Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature:

_____Shiwei Gao_____ _____April 13th, 2015_____

Name Date

Assessing the Health Effects of Air Pollution on High School Athletes

By

Shiwei Gao

Master of Public Health

Department of Environmental Health

Dana Boyd Barr, PhD

Committee Chair

Roby Greenwald, PhD

Committee Member

Paige Tolbert, PhD

Committee Member

Assessing the Health Effects of Air Pollution on High School Athletes

By

Shiwei Gao

B.S.

Wuhan University

2013

Thesis Committee Chair: Dana Boyd Barr, Ph.D.

An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of
Master of Public Health
in Environmental Health

2015

Abstract

Assessing the Health Effects of Air Pollution on High School Athletes

By Shiwei Gao

Objective

The study aimed to investigate the effect of five air pollutants-ozone, PM2.5, black carbon, particles, and polycyclic aromatic hydrocarbon, on oxidative stress of high school athletes before and after physical activity and training.

Methods

125 high school athletes from two high schools in Atlanta metropolitan area were included, and exhale breath condensate samples were collected before and after physical activity. Air pollutants concentrations were measured on site or collected from ground monitoring database during the training. The percentage concentration of oxidized glutathione (GSSG) in the glutathione (GSH)/oxidized glutathione (GSSG) pair in the breath condensate samples before and after training was measured using HPLC. Linear mixed model is used to assess the association between air pollutant exposure and changes in glutathione biomarker.

Results

In the linear mixed model, ozone exposure is significantly associated with the difference in percentage change of GSSG (P-value = 0.023). Four other pollutants did not significantly affect the percentage change of GSSG (P-value > 0.05). Age was also identified as a factor associated with GSSG level.

Conclusion

Ozone exposure has a significant effect on oxidative stress during physical activity. Lowering the pollutant exposure, such as conduct indoor exercise instead of outdoor exercise, would help protect young athletes from ozone.

Assessing the Health Effects of Air Pollution on High School Athletes

By

Shiwei Gao

B.S.

Wuhan University

2013

Thesis Committee Chair: Dana Boyd Barr, PhD

A thesis submitted to the Faculty of the

Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of
Master of Public Health
in Environmental Health

2015

Acknowledgements

Foremost, I would like to express my sincere gratitude to my field advisor Dr. Roby Greenwald for providing me with all necessary facilities and guidance for the research. His guidance helped me in all the time of research and writing of this thesis.

Besides, I would also like to thank my thesis advisor Dr. Dana B. Barr for her continuous support and encouragement, for her motivation, enthusiasm, and patience.

My sincere thanks also goes to Dr. Lou Ann Brown and Janine Ward from the Department of Pediatrics in the School of Medicine of Emory University for providing me the data and relevant information to complete the thesis.

Last but not least, I would like to thank my fellow classmates, Department faculty members, and anyone who directly or indirectly have lent their hand along the way.

Table of contents

Introduction

Ozone is a major component of photochemical smog. The high oxidizing potential of ozone can irritate the airway causing coughing, a burning sensation, wheezing and shortness of breath. Long-term exposure to ozone has been shown to increase the risk of respiratory illness. [1] A study covered 448,850 subjects in 96 metropolitan areas over an 18-year follow-up period has shown the correlation between long-term ozone exposure and respiratory illness.

Particulate matters with a diameter less than 2.5 μm are identified as fine particles and are named $PM_{2.5}$. $PM_{2.5}$ concentration has been linked with respiratory and cardiovascular morbidity and mortality. [2] Fine particle pollution is made up of a number of components, including organic chemicals, metals, dust particles, and acids.

Black carbon (BC), or elemental carbon (EC), is a $PM_{2.5}$ species in nano-size fractions (<56 nm; 56-100 nm; and 100-180 nm). [3] It is a solid, light-absorbing, graphitic carbonaceous material that generated from diesel emission. [4] As a $PM_{2.5}$ and also a carcinogen, BC is causally involved in lung cancer, cardiovascular mortality, adverse birth outcomes, and central nervous system effects. A study in 2011 by EU researchers indicated that life expectancy could be extended four to nine times by reducing one unit of BC, versus reducing one unit of $PM_{2.5}$. [5]

Polycyclic aromatic hydrocarbons (PAH), also called polyaromatic hydrocarbons, are a group of organic compounds contain only carbon and hydrogen, and multiple aromatic rings. PAHs are produced as a result of incomplete combustion of fossil fuels, like oil and coal. Because of the carcinogenicity and active role in photochemical transformations, PAHs are of increasing concern in health risk assessment as well as air pollution. [6]

One product of the metabolism of these pollutants is reactive oxygen species (ROS), which plays an important role in cell signaling and homeostasis. Excess amount of ROS will break the balance and calls in need of more antioxidants, such as glutathione, to defend the damage on cells.

