain**

23 **How many live plants are INSIDE your home?**

O None **Q23none**

O 1 **Q231**

O 2-4 **Q232-4**

O 5-8 **Q235-8**

O 9-12 **Q239-12**

O 13 or more **Q2313ormore**

24 **Does your bedding use dust-mite "proof" (protective) coverings?**

O No. **Q24yn**

O Yes.

25 **Has you had skin test for allergens**

O No. (go on to question # 26) **Q25yn**

O Yes. **If Yes,**

About how long ago was last test? _____ **Q25ifyesexplain**

Please list allergens you responded to

What is he/she allergic to?

_____ _____

_____ _____

_____ _____

_____ _____

_____ _____

_____ _____

26 **Do you have allergies?**

O No. (go on to question # 29a). **Q26yn**

O Yes. **If Yes,** what is he/she allergic to?

O Dogs **Q26dogs**

O Cats **Q26cats**

O Foods **Q26foods**

O Mold **Q26mold**

O Cigarette smoke **Q26cigarettesmoke**

O Perfume **Q26perfume**

O Detergents and Solvents **Q26detergentsandsolvents**

O Pollen, Flowers, and/or Trees **Q26pollenflowerstrees**

O Other please list **Q26other**

_____

_____

O Feathers **Q26feathers**

O Aspirin, Advil, and/or Motrin **Q26aspirinadvilmotrin**

O Night time **Q26nighttime**

O Exercise **Q26exercise**

O Stress **Q26stress**

O Seasons **Q26seasons**

O If Yes, which seasons(s)?

Q26ifyesexplain

27 **Have you ever taken allergy shots? Q27yn**

O No

O Yes. **If Yes,** about how long ago was the last shot taken? **Q27ifyesexplain**

About how often are shots taken? _____

28 **Do you ever take medication for his/her allergies?**

O No **Q28yn**

O Yes. **If Yes,** what kinds? **Q28ifyesexplain**

About how often? _____

29a **Do any parents, brothers, or sisters have asthma?**

O No **Q29ayn**

O Yes.

29b **Do any parents, brothers, or sisters have allergies?**

O No **Q29byn**

O Yes.

30 **In the last 6 months, have you ever had hay fever or allergies that affected his/her nose, sinus or chest?**

O No. (go on to question # 31) **Q30yn**

O Yes. **If Yes**, which illness?

O Pneumonia. When? _____/_____ **Q30pneumonia**
Month Year

O Bronchitis. When? _____/_____ **Q30bronchitis**
Month Year

31 **Do any of the following trigger your asthma?**

O Exercise

O Never **O** Occasionally **O** Often **O** Always

Q31exercisenever Q31execiseoccasionally Q31exerciseoften Q31exercisealways

O Excitement

O Never **O** Occasionally **O** Often **O** Always

Q31excitementnever Q31excitementoccasionally Q31excitementoften Q31excitementalways

O Grass

O Never **O** Occasionally **O** Often **O** Always

Q31grassnever Q31grassoccasionally Q31grassoften Q31grassalways

O Mold/ mildew

O Never **O** Occasionally **O** Often **O** Always

Q31moldnever Q31moldoccasionally Q31moldoften Q31moldalways

O Vog

O Never **O** Occasionally **O** Often **O** Always

Q31vognever Q31vogoccasionally Q31vogoften Q31vogalways

O Pets/ pollen

O Never **O** Occasionally **O** Often **O** Always

Q31petspollennever Q31petspollenoccasionally Q31petspollenoften Q31petspollenalways

