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Effects of ambient particulate matter on aerobic exercise performance

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ABSTRACT

Background/Objective: Wintertime thermal inversions in narrow mountain valleys create a ceiling effect, increasing concentration of small particulate matter ($PM_{2.5}$). Despite potential health risks, many people continue to exercise outdoors in thermal inversions. This study measured the effects of ambient $PM_{2.5}$ exposure associated with a typical thermal inversion on exercise performance, pulmonary function, and biological markers of inflammation.
Methods: Healthy, active adults (5 males, 11 females) performed two cycle ergometer time trials outdoors in a counterbalanced design: 1) low ambient $PM_{2.5}$ concentrations (<12 μg/m^3), and 2) an air quality index (AQI) ranking of "yellow." Variables of interest were exercise performance, exhaled nitric oxide (eNO), c-reactive protein (CRP), forced vital capacity (FVC), and forced expiratory volume in 1 s (FEV_1).
Results: Despite a significant difference in mean $PM_{2.5}$ concentration of 9.3 ± 3.0 μg/m^3 between trials ($p < .001$), there was no significant difference ($p = .424$) in the distance covered during low $PM_{2.5}$ conditions (9.9 ± 1.7 km) compared to high $PM_{2.5}$ conditions (10.1 ± 1.5 km). There were no clinically significant differences across time or between trials for eNO, CRP, FVC, or FEV_1. Additionally, there were no dose-response relationships ($p > .05$) for $PM_{2.5}$ concentration and the measured variables.
Conclusion: An acute bout of vigorous exercise during an AQI of "yellow" did not diminish exercise performance in healthy adults, nor did it have a negative effect on pulmonary function or biological health markers. These variables might not be sensitive to small changes from acute, mild $PM_{2.5}$ exposure.

Introduction

Wintertime thermal inversions occurring in geographical regions confined by mountains have the potential to trap air pollutants. Due to its geography of a narrow valley bordered by high mountains and frequent winter thermal inversions, Cache Valley in northern Utah is particularly susceptible to episodes of poor air quality.[1] In fact, according to the American Lung Association,[2] Logan, UT, with a population of about 50,000, ranked number 8 in the United States for short-term particle pollution, just ahead of Los Angeles with a population of about 3.8 million. In January 2004, residents of Cache Valley experienced the nation's worst $PM_{2.5}$ (particulate matter ≤ 2.5 μm in diameter) air pollution episode ever registered.[3] The predominant chemical component of the PM in Cache Valley is ammonium nitrate (NH_4NO_3) formed through acid-base reactions between gas-phase ammonia from the excreta of dairy cattle and nitrogen oxides from vehicle exhaust and other combustion products.[3]

Previous research has been published specific to the effects of Cache Valley PM on humans. As far back as the mid-1980s data were collected to determine if there was an association between respiratory hospital admissions and PM pollution in the valley.[4] The results suggested that PM pollution plays a role in the incidence and severity of respiratory disease. More recently, Watterson and colleagues performed a series of studies using cultured human bronchial epithelial cells treated with $PM_{2.5}$ collected in Cache Valley.[5–7] The $PM_{2.5}$-exposed cells triggered an inflammatory response, upregulation of cytokine receptors and both interleukins 1 and 6,[7] through mechanisms involving the unfolded protein response, which is a cellular response to endoplasmic reticulum stress.[6]

It is logical to assume that exposure to ambient PM is likely to increase during bouts of aerobic exercise, placing exercisers at an

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increased health risk. McCafferty[8] hypothesized three reasons for this increased risk. First, with an increase in V_E during exercise there is an increase in the quantity of pollutants inhaled. Increased PM deposition as a result of the high ventilation rates that occur during exercise has been documented.[9] Second, a larger percentage of air is inhaled through the mouth during exercise, thereby bypassing some of the filtration that normally takes place in the nasal passages. Third, the velocity of airflow is increased during exercise, and this might carry pollutants deeper into the respiratory tract.

Of the pollutants in the air quality index (AQI) evaluated by the United States Environmental Protection Agency (EPA), $PM_{2.5}$ is the greatest concern in Cache Valley. However, of the limited research on the effects of airborne pollutants on exercisers, the majority of these studies have focused on ozone, and there are very few studies specific to PM.[10] Nevertheless, a review specific to PM and exercise was published by Cutrufello and colleagues.[11] This review cited studies that reported a decrease in FVC and FEV_1 among healthy[12] and asthmatic subjects[13] that exercised near busy streets, and an increase in blood neutrophil concentration following intermittent exercise during wood smoke exposure.[14] However, there was a lack of controlled studies that measured PM levels cited in this review, and no studies specific to PM from thermal inversions.