Glutathione (GSH) reduces disulfide bonds formed within cytoplasmic proteins and transformed to glutathione disulfide (GSSG) by donating the hydrogen ion and electron in the sulfhydryl bond to ROS such as hydroxyl radical. The hydroxyl radical will be reduced to water, two oxidized GSH will form a disulfide bond. By doing that, glutathione helps maintaining the oxidizing potential in the body. In healthy cells and tissue, GSSG is reduces back to GSH quickly and thus, the GSH: GSSG ratio remains generally constant. An increase in the relative amount of GSSG suggests than the airways are exposed to more oxidants than the amount they can enzymatically reduce. Therefore, the redox potential of GSH/GSSG couple is considered an indicator for oxidative stress, which causes symptoms and adverse health effects described above.

Inhalation of multiple air pollutants imposes special risks for athletes. [7] One of the reasons is the proportionate increase in the quantity of ozone inhaled with increases in minute ventilation during exercise. Besides, the increased airflow velocity carries ozone deeper into the respiratory tract. Furthermore, a considerable amount of air is inhaled through the mouth during exercise, bypassing the nasal mechanisms for the filtration of large particles and soluble vapors. Multiple studies have also shown the positive correlation between exercise and pulmonary diffusion capacity, suggesting that the diffusion of ozone increases with exercise. [8-10]

However, other evidence indicates that aerobic exercise protects against [11] or has no effect [12] on oxidative stress produced by ozone.

The study thus focuses on the effects of pollutants exposure on athletes when physical activity is involved while controlling for demographic variance, type and duration of exercise, etc. It will help understand how oxidative stress change before and after physical activity due to the exposure of different chemicals.

Methods

Study design

We selected two high schools in Atlanta based on their location and potentially different exposure level. These high two schools, one located in central Atlanta and one in rural area downwind from downtown, represented different types of ground level air pollutant exposure. 84 male student athletes (67.2%) and 41 female student athletes (32.8%) with an average age of 16.4 participated in the study under the consent of their guardians. Samples were collected over five time periods between 2012 and 2014 (December in 2012, March, April, August, September, and December in 2013, April to July in 2014). During each period, exhaled breath condensate samples before and after one session of physical activity (average duration, 134 minutes) were collected from each subject.

Ambient and indoor air pollutants measurement

One minute average concentration of black carbon, particle number, and PAHs was measure at the school sports field during each sports training session. Ambient ozone concentration were made available by a nearby EPA ground monitoring site. Since ozone concentration was much lower in indoor environment and athletes were trained in stadiums instead of outdoor field during the winter, indoor ozone concentration is measured separately for winter physical activity. Previous studies revealed the short-term associations between ambient air pollutants and pediatric asthma emergency department visits and hospital admissions. [13, 14] Thus, we also collected the average daily ozone concentration one to three days before the subjects conducted a training session or exercise. The volume concentration of PM2.5 was also measured and had been converted to mass concentration for analytical purposes through multiplication of synthetic density. Average concentration of each chemical were calculated from the one minute average data and were combined with the subject-specific exposure duration to generate subject-specific exposure level.

Exposure = Concentration * Duration

GSH and GSSG measurements

Glutathione in the reduced and oxidized forms were measured using High Performance Liquid Chromatography (HPLC) at the Pediatrics Department at Emory University. HPLC with fluorescence detection of dansyl derivatives is used for quantification of GSH and GSSG. The dansylated derivatives were separated on an Ultrasil amino column by normal phase gradient chromatography. The mobile solvent was 80% HPLC grade methanol in water and the salt solvent was 0.8 M sodium acetate in acetic acid and methanol. [15] The aqueous layer of the derivatized sample was injected. The concentration of the respective derivatives was calculated in reference to the area of the internal standard. GSH and GSSG standards were prepared from a range of 1-2000 nM. GSH standards were treated with 10mM dithiothreitol to reduce reversible disulfide formation. A standard curve was created from integrated area of peaks for this concentration range. Control EBC samples were spiked with varying amounts of GSH and GSSG in the nanomolar range to determine potential shifts in retention time or peak area in the EBC.

Statistical analysis

Percentage of GSSG in the GSH/GSSG environment before and after physical activity were derived from the amount of GSSG and GSH measured by HPLC analytical tools and were log-transformed. The change in the log percentages for each subject after daily exercise was calculated. The outcome would be measure by the difference between the natural logarithm of GSSG percentage before practice to the GSSG percentage after practice.

The exposure-response relationship between biomarker levels and air pollution exposure was investigated through linear mixed model. Mixed models were used since there are numerous repeated measures for many of the subjects. Linear mixed models were built for each of the pollutants with demographic variables as covariates and change in percentages as the dependent variable. F-test, and type 3 Chi-sq tests were conducted for each fixed effect parameter estimates.

The random effect in the study is the variation within individual (identified by their ID) which constitutes the intercept of the regression model. All association are presented as an interquartile range (IQR) increase in pollutant exposures.

Between-pollutant confounding was tested using multi-pollutant model. The estimates from single- and multi- pollutant models were compared. Other potentially confounding was evaluated by adding interaction terms to the regression model.

All calculation were performed using the Microsoft Excel 2013 package and SAS 9.4.

Table 1. Descriptions (mean, standard deviation, maximum, minimum, interquartile range) of air pollutants concentrations.