O Others (please list) _____ _____

O Never **O** Occasionally **O** Often **O** Always

Q31others Q31othersnever Q31othersoccasionally Q31othersoften Q31othersalways

32 **Do you use medication(s) for asthma?**

O No (go on to question # 34) **Q32yn**

O Yes. **If Yes**, select the medicine from the next 3 pages

33 **Do you use a 'spacer' with the inhaler?**

O Not at all. **Q33notatall**

O Sometimes **Q33sometimes**

O Always **Q33always**

34 **About how often have you had asthma episodes in the past 6 months?**

O No asthma episodes in the last 2 weeks **Q34noasthmaepisodes**

O 1-5 times in 1 week **Q341-5timesin1week**

O 1-5 times in 2 weeks **Q341-5timesin2week**

O Other (please explain) **Q34other**

35 **Have you done any of the following in the last 6 months?**

Missed work because of asthma? **Q35missedworkyn**

O No

O Yes. **If Yes,** how many days? _____ **Q35ifyesexplain**

Visited his/her doctor for asthma? **Q35visitedyn**

O No

O Yes. **If Yes,** how many times? _____ **Q35ifyesexplain**

Gone to the emergency room for asthma? **Q35gonetoemergencyyn**

O No

O Yes. **If Yes,** how many times? _____ **Q35ifyesexplain**

Stayed in the hospital because of asthma? **Q35stayedinhospitalyn**

O No

O Yes. **If Yes,** how many times? _____ **Q35ifyesexplain**

Been awakened by wheezing, cough, or shortness of breath? **Q35beenawakenedyn**

O No.

O Yes. **If Yes,** how many nights? _____ **Q35ifyesexplain**

Have **you** missed work because of your asthma? **Q35missedworkyn**

O No

O Yes. **If Yes,** how many times?_____ **Q35ifyesexplain**

37 **Has a doctor ever said you had asthma?**

O No. (go on to question # 38) **Q37yn**

O Yes. **If Yes,** what is this doctor's specialization?

O Family practice **Q37familypractice**

O Pulmonologist **Q37pulmonologist**

O Allergy specialist **Q37allergy**

O Pediatrics **Q37pediatrics**

O Other _____ **Q37other**

38 **Pick one of the following statements that best describes your asthma during the last 6 months.**

O He/she has not used any medication (inhalers/pills, etc.) for his/her asthma, and did not see a doctor for asthma. **Q38notusedanymedication**

O He/she had to use some medication (inhalers/pills/etc.) for his/her asthma, but did not see a doctor for asthma. **Q38usedsomemedicinenotseeadoctor**

O He/she had to use some medication (inhalers/pills/etc.) for his/her asthma, and did see a doctor for asthma. **Q38usedsomemedicineseedoctor**

O He/she had to some medication (inhalers/pills/etc.) for his/her asthma, and visited an emergency room or stayed overnight in a hospital for asthma. **Q38usedsomemedicinevisitedemergencyroom**

39a **During the last 6 months, in the morning, have you coughed everyday for 2 months in a row?**

O No **Q39ayn**

O Yes

39b **During the last 6 months, during the day, have you coughed everyday for 2 months in a row?**

O No **Q39byn**

O Yes

40 **During the last 6 months, have you ever been awakened <u>at night</u> (more than once per night) by coughing and/or wheezing?**

O No (go on to question # 41) **Q40yn**

O Yes. **If Yes,** about how many nights?

Coughing:
- **O** 1-7 nights **Q40coughing1-7nights**
- **O** 1-2 weeks **Q40coughing1-2weeks**
- **O** 2-4 weeks **Q40coughing2-4weeks**
- **O** 1-2 months **Q40coughing1-2months**
- **O** More than 2 months **Q40coughingmorethan2months**

Wheezing:
- **O** 1-7 nights **Q40wheezing1-7nights**
- **O** 1-2 weeks **Q40wheezing1-2weeks**
- **O** 2-4 weeks **Q40wheezing2-4weeks**
- **O** 1-2 months **Q40wheezing1-2months**
- **O** More than 2 months **Q40morethan2months**

41 **Not counting when you had a cold or flu, is he/she usually congested in the chest or coughs up phlegm (this is also called "mucous" or "sputum" and comes up from your lungs)?**

O No (go on to question # 43) **Q41yn**

O Yes.

42 **Has he/she also had congestion or coughed up phlegm for at <u>least two months</u> in a row in the past year?**

O No **Q42yn**

O Yes

43 **How many attacks of wheezing have you had <u>in the last 6 months</u>?**

O None **Q43none**

O 1 to 3 **Q431to3**

O 4 to 12 **Q434to12**

O More than 12 **Q43morethan12**

44 **<u>In the last 6 months</u>, how often, on average, has your sleep been disturbed due to wheezing?**

O Never woken with wheezing **Q44neverwokenwithwheezing**

O Less than one night per week **Q44lessthanonenight**

O One or more nights per week **Q44oneormorenight**

45 **<u>In the last 6 months</u>, has wheezing ever been severe enough to limit your speech to only one or two words at a time between breaths?**

