Measuring Exposure and Inhaled Dose of PM and Black Carbon among Adolescents Engaged in Physical Activity

By

Gabrielle Fanning-Dowdell

Master of Public Health

Environmental Health

Roby Greenwald, PhD

Committee Chair

Paige Tolbert, PhD

Committee Member

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Gabrielle Fanning-Dowdell

Bachelor of Science: Biology and Society

Cornell University

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Abstract

Athletes who engage in physical activity in areas of high exposure are at increased risk of high doses of ultrafine particulate matter and black carbon due to increases in the rate and depth of ventilation that occur. The objectives of this study were to estimate exposure and inhaled dose of ambient air pollution at two high schools in Atlanta during the hours when students are engaged in physical activity in indoor and outdoor settings and to examine the association between dose and activity level. The two high schools chosen included one in a suburban setting surrounded by forest and the other was in an urban setting located near a major highway and a freight-rail hub.

Data was collected in seven sampling sessions over a period of four months. The estimated dose of inhaled ultrafine particulate matter and black carbon were calculated based on heart rate, spriometric, and air quality measurements taken for each participant during the sampling sessions. ANOVA and Wilcoxon rank sum tests were used to examine how cumulative particle dose varied by study population, location of the physical activity and the sport being played. Linear regression was used to examine the relationship between measured physical activity and cumulative inhaled particle dose.

The cumulative particle dose for athletes practicing indoors was significantly lower than it was for athletes practicing outdoors ($p<0.0001$). There was not a significant difference in cumulative dose between sports that were played in the same environment. There was however a significantly higher inhaled cumulative dose for athletes practicing indoors at the urban school than the suburban school. When controlled for other factors including exposure time, ambient particle concentration and FVC physical activity was found to have a significant effect on cumulative particle dose of 11.55% for each .01 increase in physical activity($p<0.0001$).

Key words: Inhaled particle dose, PM, Physical activity

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Table of Contents

Introduction and Rationale

Air quality in the Atlanta metropolitan region has been an area of concern for residents, since the area is frequently in exceedance of National Ambient Air Quality Standards for $PM_{2.5}$ and O_3 (ARC 2004), (EPA 2008). Athletes who engage in physical activity in areas of high exposure are at increased risk of high doses of air pollutants due to a number of factors (Carlisle and Sharp 2001) . During exercise, larger fractions of air are inhaled through the mouth, bypassing the protective filtration mechanisms of the nasal pathway. The increase in velocity of airflow causes pollutants to be carried deep into the respiratory tract. In addition, the increase in minute ventilation during exercise is associated with increased quantities of pollutants inhaled (Mc Cafferty 1981). Thus it is important to improve understanding of the relationship between dose and activity level in order to identify groups at risk of increased inhaled dose.

Fine Particulate Matter ($PM_{2.5}$) and Ultrafine Particulate Matter

Particulate matter contains a mixture of solid and liquid particles that may be organic or inorganic in nature. Fine particles are defined by their aerodynamic diameter of 2.5 micrometers or less. Fine particulate matter is mainly generated from combustion particles from motor vehicles as well as the burning of coal, fuel, oil, and wood. Particles can also be produced through intermediate reactions of gases in the atmosphere. They primarily consist of metals, hydrocarbons and secondary particles (de Kok et al. 2006). The smallest particles, usually formed by combustion processes and gas-to-particle conversions, are usually complex in composition and generally contain sulfates, nitrates and polar oxidized organics (FinlaysonPitts and Pitts 1997). Because of their small size, these particles are able to travel deep into the respiratory tract and travel into the bloodstream. (WHO 2003)

High exposure to PM has been associated with numerous adverse health effects including premature death in individuals with heart or lung disease, non fatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function and increased irritation of the airways, coughing or shortness of breath (WHO 2003) (Chalupa et al. 2004). Some studies have found ultrafine particle count to be inversely associated with measures of lung function (Penttinen et al. 2001) while others have found no association (de Hartog et al. 2003).

Contributions of high traffic volume

The intensity of traffic is one of the most important determinants of anthropogenic ambient PM concentration. All motor vehicles that operate on fossil fuel combustion emit particulate matter; however diesel engines emit more particles per vehicle kilometer than engines that run on gasoline. Because of the high prevalence of gasoline engines, they may also make up a substantial proportion of the PM emitted during periods of high traffic activity. Most particles emitted by fossil-fuel burning engines are smaller than 2.5 micrometers in diameter, most of the total mass of these particles are smaller than 0.5 micrometers in diameter (USEPA, 1995). The intensity of traffic can also influence the physiochemical characteristics of PM, increasing the concentration of Polycyclic aromatic hydrocarbons (PAH) and their derivatives, metals and capacity to generate free radicals (de Kok et al., 2006). Combustion of fossil fuels leads to the emissions of PAH and their derivatives, in addition automobile catalysts can emit metals into the air (Rauch et al. 2001). The amounts of PAH and metals can play a large role in determining the toxicity of PM (de Kok et al., 2006).