	Mean ± SD		Maximum		Minimum		IQR	
	Female	Male	Female	Male	Female	Male	Female	Male
Ozone, ppb	35.1 ± 25.2	36.7 ± 21.4	77.0	77.0	6.4	6.3	47.4	42.2
BC, µg*m-3	0.5 ± 0.4	0.6 ± 0.4	1.8	1.8	0.2	0.0	0.2	0.4
$PM_{2.5}$, µg*m-3	12.9 ± 5.1	9.4 ± 4.5	21.4	21.4	2.3	2.3	6.1	6.5
PNC, #*cm-3	6388.5 ± 6181.5	8739.1 ± 6532.6	23976.2	23976.2	1694.7	1694.7	4137.6	5585.4
PAH, µg*m-3	10.0 ± 3.7	7.5 ± 6.6	15.7	32.9	2.3	2.0	5.1	7.5

Definition of abbreviations: BC = black carbon; PM = particulate matter; PNC = particle number concentration; PAH = Polycyclic aromatic hydrocarbon; SD = standard deviation; IQR = interquartile range.

Results

Air pollutants concentration

The daily average concentration of black carbon, $PM_{2.5}$, PNC, and PAH remained constant during the study period (Figure 1b, 1c, 1d, 1e). Concentration of ozone was significantly lower during the winter (Figure 1a) because the indoor ozone concentration is measured instead of ambient ozone concentration. The distribution of daily average concentration of the five pollutants by gender are shown in Table 1. The concentration of ozone is positively correlated with the concentration of $PM_{2.5}$ (p-value: 0.01) and PNC (p-value: <.0001) ; the concentration of black carbon is positively correlated with the concentration of PNC as well (p-value: <.0001) ; on the contrary, the concentration of $PM_{2.5}$ is negatively correlated with the concentration of PNC (p-

value: <.0001) ; and the concentration of PAH is negatively correlated with that of PNC (p-value: 0.04) (Table 2).