The purpose of the present study was to measure the effects of ambient $PM_{2.5}$ exposure from a typical thermal inversion in Cache Valley on exercise performance, pulmonary function, and biological markers of inflammation. We hypothesized an exacerbation of the biological damage done by Cache Valley PM during exercise compared to rest, and a decrease in physical performance with exercise in a polluted environment compared to more favorable ambient conditions. Furthermore, a dose-response relationship for pollution and biological markers and performance decrement was hypothesized such that tests performed under the worst air quality would result in the most dramatic changes in biomarkers and produce the greatest challenge to exercise performance.

Methods

Study design and overview

The study used a quasi-experimental within-groups design. Following a preliminary screening session, each study participant performed two trials, separated by at least 48 h. Each trial consisted of a resting portion and an exercise portion. One trial was performed under conditions of low $PM_{2.5}$ concentration ($PM_{2.5}$ of 0–12 $\mu g/m^3$), and one trial was done when the air quality was worse but still within the acceptable range established by the EPA ($PM_{2.5}$ of 13–35 $\mu g/m^3$). The trials were counterbalanced such that some participants performed their first trial during low $PM_{2.5}$ concentrations while others performed their first trial during higher concentrations.

Participants

Recreationally active adults, defined as exercising at least 150 min/week, were recruited from within Cache Valley, Utah. Those interested in the study completed a preliminary health screening that included a medical history questionnaire, physical examination, and blood chemistry profile. Current smokers, including those who quit less than 6 months prior to the health screening, and those with documented presence of cardiovascular or cardiopulmonary disease were excluded. The study was approved by the IRB of Utah State University (protocol #6117), and participants signed a written informed consent prior to participation.

Procedures

All testing took place in the same location during January and February 2015, as thermal inversions in Cache Valley are most prevalent during winter months. Thermal inversion forecasting was used in an attempt to predict the dates that $PM_{2.5}$ would likely be elevated. Hour-averaged $PM_{2.5}$ data were obtained from the Utah Department of Environmental Quality, Division of Air Quality website (http://www.airquality.utah.gov/aqp/trend_charts/getData.php?id=cache) for each participant during each trial.

Prior to each trial baseline measurements of pulmonary function, exhaled nitric oxide (eNO), and plasma C-reactive protein (CRP) were taken indoors. Pulmonary function (forced vital capacity [FVC] and forced expiratory volume in 1 s [FEV_1]) was assessed with a MicroPlus spirometer (Micro Direct Inc., Lewiston, ME) from a seated position. Fractional eNO, measured by Niox Mino (Circassia Pharmaceuticals Inc., Chicago, IL), is a marker of lung eosinophilic airway inflammation and has been used to monitor the airway inflammatory response to air pollution.[15] Plasma CRP was used as a marker of systemic inflammation. Participants were fitted with a Polar T31 telemetric heart rate (HR) monitor (Polar Electro Oy, Lake Success, NY), and peripheral oxygen saturation (SpO_2) was measured with a finger pulse oximeter (SportStat, Nonin Medical Inc., Plymouth, MN). HR was recorded every 2 min and SpO_2 every 5 min throughout the resting and exercise portions of each trial.

Following baseline measurements, participants went outside for a 20-min seated resting trial, after which FVC, FEV_1, and eNO were repeated. Following this resting period, participants performed a 20-min time trial on a mechanically-braked cycle ergometer (model 824e, Monark Exercise, Vansbro, Sweden) against a resistance that was approximately 3.5% of their body mass. This resistance was determined through pilot testing as being challenging yet a workload that participants could maintain for 20 min. They were instructed to ride as hard as possible for the 20 min, and were blinded to the speedometer and odometer. A time update and verbal encouragement were given at 5 min intervals and during the final 30 s and 10 s. The distance covered was recorded as the measure of performance. Time trials have greater validity and reliability than time to exhaustion tests.[16] Active recovery (slow pedaling against a light load) took place for 5 min then final measurements of FVC, FEV_1, eNO, and CRP were made. Additionally, the participants returned 24 h later for another CRP measurement.

Statistical analyses

Mean comparison of the distance covered between the two 20-min time trials was made with a dependent *t*-test. A two-way repeated-measures ANOVA was used to compare the means of the physiological markers of interest (FVC, FEV_1, eNO, and CRP) across time (baseline, post-rest, and post-exercise) and trials (low $PM_{2.5}$ and high $PM_{2.5}$). Given that each participant experienced a different range of $PM_{2.5}$ concentrations, regression analysis was done on the $PM_{2.5}$ difference (high $PM_{2.5}$ − low $PM_{2.5}$) and the magnitude of change in the variables of interest to determine if a dose-response relationship existed. All analyses were done using SPSS (version 24, IBM Corp., Somers, NY). Statistical significance was accepted at an alpha level of $p \leq .05$.

Results

Thirty-three people participated in the preliminary screening process. Two failed the health screening, and five decided not to participate after the initial consultation. Additionally, one subject could not complete the exercise protocol, and one subject