The Effect of Exposures to Aircraft Ultrafine Particles on Acute Cardiorespiratory Health, and Control Using Personal Protective Equipment

Mariah Dittmore

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Committee:

Edmund Seto (Chair)

Elena Austin

Christopher Simpson

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Abstract

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Mariah Dittmore

Chair of the Supervisory Committee:

Edmund Seto

Department of Environmental and Occupational Health Sciences

Background: JP-8, Jet A-1, and Jet A are kerosene-based aviation fuels. Jet fuel combustion produces complex pollutant mixtures including VOCs, CO_2, CO, NOx, SOx, PAHs and PM. Particles are characterized by size, with ultrafine particles (UFPs -- those particles < 100 nm in diameter) typically quantified by particle number concentration. Previous studies have reported higher concentrations of small UFPs from aircraft combustion emissions, reported as concentrations in the 5 to 40 nm in diameter range. The size distribution and concentration are dependent on the aircraft type, engine, airport, and weather conditions, suggesting that health outcomes may vary by exposure scenario. Exposures to UFPs have been associated with decreased lung function and increased airway inflammation in those with asthma, as well as oxidative stress in those who are healthy. The goal of this study was to characterize outdoor particle exposures under the flight path near Sea-Tac International Airport in SeaTac, Washington, and to demonstrate feasibility of assessing differences in short-term cardiorespiratory outcomes using crossover study design with controlled exposures and a repeated health measures design.

Methods: All data for the study were collected at the SeaTac Community Center (Center) located in SeaTac, Washington. The Center is directly under the flight path of Sea-Tac International Airport, with the north end of the runways located approximately 1.5 km southwest of the site. Data collection occurred in two separate phases: Phase 1 was a preliminary exposure sampling day in October 2021 to test the study design and protocols. During this phase, a powered air purifying respirator (PAPR) was tested to ensure efficacy in removing ultrafine particles under the face shield. Phase 2, a randomized blinded crossover study of four adults, two healthy and two with well-controlled asthma, was conducted in May 2022. In the crossover study, participants walked a set path around the perimeter of the Center for 90 minutes, wearing a sham filter on one day (exposed), and a working filter (not exposed) on a different day. Repeated cardiorespiratory assessments were conducted on both days at baseline (before walk), and at resting periods 30, 60, and 90 minutes during the walk. Air monitoring instruments were used to measure NO_2, BC, $PM_{0.3}$ to PM_{10}, and UFP concentrations. Noise measurements were also collected during the study. Health measurements included neuropsychological (Stroop test and Ecological Momentary Stress questionnaire), cardiological (blood pressure (BP), heart rate (HR) and heart rate variability (HRV), and respiratory (spirometry) data. Day-specific baseline-adjusted differences between exposed and non-exposed conditions were used to assess the health effects at the three time points.

Results: UFPs were observed at higher concentrations in the smaller size bins, with the highest counts measured for sizes 36.5 nm and below. The particles with the greatest counts were often found in the 11.5 and 20.5 nm size range, which is typically attributed to aircraft emissions. HR, HRV, FEV_1, and FVC were observed to have the biggest effects with exposure for the asthmatic group. For HR and HRV, opposite effects were found with exposure for healthy versus asthmatic groups. The healthy group's HRV increased while the asthmatic group decreased at the 90-minute time. The healthy and asthmatic groups had increased and decreased FEV_1 and FVC at the same time points, with the asthmatic group exhibiting greater effects with exposure.

Conclusion: Smaller UFPs were shown to be in higher concentrations during takeoff and when landing was more frequent. Preliminary findings from the small crossover study illustrate potential differences in cardiorespiratory health effects with exposure between healthy and asthmatic with aircraft-related air pollution exposure. However, a larger study is needed to determine if these preliminary findings are robust.

Background

Jet Fuel Composition, Pollution, and Toxicity Studies

Jet fuel composition has changed over the years. In 1951, wide cut jet fuel (JP-4) was standardized for use for the Air Force. JP-4 had a composition of about 50-60% gasoline and 40-50% kerosene (Mattie and Sterner, 2011). JP-4 was highly volatile, so since then has been under reconstruction. Other various fuel compositions have been created over the years; however, JP-8 is the most current jet fuel in use by the Air Force, developed to provide a safer jet fuel that is less volatile. JP-8 conversion from JP-4 was completed in 1994. JP-8 is very similar to commercial Jet A-1 or Jet A which is currently in use (Karanikas et al., 2021).