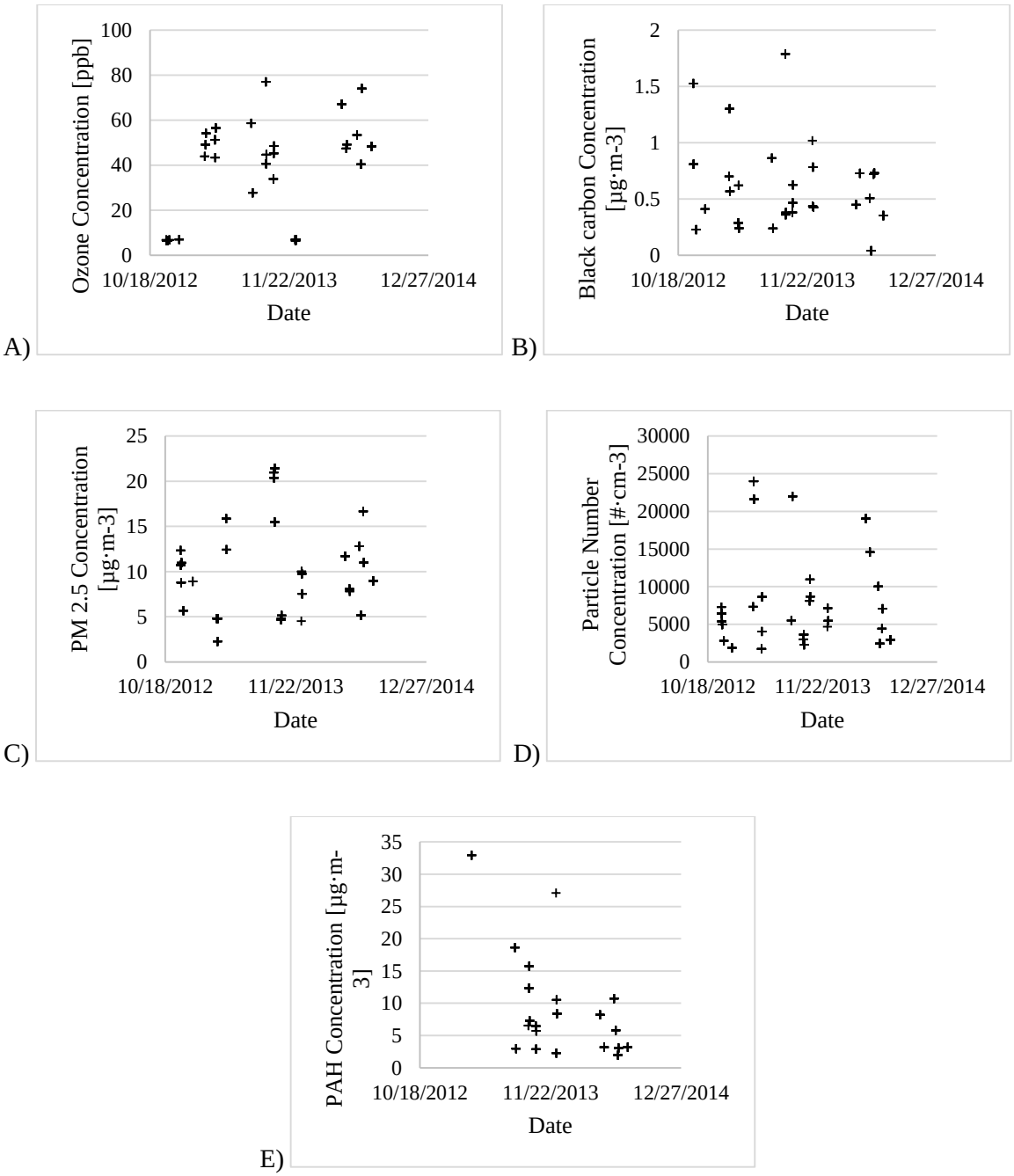


Figure 1. Time series of air pollutant concentrations from Nov. 2012 to Sep. 2014 in Atlanta, GA. A) Ozone, B) black matter, C) $PM_{2.5}$, D) PNC, E) PAH.

Table 2. Concentration correlation matrix (daily average pollution levels)

Pollutant	Ozone, ppb	BC, ug*m-3	$PM_{2.5}$, ug*m-3	PAH, ug*m-3	PNC, #*cm-3
Ozone, ppb	1.00	0.071	0.18*	-0.024	0.36**
BC, µg*m-3		1.00	0.074	0.10	0.36**
$PM_{2.5}$, µg*m-3			1.00	0.077	-0.46**
PAH, µg*m-3				1.00	-0.17*
PNC, #*cm-3					1.00

Definition of abbreviations: BC = black carbon; PM = particulate matter; PNC = particle number concentration; PAH = Polycyclic aromatic hydrocarbon
* P-value < 0.05; ** P-value < 0.001 from Pearson Correlation Coefficients test.

Air pollutants exposure

Male and female subjects had similar daily individual duration of physical activity. However, the variation in exposure duration was smaller during winter than in other seasons (Figure 2), probably due to limited space and activity types. The exposures of some pollutants, defined as the product of average concentration and individual exposure duration, varied considerably by time. Overall, the ozone (p-value:<.0001) and $PM_{2.5}$ (p-value: <.0001) exposure tend to increase over time (Figure 3a, 3b). The PAH exposure, however, decreased significantly (<.0001) (Figure 3e). Exposure of black carbon and PNC is not correlated with time (Figure 3c, 3d). Table 3 shows the mean, standard deviation, maximum, minimum, and interquartile range of pollutant exposure for individuals.

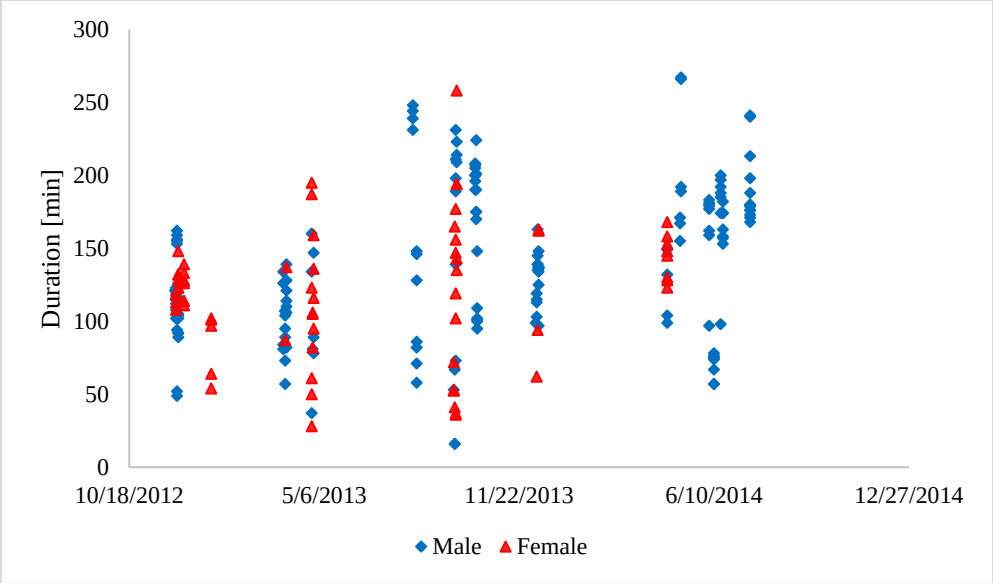
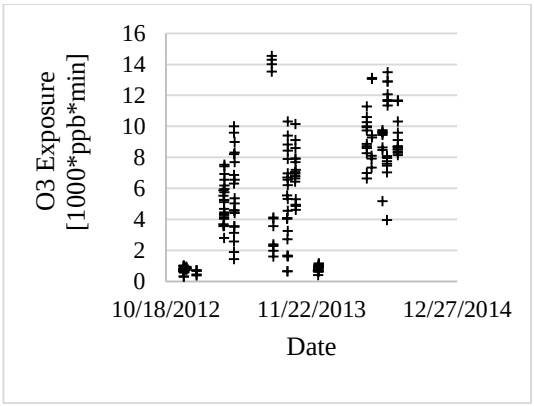
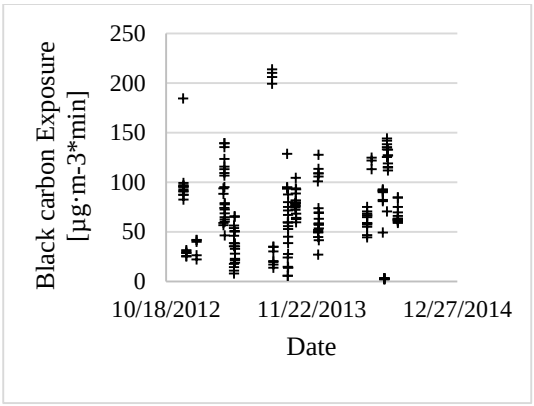