Polycyclic Aromatic Hydrocarbons

PAHs are products of incomplete combustion of organic material. Emission sources include vehicles, domestic heating and industrial processes. PAHs are generated in the gas phase, those that have fewer than four rings may continue to exist in this phase while larger particles may condense upon cooling and adsorb to particles in the ambient air (Baek 1991). PAH from combustion and traffic usually adhere to particles smaller than $PM_{2.5}$ (Pierce 1975). The size distribution of the particles that PAHs adhere to has important implications for determining human exposure, as well as their residence time in the atmosphere (Baek, 1991). PAH that adhere to fine articulate matter can remain in the environment for longer periods of time than those attached to larger particles. Particles within the range of smaller than 2.5 microns are too small to be removed from the environment by simple sedimentation, wet or dry deposition and have the potential to be transported over large distances depending on atmospheric and meteorological conditions (Baek, 1991).

Several PAH found in ambient air, as a result of combustion processes, are known carcinogens. The longer they are persistent in the environment the higher the chance that they can undergo chemical reactions. Several mono-and di-nitro PAH derivatives which are known to be directly mutagenic have been identified in ambient air as well as diesel soot, automobile exhaust and ambient air (DeKok, 2006).

Black Carbon

Aerosol black carbon can be created through combustion of gasoline or diesel fuel. It also makes up a substantial proportion of fine particle mass and can cause visibility impairment in the atmosphere (Miguel et al. 1998). It is easily inhaled and has been associated with adverse health effects, however it is still unknown whether these effects are due to the toxicity of black carbon itself or other pollutants that are associated with it. Black carbon has been associated with asthma, respiratory irritation, low birth weight, heart attacks and lung cancer. (EPA 2012)

Nitrogen Oxides

Nitrogen oxides are another product of combustion emissions. The main source of NO in the air is from motor vehicle emissions. Nitrogen oxides are also a precursor for other secondary air pollutants, which can also cause negative consequences to human health. These include nitric acid, the nitrate of secondary inorganic aerosols and photo oxidants including ozone. (WHO 2003)

Particle Inhalation and Deposition during Exercise

During exercise the volume of air inhaled per breath, as well as the respiratory rate, increase. An increase in the volume of air inhaled will cause an increase in inhaled dose, however an increase in respiration rate may cause a decrease in particle deposition since the air is being circulated through the lungs at a faster rate resulting in a decreased time for diffusional transport. The increase in minute ventilation during exercise may cause particle intake rate to increase by more than six to eightfold. Deposition of these particles has been found to increase with increasing tidal volume and to decrease with increasing flow rates during exercise. Nevertheless the total amount of ultrafine particle deposition was found to increase during exercise by 32% compared to rest (Daigle et al. 2003). The increase in deposition fraction that occurs during exercise may be increased further in adults with asthma (Chalupa et al. 2004).

Differences have been found in ultrafine particle deposition between men and women for 40-60 nm particles while at rest (Jaques and Kim 2000), other studies (Daigle et al. 2003, Chalupa et al. 2004) have found no significant difference. Information about particle deposition in adolescent male and females engaged in physical activity has not been thoroughly studied.

Potential Health Effects

Inhaled $PM_{2.5}$ and ozone exposure have been shown to have detrimental effects on the airways and cardiovascular system. Inhaled $PM_{2.5}$ may contain a variety of chemicals that may be harmful or irritating to the lungs and other tissues once they enter the bloodstream. Physical activity has been shown to increase exposure and inhaled dose due to the increase in depth and frequency of ventilation that takes place during exercise. The increase in inhaled ultrafine and fine PM has been shown to cause a decrease in lung function in adults (Rundell et al. 2008) but has not yet been studied in adolescents.

Methods

Specific Aims

The aims of this study are to measure exposure and inhaled dose of ambient air pollution at two high schools in Atlanta, GA during the hours when students are engaged in outdoor physical activity and to measure the association between inhaled dose and activity level.

Expected Outcomes

Inhaled dose of gas phase and particulate pollutants will be higher in adolescents engaged in higher levels of physical activity than those who are engaged in low levels of physical activity.

Site Selection

Black carbon and PM concentrations were measured at two high schools in the Atlanta area, one is located 400m east of I-75/85 and 200m from a freight rail hub. The other is located in between two state parks and is surrounded by forest. The demographic characteristics of the student body at both schools were similar.

Subject Recruitment

Schools were asked to participate and permission was received from the school principal as well as the coaches. Visits were made prior to the sampling sessions during which students who were interested in participating could learn more about the study and pick up consent forms to review. Consent from a parent or legal guardian was required for students under 18 years of age. Subjects were given $5 as compensation for each day of participation. The study population included males and females ages 14-18. Athletes participating in a variety of sports activities were invited to participate. Both asthmatic and non-asthmatic students were included.

Health and Demographic Questionnaire

A one-page written questionnaire was given to all participants at the time of sampling. From this form domiciliary addresses, asthma status, exposure to tobacco products were obtained. The address of the subjects was used to determine proximity of their home to major pollutant sources. Asthma information obtained included self-report of physician diagnosis, asthma and allergy symptoms, symptom frequency and medications.

Outdoor Sampling

In the fall a one week of outdoor sampling took place at Arabia Mountain High School during which subjects from the football team and color guard participated. In the spring three outdoor sampling sessions took place which included participants from the track team and soccer team.