JP-8, Jet A-1, and Jet A are kerosene-based aviation fuels. The American Society for Testing and Materials (ASTM International) has published many specifications on the fuel composition and test results for performance characteristics. These characteristics include net heat of combustion, density, and smoke point (Karanikas et al., 2021). ATSM International also reports Jet A and Jet A-1 are blends of hydrocarbons, however the exact chemical composition is not possible to define. Testing has showed that in general, the aircraft fuels are made up of refined conventional petroleum, crude oil, natural gas liquid condensates, heavy oil, shale oil, and oil sands. These oils are then often mixed with aliphatic hydrocarbons, aromatic hydrocarbons, and olefins (Karanikas et al., 2021). Figure 1 shows the chemical structures of the hydrocarbon components in aircraft fuels (ATSDR, 1993).

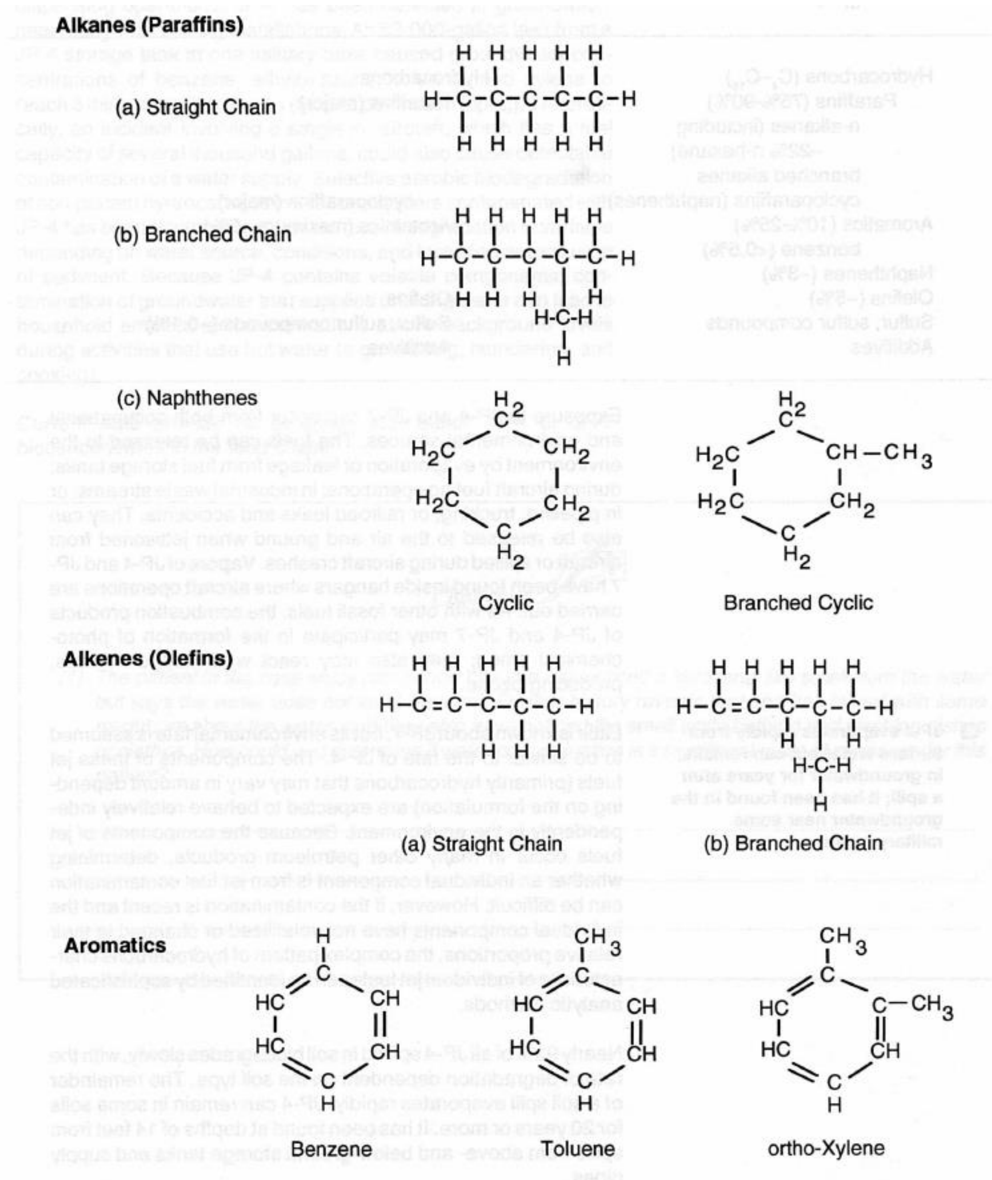

Figure 1. Hydrocarbon components in aircraft fuels. (ATSDR, 1993)

While it is estimated that many of the general population are exposed to pollutants from aircraft fuel, the estimated occupational exposure to JP-8 or Jet A-1 is two million people. Occupational exposures can come from chronic and acute inhalation, dermal contact, and incidental ingestion. These workers could be exposed during transport, storage, and supplying the fuel for aircrafts, as well as maintenance, exhaust vapors, and contaminated skin and/or food and drinks. The safety data sheet (SDS) of Jet A-1 states that exposures may cause defatting of skin, leading to dermatitis and leaving the skin more susceptible to penetration and irritation (Karanikas et al., 2021). It also states that under poor personal hygiene and repeated high exposures, jet fuel can lead to eye irritation, redness, stinging, and lacrimation. Exposures to high concentrations can lead to loss of consciousness, which can eventually lead to convulsions and death. Prolonged exposures can lead to potential cardiovascular, endocrine, and hepatic damage, with possible central nervous system damage, that can lead to headaches, dizziness, fatigue, loss or coordination, unconsciousness, and narcosis (Karanikas et al., 2021).

An occupational exposure study of 29 aircraft factory workers was conducted to look at the health effects from aircraft fuel exposures. The results from these workers showed that ingestion of the fuel may lead to irritation in the gastrointestinal system, abdominal pain, nausea, vomiting, and diarrhea. Ingestion of kerosene has resulted in breathing difficulties, vomiting, drowsiness, abdominal pain, restlessness, convulsions, and coughs (Karanikas et al., 2021).