O No **Q45yn**

O Yes

46 **How much and how often do you exercise? (please check)**

	Rarely	Occasionally	Often
Very Light Exercise	indoor ___ **Q46verylightexerciserarely** (example: Nintendo) outdoor ___ (example: easy walking)	indoor ___ outdoor ___ **Q46verylightexerciseoccasionally**	indoor ___ outdoor ___ **Q46verylightexerciseoften**

Light Exercise	indoor ___ (example: ping pong or volleyball) outdoor ___ **Q46lightexerciserarely**	indoor ___ outdoor ___ **Q46lightexerciseoccasionally**	indoor ___ outdoor ___ **Q46lightexerciseoften**
Medium Exercise	indoor ___ outdoor ___ **Q46mediumexerciserarely**	indoor ___ outdoor ___ **Q46mediumexerciseoccasionally**	indoor ___ outdoor ___ **Q46mediumexerciseoften**
Heavy Exercise	indoor ___ outdoor ___ (example: soccer or aerobics) **Q46heavyexerciserarely**	indoor ___ outdoor ___ **Q46heavyexerciseoccasionally**	indoor ___ outdoor ___ **Q46heavyexerciseoften**

47 **Do you currently take vitamins? Q47yn**

O No (go on to question # 48)

O Yes. **If Yes,** what kind of vitamin does he/she take, and how often are they taken?

Multi-vitamin

O Once a day **Q47multivitonceaday**
O Once every few days **Q47multivitonceeveryfewday**
O About once a week **Q47multivitaboutonceaweek**
O I do not take this vitamin **Q47multivitmyadultnottakevitamin**

48 **What kind of vitamin do you currently take, and how often are they taken?**

Vitamin C _____ mg **Q48vitaminchowmuch**
O Once a day **Q48onceaday**
O Once every few days **Q48onceeveryfewday**
O About once a week **Q48aboutonceaweek**
O I do not take this vitamin **Q48adultdoesnottakethisvitamin**

Vitamin E _____ IU **Q48vitaminehowmuch**
O Once a day **Q48onceaday**
O Once every few days **Q48onceeveryfewday**
O About once a week **Q48aboutonceaweek**
O I do not take this vitamin **Q48adultdoesnottakethisvitamin**

Other Vitamins (please list them and state how often they are taken)

Q48othervitaminsname - Q48othervitaminshowoften

Q48othervitaminsname - Q48othervitaminshowoften-

Q48othervitaminsname - Q48othervitaminshowoften

Q48othervitaminsname- Q48othervitaminshowoften

49 **Identify the things which can start an asthma episode (check each that applies to you).**

O Exercise **Q49exercise**

O Respiratory infections **Q49respiratoryinfections**

O Change in temperature **Q49changeintemp**

O Animals **Q49animals**

O Food **Q49food**

O Aspirin or ibuprofen **Q49aspirin**

O Gecko or skink droppings **Q49gecko**

O Cold Air **Q49coldair**

O Strong odors or fumes **Q49strongodors**

O Chalk dust **Q49chalkdust**

O Carpets in the room **Q49carpetsintheroom**

O Pollens **Q49pollens**

O Mold **Q49mold**

O Smoke (any kind) **Q49smoke**

O Other **Q49other**

_____

_____

_____

_____

50 **List any environmental control measures, pre-medications, and/or dietary restrictions that help you avoid or prevent an asthma episode.**

Q50listanyenvironmentalcontrolmeasures

_____

_____

_____

_____

☺ Which one of the following gifts would you like as a token of our appreciation for your help?

O Blockbuster coupon
O Movie coupon
O McDonalds coupon
O Nothing thanks, just glad to help

Appendix B: Frequency Table for Visual Vog Index (VVI) between any 2 Observers.

VVI - Observer 2 vs. Observer 1.

VVI from Observer 1	VVI from Observer 2				Total
	0	1	2	3	
0	16 (53.33%)*	2 (6.67%)	1 (3.33%)	1 (3.33%)	20 (66.67%)
1	5 (16.67%)	1 (3.33%)*	1 (3.33%)	0 (0.00%)	7 (23.33%)
2	0 (0.00%)	1 (3.33%)	1 (3.33%)*	1 (3.33%)	3 (10.00%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	21 (70.00%)	4 (13.33%)	3 (10.00%)	2 (6.67%)	30** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 18 days or 60% of the time (marked gray).
**For 64 days data were not collected by both Observer 1 and Observer 2 during Spring 2006 study period.