Figure 2. Individual exposure time during physical activity by date.

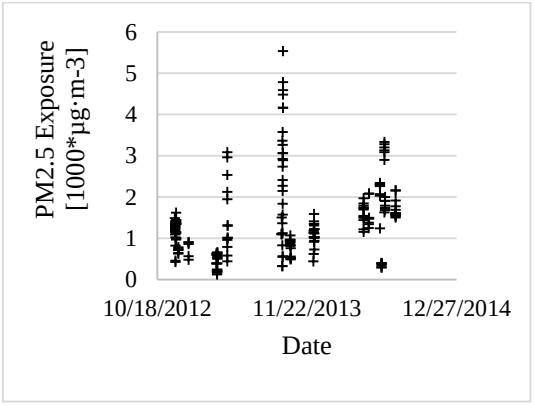
A)



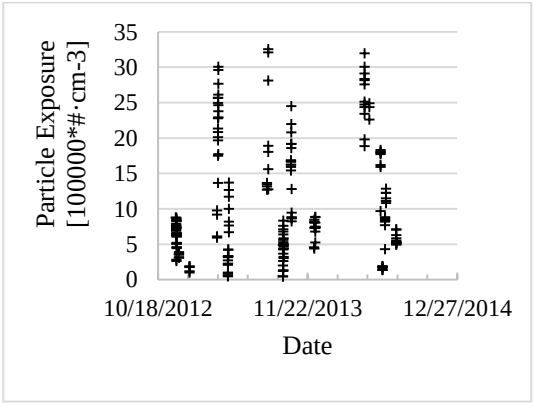
B)



C)



D)



E)

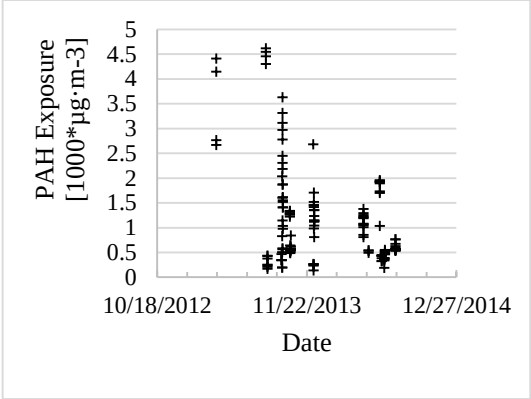


Figure 3. Time series of individual exposure over the study period from Nov. 2012 to Sep. 2014 in Atlanta, GA. A) Ozone, B) black matter, C) $PM_{2.5}$, D) PNC, E) PAH.

Table 3. Descriptions (mean, standard deviation, maximum, minimum, interquartile rage) of air pollutants exposure.

	Mean ± SD		Maximum		Minimum		IQR	
	Female	Male	Female	Male	Female	Male	Female	Male
Ozone	3989.5 ± 3511.8	5527.9 ± 3962.0	11282.9	14542.7	378.0	310.2	6012.9	7530.1
BC	52.4 ± 27.8	77.7 ± 42.7	128.7	213.8	8.1	2.2	40.5	46.0
$PM_{2.5}$	1530.4 ± 1018.6	1336.5 ± 889.7	5531.3	4780.9	197.5	129.4	955.7	958.9
PAH	1236.1 ± 648.6	1131.2 ± 1065.6	2780.7	4620.2	140.1	170.5	428.3	952.7
PNC	836746.5 ± 882857.6	1129802.0 ± 760184.0	3197224.8	3252758.8	47451.6	47556.8	498653.1	1140589.2

Definition of abbreviations: BC = black carbon; PM = particulate matter; PNC = particle number concentration; PAH = Polycyclic aromatic hydrocarbon; IQR = interquartile range

Ozone exposure is in ppb*min, black carbon exposure is in $\mu g*m^{-3}*min$, $PM_{2.5}$ exposure is in $\mu g*m^{-3}*min$, PAH is in µg*m-3*min, PNC exposure is in $\#*cm^{-3}*min$

Difference in GSSG percentage change

The average difference of GSSG percentage is -0.368 with a standard deviation of 10.53, median of 0.01, and interquartile range of -0.79 to 2.42. There was no significant association observed between the log difference of the percentage of GSSG and date (p-value: 0.17) (Figure 4). Gender is not correlated with percentage change of GSSG as well. The log difference of the GSSG percentage and the log exposure levels of the pollutants are used as dependent variable and independent variables, respectively, in the linear mixed model.