An occupational exposure study was conducted among military workers exposed to noise and aircraft fuel. Their JP-8 exposure was below 350 mg/m^3, which was the PEL at the time this study was performed. The results showed that noisy work environments plus the additional exposure of aircraft fuel was associated with increased odds of hearing loss. The incidence of hearing loss also was shown to increase as the time on the job increased (Mattie and Sterner, 2011).

A study by Smith et al. 1997 (Mattie and Sterner, 2011) examined an association between postural stability and exposure to JP-8 jet fuel vapors in aircraft maintenance personnel. The study looked at exposures from naphthas, benzene, toluene, m-,o-,p-xylenes. The study reported significant association between exposure to solvents and increased postural sway response. The study also showed a strong association between sway length and benzene implying influence of benzene exposure on vestibular/proprioception functionalities.

Jet fuel combustion produces volatile organic compounds (VOCs), CO_2, CO, NO_x, SO_x, polycyclic hydrocarbons (PAHs), and particulate matter (PM) (Bendsten et al., 2021). Incomplete combustion leads to char and soot, which is commonly measured in airport emission studies as black carbon (BC). PM is characterized by size ranges, with ultrafine particles (UFPs) classified as having at least one dimension < 100 nanometers (nm). Many studies report high concentrations of UFPs from aircraft combustion emissions, with the size of the particles being towards the smaller end of the scale of UFPs present in ambient environmental samples, ranging from 5 to 40 nm in diameter, while UFPs from areas near surrounding freeways are typically larger, > 35 nm (Bendsten et al., 2021). The size distribution and concentration of particles are dependent on the aircraft, airport, engine, and environmental conditions. The highest reported UFP levels were found inside a military airport, and were was measured to be 4.0 million particles/ cubic centimeter (cc) (Bendsten et al. 2021). Due to the previously mentioned factors that affect the size distribution and concentration of aircraft UFPs, health outcomes can vary by exposure.