VVI - Observer 3 vs. Observer 1.

Observer 1	Observer 3				Total
	0	1	2	3	
0	15 (50.00%)*	1 (3.33%)	2 (6.67%)	1 (3.33%)	19 (63.33%)
1	6 (20.00%)	0 (0.00%)*	2 (6.67%)	0 (0.00%)	8 (26.67%)
2	1 (3.33%)	1 (3.33%)	1 (3.33%)*	0 (0.00%)	3 (10.00%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	22 (73.33%)	2 (6.67%)	5 (16.67%)	1 (3.33%)	30** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 16 days or 53.3% of the time (marked gray).
** For 64 days data were not collected by both Observer 1 and Observer 3 during Spring 2006 study period.

VVI - Observer 4 vs. Observer 1.

Observer 1	Observer 4				Total
	0	1	2	3	
0	8 (44.44%)*	3 (16.67%)	2 (11.11%)	0 (0.00%)	13 (72.22%)
1	0 (0.00%)	1 (5.56%)*	2 (11.11%)	0 (0.00%)	3 (16.67%)
2	0 (0.00%)	0 (0.00%)	1 (5.56%)*	1 (5.56%)	2 (11.11%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	8 (44.44%)	4 (22.22%)	5 (27.78%)	1 (5.56%)	18** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 10 days or 55.6% of the time (marked gray).
** For 76 days data were not collected by both Observer 1 and Observer 4 during Spring 2006 study period.

VVI - Observer 5 vs. Observer 1.

Observer 1	Observer 5				Total
	0	1	2	3	
0	7 (21.21%)*	9 (27.27%)	2 (6.06%)	2 (6.06%)	20 (60.61%)
1	1 (3.03%)	4 (12.12%)*	1 (3.03%)	2 (6.06%)	8 (24.24%)
2	0 (0.00%)	2 (6.06%)	3 (9.09%)*	0 (0.00%)	5 (15.15%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	8 (24.24%)	15 (45.45%)	6 (18.18%)	4 (12.12%)	33** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 14 days or 42.4% of the time (marked gray).
**For 61 days data were not collected by both Observer 1 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 1.

Observer 1	Average Access				Total
	0	1	2	3	
0	15 (45.45%)*	4 (12.12%)	1 (3.03%)	0 (0.00%)	20 (60.61%)
1	3 (9.09%)	3 (9.09%)*	2 (6.06%)	0 (0.00%)	8 (24.24%)
2	0 (0.00%)	1 (3.03%)	4 (12.12%)*	0 (0.00%)	5 (15.15%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	18 (54.55%)	8 (24.24%)	7 (21.21%)	0 (0.00%)	33** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 22 days or 66.7% of the time (marked gray).
**For 61 days data were not collected by both Observer 1 and Average Access during Spring 2006 study period.

VVI - Observer 3 vs. Observer 2.

Observer 2	Observer 3				Total
	0	1	2	3	
0	40 (70.18%)*	2 (3.51%)	1 (1.75%)	0 (0.00%)	43 (75.44%)
1	3 (5.26%)	2 (3.51%)*	1 (1.75%)	0 (0.00%)	6 (10.53%)
2	2 (3.51%)	0 (0.00%)	3 (5.26%)*	0 (0.00%)	5 (8.77%)
3	0 (0.00%)	0 (0.00%)	2 (3.51%)	1 (1.75%)*	3 (5.26%)
Total	45 (78.95%)	4 (7.02%)	7 (12.28%)	1 (1.75%)	57** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 46 days or 80.7% of the time (marked gray).
**For 37 days data were not collected by both Observer 2 and Observer 3 during Spring 2006 study period.

VVI - Observer 4 vs. Observer 2.

Observer 2	Observer 4				Total
	0	1	2	3	
0	21 (51.22%)*	8 (19.51%)	6 (14.63%)	0 (0.00%)	35 (85.37%)
1	0 (0.00%)	0 (0.00%)*	2 (4.88%)	0 (0.00%)	2 (4.88%)
2	0 (0.00%)	0 (0.00%)	2 (4.88%)*	0 (0.00%)	2 (4.88%)
3	1 (2.44%)	0 (0.00%)	0 (0.00%)	1 (2.44%)*	2 (4.88%)
Total	22 (53.66%)	8 (19.51%)	10 (24.39%)	1 (2.44%)	41** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 24 days or 58.5% of the time (marked gray).
**For 53 days data were not collected by both Observer 2 and Observer 4 during Spring 2006 study period.