Indoor Sampling

In the winter there were four sampling sessions with the boys' basketball team and cheerleaders at the urban school and two sampling sessions with the girls' basketball team at the suburban school.

Air Quality Measures

Amounts of O_3 in the air were measured with the Thermo Scientific Model 49i Ozone analyzer, which is a dual-cell, UV photometric gas analyzer that can measure amounts of ozone from concentrations of 0.05 ppb up to 200 ppm. The amounts of nitrogen oxides was measured using the NO-NO_2-NO_x analyzer, Model 42i from Thermo Scientific which uses chemiluminescence technology to measure amounts of nitric oxides from sub ppb levels up to 100ppm.

To measure particle count the TSI Condensation Particle Counter 3007 was used which measures ultrafine particles >1.0µm and a concentration range of 0 to 100,000 particles/cm^3. The TSI P-trak ultrafine particle counter was used to assess ultrafine particle levels larger than 0.02 µm. The MicroAeth (AethLab) was used to measure the mass concentration of black carbon, which analyses air samples in real time.

Health Measures

Pulmonary function tests were performed on each participant before and after engaging in physical activity using the NDD EasyOne spirometer. The FVC test was used to measure the forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), the ratio of FEV_1 to FVC, the peak expiratory flow (PEF) and the forced expiratory flow, 25-75% $FEF_{25\text{-}75}$. The slow vital capacity (SVC) test was used to measure the tidal volume (VT). The flow volume loops and % predicted values from the NDD Easy One spirometer were used to assess the accuracy of the FVC tests. Predicted lung capacity values were given based on NHANES III data. Information regarding gender, race, age, weight and height were entered into the spirometer for the purposes of calculating predicted values. Because height is an important factor in determining predicted lung function, the height was measured once for each participant before being entered into the spirometer.

The exhaled nitric oxide concentrations were measured using the NIOX MINO before and after practice.

Physical Activity Level

The continuous monitoring of heart rate, breathing rate and physical activity during practice were measured using the Zephyr BioHarness, which consists of a chest strap and a physiological monitoring unit which attaches to the chest strap. Activity output was a result of vector magnitude addition, the acceleration vectors were measured in g's and the final output was given in vector magnitude units. Possible values for this measurement ranged from 0 to 1, .2 would be a measurement of walking and .8 a full sprint.

Estimation of Dose

There have been several studies that have created regression equations to predict the minute ventilation based on heart rate, however these equations were found not to be accurate for predicting minute ventilation at the individual level because of variation in this relationship between individuals (James et al. 1993; Samet 1993; Zuurbier et al. 2009). The populations used in these studies were significantly older than our study subjects. Maximal heart rate is found to decrease with age, the equations from these studies did not seem to translate well to our study population of adolescents especially at higher heart rates (Robergs et al. 2002) . These equations yielded minute ventilation and vol/breath estimations that were higher than the measured forced vital capacity. This was an indicator that the calculations were inaccurate since it is not possible for the volume inhaled in a breath to exceed the forced vital capacity since it is a measure of the maximum lung volume that is used for breathing. For this reason an alternative method was developed to estimate the minute ventilation which took more variables related to our study population into account.

The measured tidal volumes from the Slow Vital Capacity tests were difficult to obtain and gave inconsistent results among the same subjects. For this reason a predicted tidal volume was calculated based on predicted body weight. The predicted body weight was calculated by using the ARDSNET formulas;

Males: PBW(kg)= 50+0.91 x (height(cm)-152.4)

Females: PBW(kg)=45.5 x

(Fernandez-Bustamante et al. 2011)

A tidal volume of 7mL/kg predicted body weight was then assumed. The maximum heart rate was then calculated based on age using the following equation;

$$HR_{Max}=205.8-0.685(age)$$

(Robergs 2002)

The resting heart rate was estimated by taking the 1st percentile of the individual heart rate for each individual subject on that practice session. Typically the bio harness was worn during periods of rest as well as periods of rigorous physical activity. In some cases the calculated HR_{Max} was exceeded during practice. In this situation the highest HR was used in place of the calculated HR_{Max}.

The fraction of the HR_{Max} at each time point was then calculated after subtracting the resting heart rate from both HR_{Max} and the average heart rate at each minute during practice. FEV_1 was used rather than FVC because it is found to correlate closely to the maximum voluntary ventilation and is often used to predict this value (Kift and Williams 2008). Assuming a linear relationship between the predicted tidal volume and the measured FEV1, the volume of air inhaled per breath was then interpolated using the fraction of the maximum heart rate at each time point where at HRmax, each breath has a volume of FEV1 and at HR resting, volume of each breath is equal to the tidal volume. The minute ventilation was calculated using the breathing rate over 1 minute time averages and the one minute averages of the volume of air inhaled per breath. The minute ventilation was then used along with the air quality measurements to estimate the doses of ultrafine particles larger than 10 and 20 microns and ng of black carbon inhaled per minute.