UFPs and human health effects

Exposures to UFPs have been associated with decreased lung function and increased airway inflammation in those with asthma (Habre et al., 2018). Past UFP toxicity studies have shown inflammation and oxidative stress. This is due to the small size of the particles and diffusion driven behavior. Particles deposit into the alveolar region, evade macrophage clearance, enter the lung cells, and cross epithelial barriers into the blood, lymphatic system, and other organs. Redox reactions in the mitochondria produce reactive oxygen species that damage airway epithelial cells and macrophages (Habre et al., 2018). UFPs are particularly toxic in the body as they can remain in the lungs for long periods of time. This is due to being hydrophilic or negatively charged, which allows them to evade adhesive interactions and diffusion through pores, allowing them to evade rapid clearance. Another factor adding to their toxicity is the large surface area to mass ratio, which helps them carry reactive oxygen generating species, such as metals and PAHs, on their surfaces which make them more toxic in comparison to larger particles, such as larger PM, with equal mass (Habre et al., 2018).

A cross-over intervention study was conducted near Schiphol Airport in Amsterdam. This study examined short-term exposure to aircraft UFPs. The study placed 21, young, healthy participants, who performed intermittent cycling for 20 minutes an hour for five hours at low intensity, at a mobile exposure laboratory near the Schiphol airport. The health outcomes were measured before and after the exposure occurred (Lammers, et al, 2020). The health outcomes measured were fractional exhaled nitric oxide (FeNO), spirometry, electrocardiography (ECG), blood pressure (BP), heart rate, and oxygen saturation. Their data showed correlation between lung function, in terms of FVC, and cardiac function, in terms of corrected QT interval (QTc) and BP. The reduction of FVC and prolonged QTc was associated with particles less than 20 nm and the increase in BP was associated with road-traffic pollution, particles larger than 50 nm. The association between UFPs and respiratory health outcomes line up with previous studies, however those studies did not derive the source of UFPs (Lammers et al., 2020).

A study conducted by Wing et al. aimed to look at in utero exposures to aircraft UFPs and preterm births (PTB) (Wing et al., 2020). They looked at mothers who gave birth between 2008 to 2016 who lived within 15 km of LAX. PTBs was defined as a living birth occurring before 37-week gestation. The exposure data was obtained from the US Environmental Protection Agency (US EPA) AERMET model for meteorological parameters from surface measurements at LAX and AERMOD meteorological dispersion model for air quality effects downwind of LAX. UFP emissions are not well characterized, so UFP emissions were estimated as a nominal daily average total emission rate of 1 g/s, with high uncertainty. Their results showed that in utero exposures to aircraft UFP emissions were associated with increased odds of PTB among mothers who lived within 15 km of LAX (Wing et al., 2020). The study also found associations between PTB and road-traffic UFPs, specifically NO_2. This is the first study conducted reporting these associations.

LAX

In one study conducted in Los Angeles that UW researchers, including Dr. Tim Larson, collaborated on, UFP counts were observed be 4-fold higher than background levels as far as 10 km away from the LAX airport (Hudda et al., 2014). Compared to exposures to UFP from roadway traffic, for communities near major airports, there are many more people exposed to particles from aircraft than roadway vehicles.

Habre et al (2018) conducted a randomized crossover study of 22 adults with mild to moderate asthma. The participants walked for 2 hours, at two different times at two different locations near LAX, one control site and one exposure site. The team collected demographics, medical history, environmental conditions at the residence, commuting time, height, weight, body composition, resting heart rate, asthma questionnaire, and dietary intake from the participants at baseline. They also took respiratory tests and blood draws before and after exposures at each site. The respiratory tests included fractional exhaled nitric oxide testing (FeNO) and spirometry testing. The blood draws included looking at an IgE panel, Interleukin 6 (IL-6), soluble tumor necrosis factor receptor II (sTNFrII), von Willebran factor (vWF), and fibrinogen (HCVD3MAG-67 K). The air pollution exposure measurements included ultrafine particle number concentrations, black carbon, particle-bound PAHs, ozone, CO_2, and PM.