VVI - Observer 5 vs. Observer 2.

Observer 2	Observer 5				Total
	0	1	2	3	
0	18 (27.69%)*	24 (36.92%)	7 (10.77%)	2 (3.08%)	51 (78.46%)
1	2 (3.08%)	2 (3.08%)*	1 (1.54%)	1 (1.54%)	6 (9.23%)
2	1 (1.54%)	0 (0.00%)	2 (3.08%)*	2 (3.08%)	5 (7.69%)
3	1 (1.54%)	2 (3.08%)	0 (0.00%)	0 (0.00%)*	3 (4.62%)
Total	22 (33.85%)	28 (43.08%)	10 (15.38%)	5 (7.69%)	65** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 22 days or 33.9% of the time (marked gray).
**For 29 days data were not collected by both Observer 2 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 2.

Observer 2	Average Access				Total
	0	1	2	3	
0	42 (62.69%)*	11 (16.42%)	0 (0.00%)	0 (0.00%)	53 (79.1%)
1	2 (2.99%)	3 (4.48%)*	1 (1.49%)	0 (0.00%)	6 (8.96%)
2	0 (0.00%)	1 (1.49%)	4 (5.97%)*	0 (0.00%)	5 (7.46%)
3	0 (0.00%)	1 (1.49%)	2 (2.99%)	0 (0.00%)*	3 (4.48%)
Total	44 (65.67%)	16 (23.88%)	7 (10.45%)	0 (0.00%)	67** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 49 days or 73.1% of the time (marked gray).
**For 27 days data were not collected by both Observer 2 and Average Access during Spring 2006 study period.

VVI - Observer 4 vs. Observer 3.

Observer 3	Observer 4				Total
	0	1	2	3	
0	18 (47.37%)*	7 (18.42%)	5 (13.16%)	0 (0.00%)	30 (78.95%)
1	1 (2.63%)	0 (0.00%)*	2 (5.26%)	0 (0.00%)	3 (7.89%)
2	0 (0.00%)	1 (2.63%)	2 (5.26%)*	1 (2.63%)	4 (10.53%)
3	1 (2.63%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	1 (2.63%)
Total	20 (52.63%)	8 (21.05%)	9 (23.68%)	1 (2.63%)	38** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 20 days or 52.6% of the time (marked gray).
**For 56 days data were not collected by both Observer 3 and Observer 4 during Spring 2006 study period.

VVI - Observer 5 vs. Observer 3.

Observer 3	Observer 5				Total
	0	1	2	3	
0	14 (23.33%)*	24 (40.00%)	8 (13.33%)	2 (3.33%)	48 (80.00%)
1	3 (5%)	1 (1.67%)*	0 (0.00%)	0 (0.00%)	4 (6.67%)
2	1 (1.67%)	2 (3.33%)	1 (1.67%)*	3 (5%)	7 (11.67%)
3	1 (1.67%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	1 (1.67%)
Total	19 (31.67%)	27 (45%)	9 (15%)	5 (8.33%)	60** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 16 days or 26.67% of the time (marked gray).
**For 34 days data were not collected by both Observer 3 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 3.

Observer 3	Average Access				Total
	0	1	2	3	
0	38 (62.3%)*	10 (16.39%)	1 (1.64%)	0 (0.00%)	49 (80.33%)
1	1 (1.64%)	3 (4.92%)*	0 (0.00%)	0 (0.00%)	4 (6.56%)
2	0 (0.00%)	1 (1.64%)	6 (9.84%)*	0 (0.00%)	7 (11.48%)
3	0 (0.00%)	1 (1.64%)	0 (0.00%)	0 (0.00%)*	1 (1.64%)
Total	39 (63.93%)	15 (24.59%)	7 (11.48%)	0 (0.00%)	61** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 47 days or 77.1% of the time (marked gray).
**For 33 days data were not collected by both Observer 3 and Average Access during Spring 2006 study period.

VVI - Observer 5 vs. Observer 4.