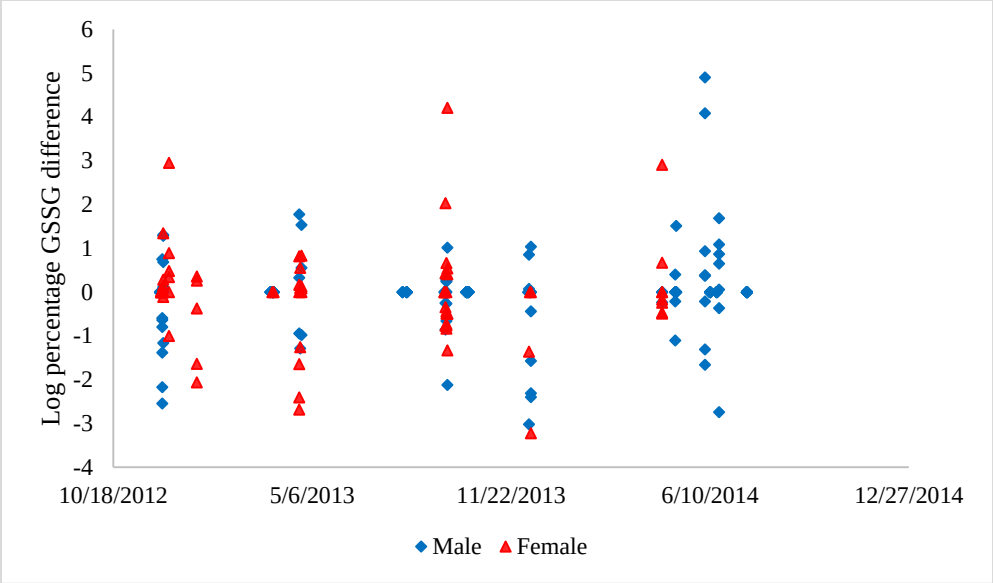


Figure 4. Log percentage difference in GSSG over the study period from Nov. 2012 to Sep. 2014

Linear mixed model

Models for 5 pollutants were created with other parameters (age, gender, ozone day-specific lag 0-3) selectively included into the models. For ozone, when all the parameters were added in the model, the sample size did not provide enough power to generate the p-value. However, we observed 4 significant associations between ozone exposure and changes oxidative stress (P-value < 0.05). Ozone exposure solely is associated with oxidative stress (P-value = 0.036); ozone exposure is also significantly correlated (P-value = 0.038) with GSSG percentage change when gender was included (P-value = 0.92); age (P-value = 0.021) along with ozone exposure (P-value = 0.023) have a significant association with the outcome; when age, gender, and ozone exposure were all included in the model, age (P-value = 0.023) and ozone exposure (P-value = 0.025) still have a significant correlation with oxidative stress. Age were also tested for confounding by assessing the correlation between ozone exposure and age, and age and log difference in GSSG percentage change. However, age is excluded as a potential confounder since the age is associated with GSSG percentage change (P-value = 0.042) but not ozone exposure (P-value = 0.93).

Similar procedures were also conducted for the other 4 pollutants, however, there was no significant association observed between the pollutant exposure and GSSG percentage change.

We created multi-pollutant models, including several two-pollutant models that paired ozone with another pollutant. However, no significant associations were observed for multi-pollutant models.

An interquartile range change in log ozone exposure significantly affected the log difference in GSSG percentage, while other pollutants does not have a significant effect on the outcome (Table 4). The changes in log GSSG percentage difference per interquartile increase for all five pollutants stratified by gender are shown in figure 5.

Table 4. Log difference in GSSG percentage change with one interquartile range increase in log-transformed exposure levels.

	IQR		Change in log %GSSG Diff		Lower Limit		Upper Limit		Interaction
	Female	Male	Female	Male	Female	Male	Female	Male	(P-value)
Log O3	2.12	2.17	0.60	0.61	0.08	0.08	1.11	1.14	0.0247
Log BC	0.88	0.62	0.06	0.04	-0.42	-0.29	0.53	0.37	0.8046
$PM_{2.5}$*	955.70	958.95	0.11	0.11	-0.17	-0.17	0.40	0.40	0.4212
Log PNC	0.94	1.13	0.22	0.26	-0.08	-0.10	0.52	0.63	0.1497
Log PAH	0.36	1.12	0.10	0.31	-0.13	-0.42	0.34	1.04	0.3501

Definition of abbreviations: BC = black carbon; PM = particulate matter; PNC = particle number concentration; PAH = Polycyclic aromatic hydrocarbon; IQR = interquartile range
*PM2.5 exposure is not log-transformed