Their exposure results showed UFPs to be significantly higher at the exposure site, as well as median particle size to be lower at the exposure site. PM concentrations were slightly higher, and BC, CO_2, and PAH concentrations were significantly higher at the exposure site. Their health measurements showed associations between airport UFPs and IL-6 in all models. Other associations between roadway traffic pollution included FEV_1 and sTNFrII, which suggested differing health effect associations between airport vs roadway traffic sourced UFPs. No other health measurements were positively associated with airport UFPs.

Aviation UFP Exposure in the Seattle Area

The Seto Laboratory at the University of Washington conducted approximately 9 months of UFP monitoring for a Washington State funded research study. This study measured total and size-specific UFP counts, black carbon, and CO_2 levels using two mobile monitoring vehicles (instrumented Toyota Prius), which were driven on roadway transects that cross perpendicular to flight paths over a study area that spans 10 miles north and south of Seattle- Tacoma International (SeaTac) airport (Austin et al., 2019, Austin et al., 2021). This study observed elevated levels of the smaller sizes of UFP <20 nm, which are attributable to a downwind plume of emissions from landing aircraft. This study defined these small particles the "ultra-ultrafine" PM, to distinguish them from the larger sized UFP with median diameter of ~50 nm that tend to be associated with roadway vehicle emissions. Inverse Distance Weighting was used to plot the spatial distribution of the % UFP with diameter < 20 nm. The data used to develop this model was based on 9 months of mobile monitoring data (77 unique 5-hour monitoring routes within the study area). The findings demonstrated a clear upwind and downwind plume of ultrafine particles North and South of the SeaTac airport that were not predicted by distance to major roadway.