Observer 4	Observer 5				Total
	0	1	2	3	
0	10 (23.26%)*	10 (23.26%)	2 (4.65%)	1 (2.33%)	23 (53.49%)
1	3 (6.98%)	3 (6.98%)*	2 (4.65%)	0 (0.00%)	8 (18.6%)
2	4 (9.3%)	2 (4.65%)	3 (6.98%)*	1 (2.33%)	10 (23.26%)
3	0 (0.00%)	1 (2.33%)	1 (2.33%)	0 (0.00%)*	2 (4.65%)
Total	17 (39.53%)	16 (37.21%)	8 (18.6%)	2 (4.65%)	43** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 16 days or 37.2% of the time (marked gray).
**For 51 days data were not collected by both Observer 4 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 4.

Observer 4	Average Access				Total
	0	1	2	3	
0	21 (48.84%)*	2 (4.65%)	0 (0.00%)	0 (0.00%)	23 (53.49%)
1	5 (11.63%)	3 (6.98%)*	0 (0.00%)	0 (0.00%)	8 (18.6%)
2	1 (2.33%)	6 (13.95%)	3 (6.98%)*	0 (0.00%)	10 (23.26%)
3	0 (0.00%)	0 (0.00%)	2 (4.65%)	0 (0.00%)*	2 (4.65%)
Total	27 (62.79%)	11 (25.58%)	5 (11.63%)	0 (0.00%)	43** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 27 days or 62.8% of the time (marked gray).
**For 51 days data were not collected by both Observer 4 and Average Access during Spring 2006 study period.

VVI - Average Access vs. Observer 5.

Observer 5	Average Access				Total
	0	1	2	3	
0	23 (25.27%)*	6 (6.59%)	0 (0.00%)	0 (0.00%)	29 (31.87%)
1	24 (26.37%)	12 (13.19%)*	2 (2.2%)	0 (0.00%)	38 (41.76%)
2	3 (3.3%)	5 (5.49%)	7 (7.69%)*	0 (0.00%)	15 (16.48%)
3	0 (0.00%)	2 (2.2%)	3 (3.3%)	4 (4.4%)*	9 (9.89%)
Total	50 (54.95%)	25 (27.47%)	12 (13.19%)	4 (4.4%)	91** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 46 days or 50.6% of the time (marked gray).
**For 3 days data were not collected by both Observer 5 and Average Access during Spring 2006 study period.

VVI - Observer 2 vs. Observer 1.

Observer 1	Observer 2				Total
	0	1	2	3	
0	35 (74.47%)*	0 (0.00%)	3 (6.38%)	0 (0.00%)	38 (80.85%)
1	4 (8.51%)	0 (0.00%)*	0 (0.00%)	0 (0.00%)	4 (8.51%)
2	2 (4.26%)	0 (0.00%)	2 (4.26%)*	0 (0.00%)	4 (8.51%)
3	0 (0.00%)	0 (0.00%)	1 (2.13%)	0 (0.00%)*	1 (2.13%)
Total	41 (87.23%)	0 (0.00%)	6 (12.77%)	0 (0.00%)	47** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 37 days or 78.7% of the time (marked gray).
**For 32 days data were not collected by both Observer 1 and Observer 2 during Spring 2006 study period.

VVI - Observer 3 vs. Observer 1.

Observer 1	Observer 3				Total
	0	1	2	3	
0	28 (77.78%)*	1 (2.78%)	1 (2.78%)	0 (0.00%)	30 (83.33%)
1	1 (2.78%)	1 (2.78%)*	0 (0.00%)	0 (0.00%)	2 (5.56%)
2	0 (0.00%)	3 (8.33%)	1 (2.78%)*	0 (0.00%)	4 (11.11%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	29 (80.56%)	5 (13.89%)	2 (5.56%)	0 (0.00%)	36** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 30 days or 83.3% of the time (marked gray).
**For 43 days data were not collected by both Observer 1 and Observer 3 during Spring 2006 study period.

VVI - Observer 4 vs. Observer 1.

Observer 1	Observer 4				Total
	0	1	2	3	
0	32 (72.73%)*	0 (0.00%)	1 (2.27%)	0 (0.00%)	33 (75%)
1	3 (6.82%)	2 (4.55%)*	0 (0.00%)	0 (0.00%)	5 (11.36%)
2	2 (4.55%)	2 (4.55%)	1 (2.27%)*	0 (0.00%)	5 (11.36%)
3	0 (0.00%)	0 (0.00%)	1 (2.27%)	0 (0.00%)*	1 (2.27%)
Total	37 (84.09%)	4 (9.09%)	3 (6.82%)	0 (0.00%)	44** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 35 days or 79.6% of the time (marked gray).
**For 35 days data were not collected by both Observer 1 and Observer 4 during Spring 2006 study period.