Statistical Analysis

Data was organized for each participant using Microsoft Excel and imported into SAS for statistical analysis. Each subject was assigned a unique ID for each day that they participated in the study. Data from the questionnaires, BioHarness and spirometers were pooled based on the unique ID number. Variables included were allergy diagnosis, asthma diagnosis, weight, height, gender, smoking of tobacco products, presence of tobacco smoke inside the home, diagnosis of asthma with current asthma, diagnosis of asthma without current asthma, taking medication for asthma symptoms and one minute time averages of activity. An FVC variable was also included; this value was an average of FVC tests from all accurate tests conducted for the given participant. Variables regarding air quality included one minute time averages of ultrafine particle concentration >10nm measured in particles/cm^3, one minute time averages of ultrafine particle concentration >20nm measured in particles/cm^3 and one minute time averages of black carbon concentration measured in ng/m^3. The estimated inhaled dose for these three parameters was used to calculate a cumulative dose estimate for each unique ID which was used for model building and comparisons. An exposure time variable was also calculated as the time elapsed from the starting time of heart rate monitoring data to the ending time. In some cases the air quality monitoring equipment was ended before the heart monitoring ending time. In these cases the time points following the ending of the air quality measurements were not included. Cumulative dose was calculated based on the sum of the particle counts or weights during the exposure time period for each participant.

Data for each individual was merged for analysis using SAS 9.3. In order to examine the variables and get frequency counts participants with multiple IDs for different sessions were counted once.

In order to examine the differences in mean cumulative dose across groups Wilcoxon rank sum tests were used, and analysis of variance was used to compare across groups with more than two categories. A p value of <0.05 was considered significant. In order to assess the strength of the effect of physical activity as a predictor of cumulative inhaled particle dose, while other factors are held constant, an associative model was constructed using linear regression. Variance inflation factors were examined to assess multicoliniarity; a cut off of 10 was used. An α value of 0.10 was used. Cook's distance and jackknife residuals were used to identify outliers in the data. The variables included in the analysis were an average of the activity measured during the practice session for each individual, the average FVC for each individual, the exposure time and the exposure concentration. The exposure time was the total time elapsed from the beginning of heart rate measures to the time that the heart rate measures ended or the air quality sampling was ended. The exposure concentration was the median particle count >10nm measured during the sampling session measured in particles/cm^3. FVC was used to indirectly control for gender and age since both influence lung size and capacity. Using these variables the following associative model was generated where x_1=Average activity, x_2=FVC, x_3=Exposure time and x_4=Median ambient particle concentration

In order to find the effect of each variable on the cumulative dose the formula

$$(e^{\beta}-1)x100$$

was used to back calculate from the log transformation of the outcome variable.

Results

Study Population Characteristics

The characteristics of the study population are summarized in Table 1. The study population included ten participants from the suburban school and fifty three participants from the urban school yielding 63 person-days. However since some people came on multiple days the number different participants was 46. Twenty seven of the participants were male and nineteen were female. Forty four (19.44%) of the participants were African American and two (4.44%) were Hispanic. None of the respondents reported the use of tobacco products, eleven (29.41%) reported that someone in their home uses tobacco products and 16 did not respond to this question.

Twenty three of the participants reported never having been diagnosed with asthma; six reported having been diagnosed with asthma as a child but no longer had asthma or did not know if they still had asthma. Seven of the respondents reported that they currently had asthma. Four of the respondents reported using asthma medication to relieve their symptoms within the last 6 months. Nine of the respondents did not answer these questions.

Thirty four (75.56%) of the athletes were sampled while engaging in physical activity indoors and eleven (32.25%) were sampled while practicing outdoors. Twenty eight (60.8%) of the athletes were assessed while playing basketball, seven (15.22%) while cheerleading, six (13.04%) while running track, three (6.53%) while practicing for field events and two (4.35%) while playing soccer.

Sampling Sessions

During the first sampling session at the urban site there were four participants from the boys' basketball team who were practicing indoors. The air was sampled from 3:24pm until 5:53pm. The second session took place at the same site indoors the following day from 3:05pm until 7:58pm. This session included six male basketball players and four female cheerleaders. The third sampling session took place at the same site the following day indoors from 3:28pm until 7:42pm. This session included nine participants from the boys' basketball team. The fourth sampling session took place the following day at the same site and included seven participants from the boys' basketball team and six girls from the cheerleading squad.

At the suburban site there were two indoor sampling sessions. The first one took place from 4:50pm to 6:26pm and there were six participants from the girls' basketball team. On the second day there were four participants from the girls' basketball team included in the analysis. This session lasted from 3:53pm to 4:45pm.

There were three outdoor sampling sessions that took place at the urban school site. The first began at 3:21pm and ended at 4:45pm. On this day only one of the participants was practicing outside and was a male from the track team. On the second sampling session at this site there were 3 male participants from the track team; 4 participants practicing field events and two male soccer players. Their practices took place between 3:12 and 6:15 pm. The third session took place from 3:04 to 6:09 pm, seven participants total were included in the analysis. All seven were male, there were three from the track team and four practicing field events.

Air Quality

The air quality summary statistics are listed in Table 3. When examining ultrafine particles larger than 10nm during the first four indoor sampling sessions at the urban school, Session 1 had the highest mean average particle count of 7,099.616 particles/cm^3 (SD=1,110.85). The ultrafine particle count larger than 20nm was highest on this day as well with an average of 7,265 (SD=1,621.250) over the entire sampling session.