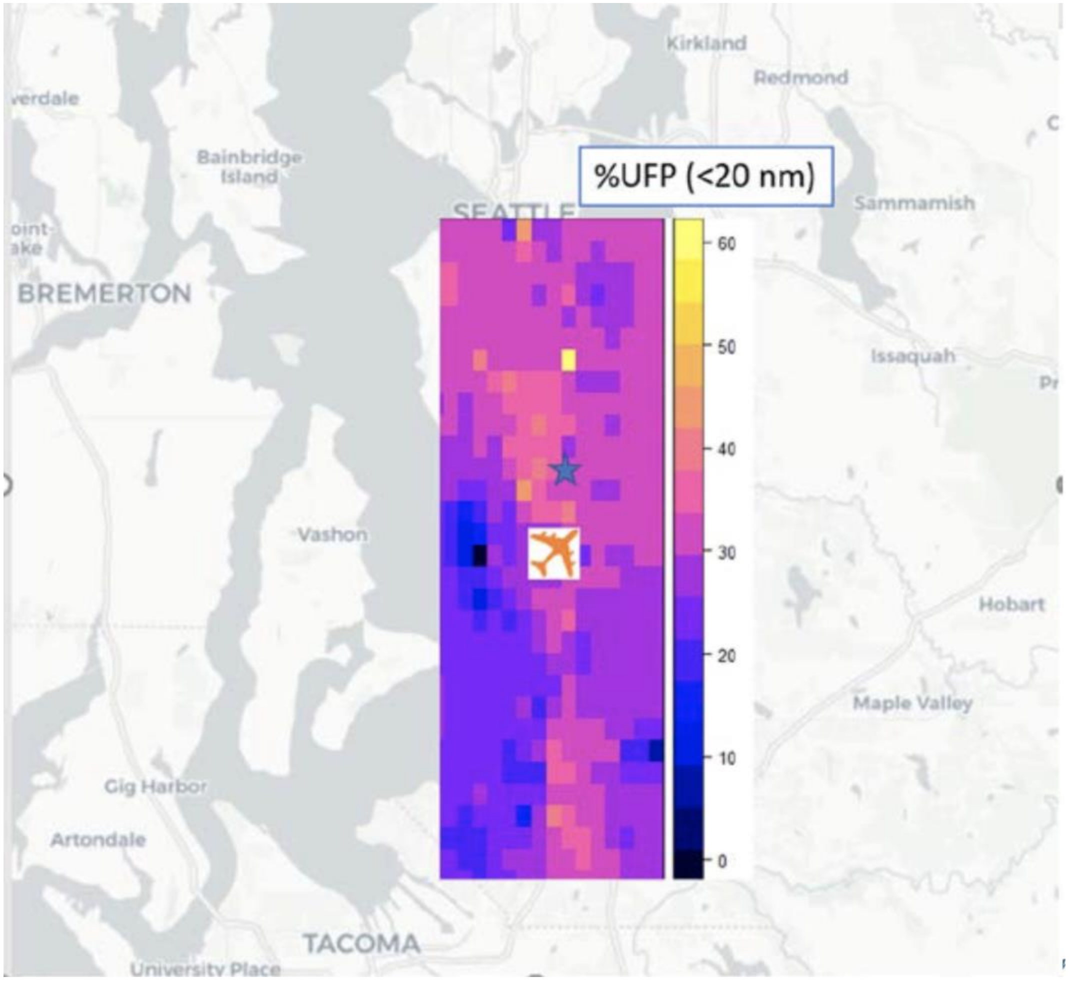

Figure 2. % UFP (diameter <20 nm)/(Total UFP). The orange airplane represents the location of SeaTac airport. The modeled area is 10 km upwind and downwind of the airport. The domain width is 5 km. I-5, the major transportation corridor runs N-S through the Eastern portion of this domain. The blue star represents the location of the SeaTac Community Center (Austin et al., 2019).

The finding of elevated counts in the smallest sizes of UFP is consistent with measurements from the LAX and Atlanta studies (Hudda et al (2014)) and is also consistent with findings from the APEX aircraft emissions study (Wey et al. (2007)). Their findings of an ultra-UFP plume have raised concern among residents of neighboring SeaTac communities, the Port of Seattle that operates SeaTac, and regional air quality and public health agencies for the need of a well-designed health study that can assess associations between ultra-UFP exposure and acute health outcomes.

Specific Aims

Studies conducted in the US and internationally have measured elevated levels of ultrafine particles (UFP) in ambient air near major airports. The patterns of elevated concentrations suggest that they are associated with aircraft emissions, flight patterns, and wind directions

Few epidemiologic studies have assessed the associations between aircraft UFP exposures and cardiorespiratory health effects. One study conducted in Los Angeles, observed that short-term exposure to aircraft related UFP is associated with elevated systemic inflammation (IL-6), whereas roadway traffic is more associated with impaired respiratory health (lower FEV_1) and inflammation (elevated sTNFrII), suggesting that the health effects of aircraft-related UFP exposure may be distinct from roadway traffic UFP exposure.

We are not aware of any studies that have systematically evaluated the association between short-term aircraft specific UFP exposure on cardiorespiratory health using well-controlled experimental exposures to filtered/unfiltered air, with participants blinded to their exposure status. Powered air purifying respirators (PAPRs), commonly used in occupational settings with High Efficiency Particulate Air (HEPA) filters, are designed to efficiently remove all sizes of particles from the breathing zone and are readily available for controlled exposure experiments in natural environments. Moreover, the use of PAPRs, which have the filter mechanism hidden within a housing, allows for blinding of participants: they do know if there is a real or sham filter within the housing.

The three specific aims for this research project are:

1. To characterize the particle concentrations and sizes at a community center under the flight path.
2. To characterize the particle exposure reduction with PAPR with for PM + organics filters.
3. To collect preliminary data on changes in cardiorespiratory measures with/without use of the PAPR to control exposures at the community center site.

The outcomes of the aims described above will help characterize airborne contaminant concentrations caused by jet fuel pollution in the community and occupational settings. The use of a PAPR and taking health measurements will help determine if any control setting may be useful in providing protection to those exposed to this pollution on a regular basis. Furthermore, the testing of the PAPR-based protocol and cardiorespiratory measurements in this project will help refine the approach for future studies. Because of the limited time and few study subjects, the goal of this project was not to obtain robust associations between exposure and health outcomes.

Methods

Study Location

All data collected were outdoors at the SeaTac Community Center (Center) located in SeaTac, Washington. The Center is located at 13735 24th Avenue South, located approximately 1.9 kilometers (km) north of the closest runway at Seattle-Tacoma International (Sea-Tac) Airport. The outdoor area includes play structures, swings, a rock-climbing wall, two half-court basketball courts, and a skate park. The Center is directly under the flight path of Sea-Tac airport, with planes landing and taking off above the center, as well as a few kilometers to the west depending on which of the 3 Sea-Tac runways was used by a given flight. Figure 3 illustrates the location of the Community Center in relation to SeaTac airport and Figure 4 shows an aerial view of the center.