VVI - Observer 5 vs. Observer 1.

Observer 1	Observer 5				Total
	0	1	2	3	
0	67 (84.81%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)	67 (84.81%)
1	0 (0.00%)	6 (7.59%)*	0 (0.00%)	0 (0.00%)	6 (7.59%)
2	0 (0.00%)	0 (0.00%)	5 (6.33%)*	0 (0.00%)	5 (6.33%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (1.27%)*	1 (1.27%)
Total	67 (84.81%)	6 (7.59%)	5 (6.33%)	1 (1.27%)	79** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 79 days or 100.0% of the time (marked gray).
**For all the days data were collected by both Observer 1 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 1.

Observer 1	Average Access				Total
	0	1	2	3	
0	64 (81.01%)*	3 (3.8%)	0 (0.00%)	0 (0.00%)	67 (84.81%)
1	2 (2.53%)	4 (5.06%)*	0 (0.00%)	0 (0.00%)	6 (7.59%)
2	0 (0.00%)	4 (5.06%)	1 (1.27%)*	0 (0.00%)	5 (6.33%)
3	0 (0.00%)	0 (0.00%)	1 (1.27%)	0 (0.00%)*	1 (1.27%)
Total	66 (83.54%)	11 (13.92%)	2 (2.53%)	0 (0.00%)	79** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 69 days or 87.3% of the time (marked gray).
**For all days data were collected by both Observer 1 and Average Access during Spring 2006 study period.

VVI - Observer 3 vs. Observer 2.

Observer 2	Observer 3				Total
	0	1	2	3	
0	21 (75.00%)*	3 (10.71%)	1 (3.57%)	0 (0.00%)	25 (89.29%)
1	0 (0.00%)	0 (0.00%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)
2	0 (0.00%)	2 (7.14%)	1 (3.57%)*	0 (0.00%)	3 (10.71%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	21 (75%)	5 (17.86%)	2 (7.14%)	0 (0.00%)	28** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 22 days or 78.6% of the time (marked gray).
**For 51 days data were not collected by both Observer 2 and Observer 3 during Spring 2006 study period.

VVI - Observer 4 vs. Observer 2.

Observer 2	Observer 4				Total
	0	1	2	3	
0	28 (80.00%)*	3 (8.57%)	1 (2.86%)	0 (0.00%)	32 (91.43%)
1	0 (0.00%)	0 (0.00%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)
2	1 (2.86%)	0 (0.00%)	2 (5.71%)*	0 (0.00%)	3 (8.57%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	29 (82.86%)	3 (8.57%)	3 (8.57%)	0 (0.00%)	35** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 30 days or 85.7% of the time (marked gray).
**For 44 days data were not collected by both Observer 2 and Observer 4 during Spring 2006 study period.

VVI from Observer 5 vs. Observer 2.

Observer 2	Observer 5				Total
	0	1	2	3	
0	35 (74.47%)*	4 (8.51%)	2 (4.26%)	0 (0.00%)	41 (87.23%)
1	0 (0.00%)	0 (0.00%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)
2	3 (6.38%)	0 (0.00%)	2 (4.26%)*	1 (2.13%)	6 (12.77%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	38 (80.85%)	4 (8.51%)	4 (8.51%)	1 (2.13%)	47** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 37 days or 78.7% of the time (marked gray).
**For 32 days data were not collected by both Observer 2 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 2.

Observer 2	Average Access				Total
	0	1	2	3	
0	37 (78.72%)*	4 (8.51%)	0 (0.00%)	0 (0.00%)	41 (87.23%)
1	0 (0.00%)	0 (0.00%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)
2	0 (0.00%)	4 (8.51%)	2 (4.26%)*	0 (0.00%)	6 (12.77%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	37 (78.72%)	8 (17.02%)	2 (4.26%)	0 (0.00%)	47** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 39 days or 83.0% of the time (marked gray).
**For 32 days data were not collected by both Observer 2 and Average Access during Spring 2006 study period.

VVI - Observer 4 vs. Observer 3.