During the indoor sampling session at the suburban schools the day with the highest count of ultrafine particles larger than 10 nm was session 5 when the count was

2.938.987(SD=1,197.683) over the entire session. The maximum count that day was 5,134 particles/cm^3. The count ultrafine particles larger than 20nm was also higher on the first day of sampling at the suburban site than the second day at the same site, however the black carbon count was highest on the second day of sampling at that site with a mean weight of 437.746 ng/m^3 of air (SD=68.698) and a maximum measurement of 575 ng/m^3.

During the three days of outdoor sampling at the urban site the highest ultrafine particle counts for particles over 10nm was during session 8. On this day there was an average count of 22,993.995 (SD=2,017.760). The black carbon measurements were highest on the last day of sampling with an average concentration of 2,993.446 ng/m^3 (SD= 7,764.659) and a maximum of 43,992 ng/m^3.

Trends in Cumulative Inhaled Particle Dose

The results from the comparisons are summarized in table 4. The mean estimated cumulative dose of ultrafine particles larger than 10nm was found to be significantly higher in males than it was in females ($p<0.0001$). There was also a significant difference in the mean estimated cumulative dose for participants who were practicing indoors at the urban site than those who were practicing indoors at the suburban site ($p<0.0001$). There was also a significant difference between those who were practicing indoors and those who were practicing outdoors ($p<0.0001$).

There were also significant differences in cumulative dose based on activity type. There was not a significant difference between basketball and cheerleading both of which took place indoors ($p=.9235$). But there were significant differences between basketball and the outdoor sports; track ($p<0.001$), soccer (0.003) and field events ($p=0.001$). Differences in estimated inhaled cumulative dose did not differ significantly across outdoor sports.

Relationship between Activity and Inhaled Particle Dose

A simple linear regression model was built to assess the strength of the different variables as predictors of cumulative inhaled particle dose. Because the cumulative particle dose in this population was right skewed, a log transformation was performed so that the outcome would be continuous. The final model included Activity, exposure time, particle concentration and FVC. This model had an R^2 value of .843 and a root mean square error of 0.375.

$$\text{Log}(\hat{Y})=20.387+2.538(x_1)+0.137(x_2)+0.015(x_3)+0.0001(x_4)$$

Where x_1=Average activity, x_2=FVC, x_3=Exposure time and x_4=Median particle concentration

Activity was found to be the strongest predictor with a β value of 2.538 ($p<0.0001$) meaning that by practicing outside there is a 153% increase in the log estimation of cumulative inhaled ultrafine particle dose or that there is a 11.55% increase in cumulative inhaled particle dose with each unit of .01 increase in activity when controlling for FVC, time exposed, ambient concentration. FVC was estimated to predict an increase of 13.7% in log cumulative inhaled particle dose and a 14.6% increase in particle dose for each unit increase in FVC when controlling for all other variables in the model ($p=0.1007$) . Exposure time was found to predict an increase of 1.5% in log cumulative inhaled particle dose and a 1.5% increase in estimated cumulative particle dose for each minute increase in exposure time when all other variables were held constant ($p<0.0001$). Median particle concentration was also found to have a significant effect ($p<0.0001$). It is estimated to cause a 0.01% increase in log cumulative inhaled particle dose and a 0.01% increase in cumulative inhaled particle dose.

Discussion

Relationship between Physical Activity and Inhaled Particle Dose

Influential factors in determining the cumulative dose that were not included in the estimation calculation are gender, indoor or outdoor location, age and exposure time. Average activity was found to have a significant effect on cumulative inhaled particle dose of 11.55% for each .01 increase in physical activity, even when controlling for ambient concentration, exposure time, and FVC, meaning that the difference between a walk, 0.2 and a sprint or high exertion at 0.8 there would be nearly a seven-fold increase in estimated inhaled particle dose for the same person exposed to the same concentration. This trend is consistent with results from previous studies showing an increase in deposition fraction in controlled settings (Chalupa et al. 2004; Daigle et al. 2003). The inhaled particle dose has a number of other influencing factors, including the ambient concentration of the pollutant, breathing rate and breath volume.

The ambient concentrations of ultrafine particulate matter and black carbon were found to be significantly higher in outdoor settings than indoor settings, thus the average inhaled particle dose was significantly higher when athletes were exercising outdoors than it was when they were practicing indoors. It is not yet known how ambient concentrations differ between the urban and suburban school environments outdoors. Beyond ambient concentration the inhaled particle dose depends upon the volume of air inhaled with each breath and the breathing rate over the period of exposure. The estimated volume of air inhaled increases as a function of the heart rate increasing with increasing physical activity over time. Physical activity modifies this relationship as it causes an increase in both the breathing rate and the volume inhaled per breath as compared with breathing rate and volume inhaled at rest. An increase in physical activity therefore is concurrent with increases in inhaled dose.