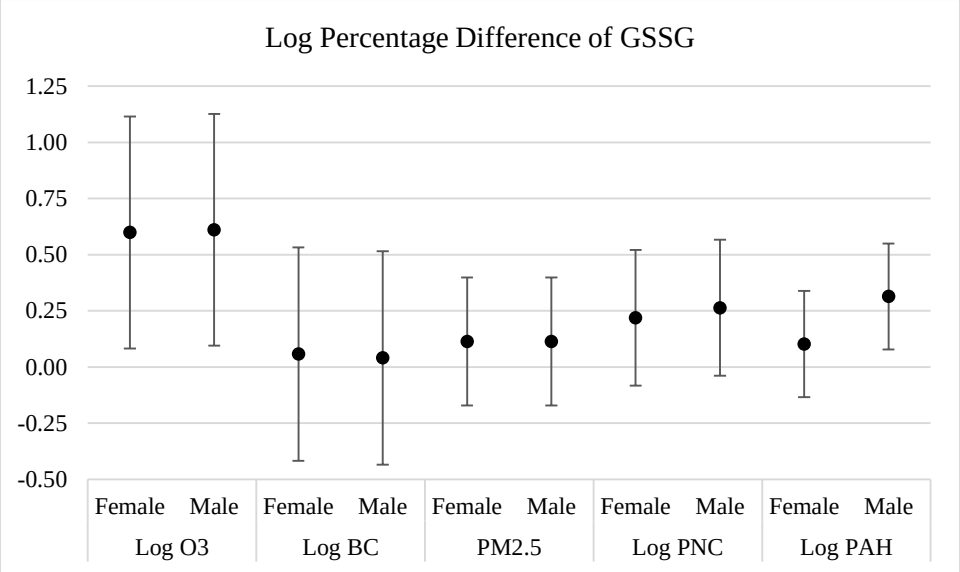


Figure 5. Log difference in GSSG percentage per IQR increase of log-transformed pollutants exposure.

Discussion

In the study, we analyzed changes in GSSG percentage for 125 student athletes in relation to air pollutant exposures during physical activity. Age and gender are tightly controlled in the study, while other demographic or physiological characteristics such as ethnicity, height and body weight of the subject group are either unitary or not likely to be related to the change in this biomarker for oxidative stress. We observed positive, statistically significant associations between ambient or indoor ozone exposure and GSSG percentage difference, which indicates that an acute increase in ozone exposure during physical activity is related to an increased amount of glutathione been oxidized, or an increased oxidative stress in the lungs.

Due to the complexity of log transformation, the interpretation of interquartile range analysis used the following equation:

$$\Delta\left[\log\left(\%GSSG_{before}\right) - \log\left(\%GSSG_{after}\right)\right] = \text{parameter estimate} \times \left[\log\left(O_{3_{75\%}}\right) - \log\left(O_{3_{25\%}}\right)\right]$$

Or

$$\Delta \log\left(\frac{\%GSSG_{before}}{\%GSSG_{after}}\right) = parameter\ estimate\ \times \log\left(\frac{O_{3_{75\%}}}{O_{3_{25\%}}}\right)$$

In this study, one interquartile range increase in log ozone exposure equals to a 7.33-time increase in ozone exposure, which change the percentage ratio of GSSG by 0.60 in female athletes and 0.61 in male athletes, holding age constant.

Exposure of black carbon, $PM_{2.5}$, particles, and PAHs, though not proven to be related to an increase in oxidative stress, is highly correlated with each other and/or with ozone exposure due to the fact that their concentrations are correlated. An increase in either one of the pollutants: ozone, $PM_{2.5}$, black carbon, or PAHs would lead to an increase in particle exposure. The study observation also supported previous researches that concluded $PM_{2.5}$ and ozone exposure, in particular, occurs higher together during summer and early fall under stagnant conditions. However, during other seasons, particulate matters and ozone exposure trends are considered separate, and sometimes, negatively associated with each other. [16] Despite the cytotoxicity and genotoxicity of $PM_{2.5}$ [17, 18], there was little evidence indicating the association between $PM_{2.5}$ and oxidative stress in blood, or in lungs [17, 19]. Our study confirmed with the finding. The association between black carbon exposure and oxidative stress in lungs is often assessed through measuring the 8-isoprostane level in exhaled breath and is proven by many studies to be positive and statistically significant. [20, 21] However, our study, through measuring changes in the percentage of GSSG in exhale breath condensate samples, did not find a significant association between black carbon exposure and oxidative stress. One possibility is that the effect size is smaller for black carbon than for ozone, therefore, our current data-base is under-powered to detect an association for black carbon. Another possibility is that physical activity modified the effect of black carbon exposure on oxidative stress in lungs, which extends to the next phase of our research on evaluating physical activity as an effect modifier of dose-response relationship of oxidative stress. Similarly, we observed no effect of polycyclic aromatic hydrocarbon on the GSSG percentage in this case. While in some published articles, there was significant association observed in median and high PAH exposure (mainly occupational exposure), and the effect varies by gender. [22] In our study, where most physical activity were conducted in acceptable outdoor levels, a significant association is not likely to be observed.