Observer 3	Observer 4				Total
	0	1	2	3	
0	22 (78.57%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)	22 (78.57%)
1	2 (7.14%)	2 (7.14%)*	0 (0.00%)	0 (0.00%)	4 (14.29%)
2	1 (3.57%)	0 (0.00%)	1 (3.57%)*	0 (0.00%)	2 (7.14%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	25 (89.29%)	2 (7.14%)	1 (3.57%)	0 (0.00%)	28** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 25 days or 89.3% of the time (marked gray).
**For 51 days data were not collected by both Observer 3 and Observer 4 during Spring 2006 study period.

VVI - Observer 5 vs. Observer 3.

Observer 3	Observer 5				Total
	0	1	2	3	
0	28 (77.78%)*	1 (2.78%)	0 (0.00%)	0 (0.00%)	29 (80.56%)
1	1 (2.78%)	1 (2.78%)*	3 (8.33%)	0 (0.00%)	5 (13.89%)
2	1 (2.78%)	0 (0.00%)	1 (2.78%)*	0 (0.00%)	2 (5.56%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	30 (83.33%)	2 (5.56%)	4 (11.11%)	0 (0.00%)	36** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 30 days or 83.3% of the time (marked gray).
**For 43 days data were not collected by both Observer 3 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 3.

Observer 3	Average Access				Total
	0	1	2	3	
0	29 (80.56%)*	0 (0.00%)	0 (0.00%)	0 (0.00%)	29 (80.56%)
1	0 (0.00%)	5 (13.89%)*	0 (0.00%)	0 (0.00%)	5 (13.89%)
2	1 (2.78%)	0 (0.00%)	1 (2.78%)*	0 (0.00%)	2 (5.56%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	30 (83.33%)	5 (13.89%)	1 (2.78%)	0 (0.00%)	36** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 35 days or 97.2% of the time (marked gray).
**For 43 days data were not collected by both Observer 3 and Average Access during Spring 2006 study period.

VVI - Observer 5 vs. Observer 4.

Observer 4	Observer 5				Total
	0	1	2	3	
0	32 (72.73%)*	3 (6.82%)	2 (4.55%)	0 (0.00%)	37 (84.09%)
1	0 (0.00%)	2 (4.55%)*	2 (4.55%)	0 (0.00%)	4 (9.09%)
2	1 (2.27%)	0 (0.00%)	1 (2.27%)*	1 (2.27%)	3 (6.82%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	33 (75%)	5 (11.36%)	5 (11.36%)	1 (2.27%)	44** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 35 days or 79.6% of the time (marked gray).
**For 35 days data were not collected by both Observer 4 and Observer 5 during Spring 2006 study period.

VVI - Average Access vs. Observer 4.

Observer 4	Average Access				Total
	0	1	2	3	
0	34 (77.27%)*	3 (6.82%)	0 (0.00%)	0 (0.00%)	37 (84.09%)
1	0 (0.00%)	4 (9.09%)*	0 (0.00%)	0 (0.00%)	4 (9.09%)
2	1 (2.27%)	0 (0.00%)	2 (4.55%)*	0 (0.00%)	3 (6.82%)
3	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)*	0 (0.00%)
Total	35 (79.55%)	7 (15.91%)	2 (4.55%)	0 (0.00%)	44** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 40 days or 90.9% of the time (marked gray).
**For 35 days data were not collected by both Observer 4 and Average Access during Spring 2006 study period.

VVI - Average Access vs. Observer 5.

Observer 5	Average Access				Total
	0	1	2	3	
0	64 (81.01%)*	3 (3.8%)	0 (0.00%)	0 (0.00%)	67 (84.81%)
1	2 (2.53%)	4 (5.06%)*	0 (0.00%)	0 (0.00%)	6 (7.59%)
2	0 (0.00%)	4 (5.06%)	1 (1.27%)*	0 (0.00%)	5 (6.33%)
3	0 (0.00%)	0 (0.00%)	1 (1.27%)	0 (0.00%)*	1 (1.27%)
Total	66 (83.54%)	11 (13.92%)	2 (2.53%)	0 (0.00%)	79** (100%)

* Both observers reported the same value for the VVI (visual Vog Index) for 69 days or 87.3% of the time (marked gray).
**For all the days data were collected by both Observer 5 and Average Access during Spring 2006 study period.

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