Cumulative Inhaled Dose

Asthma was not found to have a significant effect on the cumulative dose. This is consistent with findings from a study involving adults (mean age 23 ± 2.7) in which deposition fraction of ultrafine particulate matter was similar between healthy and asthmatic individuals during exercise although a difference was seen at rest. Deposition fraction is often used as an indicator of cumulative dose of inhaled particles (Cheng and Swift 1995). The deposition fraction is dependent upon the amount of air coming into the lungs as well as the pulmonary response to the air and its contents. However, the calculations done for the cumulative dose estimation did not take into account differences that may occur due to nasal or oral breath or asthma status. The inhaled dose therefore does not directly translate into the count of particles deposited in the lungs.

Among sports that were played inside there was no significant difference in cumulative particle dose. Similarly among sports that were played outside there was not a significant difference but there was a significant difference in estimated particle dose between indoor and outdoor sports.

It was found that adolescents who practiced outdoors had a higher cumulative dose than those who practiced indoors. In the future it would be interesting to examine the difference in air quality and inhaled particle dose between the urban sites. One limitation of this study is that only outdoor data from the urban site was included in the analysis. The location of the school may also be a determining factor in cumulative dose estimation through the influence on ambient particle concentration. Indoors there was a significant difference in cumulative particle dose between the urban and suburban schools, which may indicate that there would be a difference outdoors as well. However, this difference may also depend on the location of the gymnasium to other pollution sources in the school, the ventilation systems and other factors.

Limitations

The estimation of lung volume used per breath involved a series of assumptions. The first was the prediction of predicted body weight based on height and gender. Often times the predicted body weight was higher than the reported body weight. This would result in larger tidal volume estimation per kg of body weight than would have been estimated had the reported body weight been used. Subsequently this may result in a high dose estimate. However the predicted body weight was used because lung size is more dependent upon height than body weight (Fernandez-Bustamante et al. 2011). A second assumption that tidal volume would be 0.07L for each kg of predicted body weight was made. This was based on values for adults. The tidal volume that is generally applied in intraoperative ventilator set up is often 10 mL/kg predicted body weight. In the literature values for predicting tidal volume for adults have ranged from 6 mL/ kg for people with acute lung injury to up to as high as 12 mL/kg (Gajic 2004). One study (Fernandez-Bustamante et al.

2011) found exhaled V_T measurements to be 8.7 ± 1.6 mL/kg predicted body weight. Because our sample consists of adolescents whose lungs have not fully developed the lower end of this range was used for the V_T predictions. However the true V_T may differ significantly from this estimate depending on physical maturity and variation between individuals. Assumptions were also involved in the estimations of the maximum and minimum heart rates that may also introduce error into our estimates. Maximum HR was based on an equation from (Robergs 2002) which was estimated to have an error of 3 beats/min. The estimation of resting heart rate may not be accurate depending on the amount of time the participants were at rest while the bio harness was strapped on. In many instances the participants were not given their bio harness until after they completed the pre-practice health measurements and went straight to practice after the harness was put on. If they took the heart monitor off before their heart rate came back down to resting there may have been over estimates of resting heart rate. The final and biggest assumption made was that there is a liner association between V_T and FEV_1 and that the volume of air inhaled could be interpolated from the % maximum heart rate. The true relationship may not be linear or exponential in shape. This assumption may result in over or underestimates of volume per breath for individuals at any time point. The method did give feasible estimates that were within the limits of the FVC and V_T. This method for estimation could be validated with stress tests in which heart rate and minute ventilation are measured. Without this validation step it is difficult to interpret the accuracy of the estimated dose calculations and the validity of these findings. If shown to be valid this method of dose estimation may be useful for studies of dose as a result of ambient exposure and their changes through time.

Conclusions

It can be concluded that increase in physical activity is associated with an increase in cumulative particle dose. This has important public health implications as physical activity may subject individuals to increased doses if practicing during times of high ambient pollution concentrations. As concentrations are significantly lower inside it may be advisable to exercise indoors when ambient concentrations are high in order to reduce exposure and reduce risk of negative health effects that occur as a result of exposure and inhalation of pollutants.

References

Adams WC. 2000. Ozone dose-response effects of varied equivalent minute ventilation rates. Journal of exposure analysis and environmental epidemiology 10:217-226.

ARC. 2004. Rdp technical report-2004 update.3-22.

Baek SO, Goldstone, M. E., Kirk, P.W.W., Perry, R. 1991. Phase distribution and particle size dependency of polycyclic ariomatic hydrocarbons in the urban atmosphere. Chemosphere 22:18.

Carlisle AJ, Sharp NC. 2001. Exercise and outdoor ambient air pollution. British journal of sports medicine 35:214-222.

Chalupa DC, Morrow PE, Oberdorster G, Utell MJ, Frampton MW. 2004. Ultrafine particle deposition in subjects with asthma. Environmental health perspectives 112:879-882.

Cheng KH, Swift DL. 1995. Calculation of total deposition fraction of ultrafine aerosols in human extrathoracic and intrathoracic regions. Aerosol Sci Tech 22:194-201.