One limitation of the study is that some of the GSSG percentage changes are not available (49.4% missing) which limited the statistical power in building the linear mixed model. The pollutant exposure and lag data are also partially missing (47.7% missing) due to the limited availability of the published data from ground air quality monitors. The missing lag data may provide important information in the short-term interaction between ozone exposure and oxidative stress. [14] Another concern on the lag ozone exposure, especially during summer when students are in summer break, is the properness of using daily average lag exposure around school versus the lag exposure around home or other major areas where the subject spends during the day. The near-school lag may not reflect the true daily average ozone exposure of the individual.

Next step of the study would be whether physical activity has an effect on the interaction between air pollutant exposures and changes in GSSG percentage.

We have observed a tendency to find stronger association by increasing the sample size. Future studies may be focusing on improving the statistical power by including more subjects in wider age range, and in more diverse ethnicity groups.

References

1. Jerrett, M., et al., *Long-term ozone exposure and mortality.* N Engl J Med, 2009. **360**(11): p. 1085-95.
2. Martinelli, N., O. Olivieri, and D. Girelli, *Air particulate matter and cardiovascular disease: a narrative review.* Eur J Intern Med, 2013. **24**(4): p. 295-302.
3. Mauderly, J.L. and J.C. Chow, *Health effects of organic aerosols.* Inhal Toxicol, 2008. **20**(3): p. 257-88.
4. Lack, D.A., et al., *Characterizing elemental, equivalent black, and refractory black carbon aerosol particles: a review of techniques, their limitations and uncertainties.* Anal Bioanal Chem, 2014. **406**(1): p. 99-122.
5. Grahame, T.J., R. Klemm, and R.B. Schlesinger, *Public health and components of particulate matter: the changing assessment of black carbon.* J Air Waste Manag Assoc, 2014. **64**(6): p. 620-60.
6. Kim, K.H., et al., *A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects.* Environ Int, 2013. **60**: p. 71-80.
7. Carlisle, A.J. and N.C. Sharp, *Exercise and outdoor ambient air pollution.* Br J Sports Med, 2001. **35**(4): p. 214-22.

8. Fisher, J.T. and F.J. Cerny, *Characteristics of adjustment of lung diffusing capacity to work.* J Appl Physiol Respir Environ Exerc Physiol, 1982. **52**(5): p. 1124-7.
9. Turcotte, R., et al., *Exercise-induced oxyhemoglobin desaturation and pulmonary diffusing capacity during high-intensity exercise.* Eur J Appl Physiol Occup Physiol, 1997. **75**(5): p. 425-30.
10. Turcotte, R.A., et al., *A test for the measurement of pulmonary diffusion capacity during high-intensity exercise.* J Sports Sci, 1992. **10**(3): p. 229-35.
11. Martinez-Campos, C., et al., *Effects of exercise on oxidative stress in rats induced by ozone.* ScientificWorldJournal, 2012. **2012**: p. 135921.
12. Quadrilatero, J., et al., *Prolonged moderate-intensity aerobic exercise does not alter apoptotic signaling and DNA fragmentation in human skeletal muscle.* Am J Physiol Endocrinol Metab, 2010. **298**(3): p. E534-47.
13. Hei Collaborative Working Group on Air Pollution, P., et al., *Effects of short-term exposure to air pollution on hospital admissions of young children for acute lower respiratory infections in Ho Chi Minh City, Vietnam.* Res Rep Health Eff Inst, 2012(169): p. 5-72; discussion 73-83.
14. Strickland, M.J., et al., *Short-term associations between ambient air pollutants and pediatric asthma emergency department visits.* Am J Respir Crit Care Med, 2010. **182**(3): p. 307-16.
15. Yeh, M.Y., et al., *Non-invasive evaluation of pulmonary glutathione in the exhaled breath condensate of otherwise healthy alcoholics.* Respir Med, 2008. **102**(2): p. 248-55.
16. Laboratory, L.B.N., *IMPROVING THE UNDERSTANDING OF PM 2.5 AND OZONE CHEMISTRY FROM AIR QUALITY MONITORING FOR MORE ACCURATE PREDICTION OF POWER GENERATION IMPACTS*, in *Energy Research and Development Division, California Energy Commission*. 2013.
17. Oh, S.M., et al., *Organic extracts of urban air pollution particulate matter (PM2.5)-induced genotoxicity and oxidative stress in human lung bronchial epithelial cells (BEAS-2B cells).* Mutat Res, 2011. **723**(2): p. 142-51.
18. Li, N., et al., *Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage.* Environ Health Perspect, 2003. **111**(4): p. 455-60.
19. Sorensen, M., et al., *Personal PM2.5 exposure and markers of oxidative stress in blood.* Environ Health Perspect, 2003. **111**(2): p. 161-6.
20. De Prins, S., et al., *Airway oxidative stress and inflammation markers in exhaled breath from children are linked with exposure to black carbon.* Environ Int, 2014. **73**: p. 440-6.
21. Rosa, M.J., et al., *Domestic airborne black carbon levels and 8-isoprostane in exhaled breath condensate among children in New York City.* Environ Res, 2014. **135**: p. 105-10.
22. Guo, H., et al., *Women are more susceptible than men to oxidative stress and chromosome damage caused by polycyclic aromatic hydrocarbons exposure.* Environ Mol Mutagen, 2014. **55**(6): p. 472-81.