Daigle CC, Chalupa DC, Gibb FR, Morrow PE, Oberdorster G, Utell MJ, et al. 2003. Ultrafine particle deposition in humans during rest and exercise. Inhalation toxicology 15:539-552.

de Hartog JJ, Hoek G, Peters A, Timonen KL, Ibald-Mulli A, Brunekreef B, et al. 2003. Effects of fine and ultrafine particles on cardiorespiratory symptoms in elderly subjects with coronary heart disease: The ultra study. American journal of epidemiology 157:613-623.

de Kok TM, Driece HA, Hogervorst JG, Briede JJ. 2006. Toxicological assessment of ambient and traffic-related particulate matter: A review of recent studies. Mutation research 613:103-122.

EPA. 1995. Compilation of Air Pollutant Emission Factors. USEPA Report AP-42, US Environmental Protection Agency, Washington DC.

EPA . 2008. Us epa determination of nonattainment and reclassification of the atlanta, georgia 8-hour ozone nonattainment area. 73 FR 12013.Retrieved from http://www.epa.gov/region4/air/sips/OCE/Atlanta%20Reclassification.pdf

EPA . 2012. Black carbon health effects.Retrieved from http://www.epa.gov/airscience/air-blackcarbon.htm

Fernandez-Bustamante A, Wood CL, Tran ZV, Moine P. 2011. Intraoperative ventilation: Incidence and risk factors for receiving large tidal volumes during general anesthesia. Bmc Anesthesiol 11.

FinlaysonPitts BJ, Pitts JN. 1997. Tropospheric air pollution: Ozone, airborne toxics, polycyclic aromatic hydrocarbons, and particles. Science 276:1045-1052.

Gajic O, Dara, S.I. Mendez, J.L., Adesanya, A.O., Festic, E., Caples, S.M, Rana, R., St Sauver, J.L., Lymp, J.F., Afessa, B., Hubmayr, R.D. . 2004. Ventilator-associated lung injury in patients without acute lung injury at the onset of mechanical ventilation. Critical Care Medicine 32:1817-1824.

James DS, Roe R, Browning K, Stidley C, Chick TW, Samet JM. 1993. Estimates of ventilation from heart-rate in working copper miners. American Review of Respiratory Disease 147:A903-A903.

Jaques PA, Kim CS. 2000. Measurement of total lung deposition of inhaled ultrafine particles in healthy men and women. Inhalation toxicology 12:715-731.

Kift J, Williams E. 2008. Ventilatory capacity and its utilisation during exercise. Lung 186:345-350.

Miguel AH, Kirchstetter TW, Harley RA, Hering SV. 1998. On-road emissions of particulate polycyclic aromatic hydrocarbons and black carbon from gasoline and diesel vehicles. Environmental science & technology 32:450-455.

Penttinen P, Timonen KL, Tiittanen P, Mirme A, Ruuskanen J, Pekkanen J. 2001. Number concentration and size of particles in urban air: Effects on spirometric lung function in adult asthmatic subjects. Environmental health perspectives 109:319-323.

Pierce RC, Katz, M. . 1975. Dependency of polynuclear aromatic hydrocarbon content on size distribution of atmoshperic aerosols. Envrionmental Science & Technology 9:7.

Rauch S, Lu M, Morrison GM. 2001. Heterogeneity of platinum group metals in airborne particles. Environmental science & technology 35:595-599.

Robergs RA, Landwehr, R. . 2002. The suprising history of the "hrmax=220-age" equation. Journal of Exercise Physiology 5:10.

Rundell KW, Slee JB, Caviston R, Hollenbach AM. 2008. Decreased lung function after inhalation of ultrafine and fine particulate matter during exercise is related to decreased total nitrate in exhaled breath condensate. Inhalation toxicology 20:1-9.

Samet JM, Lambert, W.E., Mermier, C.M., Chick, T.W. 1993. Assessment of heart rate as a predictor of ventilation. Research Report Health Effects Institute:19-55.

WHO. 2003. Health aspects of air pollution with parrticulate matter, ozone and nitrogen dioxide.

Zuurbier M, Hoek G, van den Hazel P, Brunekreef B. 2009. Minute ventilation of cyclists, car and bus passengers: An experimental study. Environmental health : a global access science source 8:48.

Appendix

Table 1: Study Population Summary Statistics

	n	Percent
Male	27	58.7%
Female	19	41.3%
Black	44	95.56%
Hispanic	2	4.44%
Smoker**	0	0%
Someone in household smokes**	11	29.41%
Currently has asthma	7	19.44%
Diagnosed with asthma as a child	6	16.67%
Never diagnosed with asthma	23	63.89%
Takes medication for asthma	4	11.11%
Practiced Indoors	34	75.56%
Practiced Outdoors	11	32.35%
Basketball	28	60.87%
Cheerleading	7	15.22%
Track	6	13.04%%
Field Events	3	6.52%
Soccer	2	4.35%

Table 2: Air Quality Summary Statistics

	UFP >10nm (#/cm^3)			UFP >20nm (#/cm^3)			Black Carbon (ng/m^3)		
	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max
Session 1	7,099.616 (1,110.850)	4,637.58	9,578.420	7265.070 (1621.250)	4,010.330	9,956.330	NA	NA	NA
Session 2	6,092.203 (1,235.915)	4,637.58	12,570.000	5253.027 (1104.132)	4010.333	11,500.00	NA	NA	NA
Session 3	5,240.830 (678.951)	.750	6,344.483	5,373.457 (749.324)	0.753	6,733.000	NA	NA	NA
Session 4	4,897.394 (378.345)	4,538.390	13,733.600	5,774.007 (505.824)	4,538.230	6334.167	NA	NA	NA
Session 5	2,938.987 (1,197.683)	1,351.780	5,134.900	3,727.103 (1,468.819)	1,655.500	6,540.333	234.549 (111.055)	7	574
Session 6	1,814.516 (218.937)	1,555.750	2,494.780	2,303.598 (296.673)	1,971.667	3,344.000	437.746 (68.698)	268	575
Session 7	7,408.104 (2,461.158)	2,551.270	16,142.430	NA	NA	NA	2,993.446 (7,764.659)	116	43,992
Session 8	22,993.995 (2,017.760)	18,857.000	28,904.100	NA	NA	NA	2,024.279 (4,805.653)	16	38,224
Session 9	19,343.686 (2,482.690)	14,335.600	25,324.500	NA	NA	NA	708.441 (483.961)	31	3,018

Table 3: Sampling Sessions

	Site	Setting	Time of Day	Activities	N
Session 1	Urban	Indoor	3:24pm-5:35 pm	Boys Basketball	4
Session 2	Urban	Indoor	3:05pm-7:58pm	Boys Basketball Cheerleading	6 4
Session 3	Urban	Indoor	3:28pm-7:42 pm	Boys Basketball	9
Session 4	Urban	Indoor	3:21pm-6:48pm	Boys Basketball Cheerleading	7 6
Session 5	Suburban	Indoor	4:05pm-6:26pm	Girls Basketball	6
Session 6	Suburban	Indoor	3:53pm-4:45pm	Girls Basketball	4
Session 7	Urban	Outdoor	3:21pm-6:15pm	Boys Track	1
Session 8	Urban	Outdoor	3:12pm-6:15pm	Boys Track Boys Field Events Boys Soccer	3 4 2
Session 9	Urban	Outdoor	3:04pm-6:09pm	Boys Track Boys Field Events	3 4

Table 4: Comparisons of Cumulative Dose Across Groups

Characteristic	Level	Log UFP Cumulative Dose Mean (95% CI)	UFP Cumulative Dose Geometric Mean (95%CI)	P Value
Gender	Male	24.438(24.216-24.659)	$4.103x10^{10}$ ($3.288x10^{10}$-$5.120x10^{10}$)	<0.0001
	Female	23.134(22.841-23.426)	$1.114x10^{10}$($8.312x10^{-9}$ -$1.49x10^{9}$)	
Site	Urban	24.262(24.053-24.471)	$3.442x10^{10}$($2.793x10^{10}$-$4.242x10^{10}$)	<0.0001
	Suburban	22.744(22.317-23.170)	$7.544x10^{9}$($4.9x10^{9}$-$1.155x10^{10}$)	
Activity Type	Basketball	23.658(23.448-23.868)	$1.88x10^{10}$($1.525x10^{10}$-$2.321x10^{10}$	
	-track			<0.0001
	-soccer			0.0030
	-cheerleading			.9235
	-field events			0.0001
	Track	25.140(24.835-25.445)	$8.283x10^{10}$($6.216x10^{10}$-$1.124x10^{10}$)	
	-Soccer			0.918
	-Cheerleading			<0.001
	-Field Events			0.976
	Soccer	24.328(24.721-25.935)	$3.611x10^{10}$($5.447x10^{10}$-$1.834x10^{11}$)	
	-Cheerleading			<0.0001
	-Field Events			
	Cheerleading	23.481(23.169-23.793)	$1.576x10^{10}$($1.154x10^{10}$-$2.154x10^{10}$	<0.0001
	Field Events	25.054(24.660-25.449)	$7.600x10^{10}$($5.125x10^{10}$-$8.619x10^{9}$)	
Setting	Outdoor	25.137(24.900-25.374)	$8.258x10^{10}$($6.515x10^{10}$-$1.0466x10^{11}$)	<0.0001
	Indoor	23.628(23.424-25.374)	$1.826x10^{10}$($1.489x10^{10}$-$1.04x10^{11}$)	
Indoor	Suburban	22.744(22.317-23.170)	$7.544x10^{9}$($4.922x10^{9}$-$1.155x10^{10}$)	<0.0001
	Urban	24.262(24.053-24.471)	$3.442x10^{10}$($2.791x10^{10}$-$4.242x10^{10}$)	

Table 5: Linear Regression Results

Effect	Estimates	Standard Error	Wald 95% CL	Wald Chi Square	P value
Intercept	20.387	0.4810	19.483,21.291	1953.460	<0.0001
Average Activity	2.5380	0.8590	0.855, 4.221	8.740	0.0031
FVC	0.1370	0.0840	-0.027,0.301	2.700	0.1007
Exposure Time	0.0150	0.0020	0.0116,0.0182	77.040	<0.0001
Median Particle concentration	0.0001	0.0001	0.0001,0.0001	200.720	<0.0001

Figure 1: Variation in Estimated Particle Dose over Time