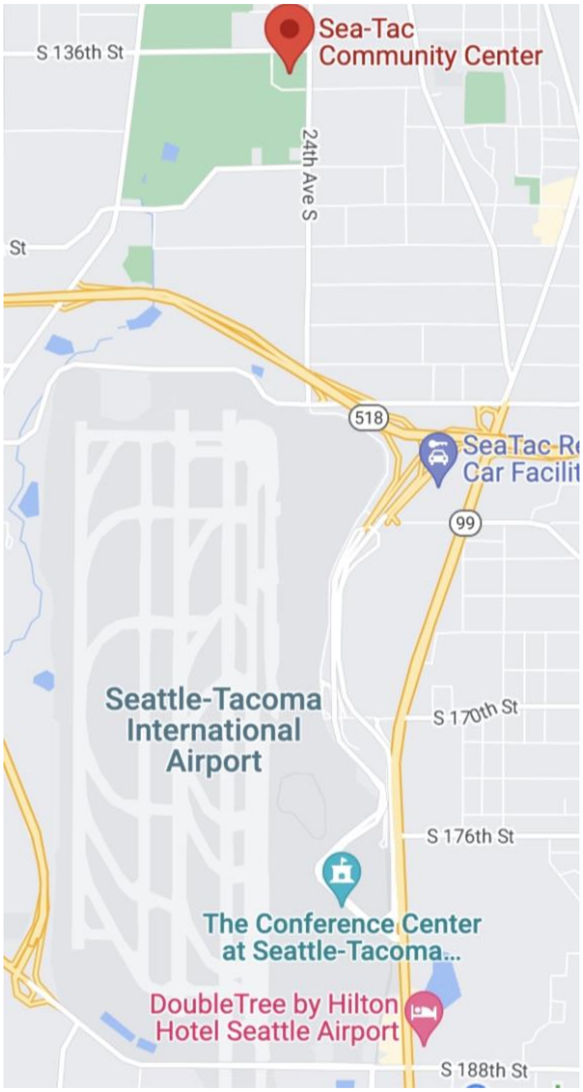

Figure 3. From Google Maps, SeaTac Community Center in relation to SeaTac Airport

Figure 4. Aerial view of Sea-Tac Community Center from Google Maps

Experimental Study Design

Data collection occurred in two separate phases, including a preliminary exposure sampling day and a week-long sampling event collecting exposure and human health data. The initial exposure sampling event that took place in October 2021, was conducted to ensure that study design and protocols worked effectively. It was also to ensure that the exposure levels measured were at elevated levels in comparison to known background levels. The PAPR, 3M™ Versaflo™ Easy Clean PAPR Kit TR-600-ECK model with 3M Organic Vapor/HEPA Cartridge (6510N), was brought and tested to ensure efficacy at the site.

We conducted a randomized blinded experimental crossover study of four adults, two healthy and two with well-controlled asthma during May 2022. The crossover design has advantages over conventional randomized intervention study designs. In a crossover study, each subject is compared to themself: they receive both the intervention (PAPR with filter) and the control (the sham filter) on different days, with the order randomly chosen. Their health outcomes when exposed are compared to their health outcomes when not exposed. This helps control for variations in other factors between persons in the study that may confound the association between exposure and outcome. Each participant was tested for two days, with at least a 24-hour washout period in between test days. One day the participant had the sham filter, and one day they had the PM + VOC filter in their PAPR. Eligibility criteria included: non-smokers, no pre-existing cardiorespiratory conditions. Asthmatics were allowed to participate, as long as their asthma was well-controlled. Additional criteria included no history of COVID-19 infection, English-speaking (for communication to answer surveys), adults aged 18 years or older. Participants were recruited from UW as a convenience sample.

Participants were transported to and from the Center in the study staff's personal vehicles, with closed window conditions with the vehicles' HVAC systems providing filtered air and N95 masks worn by those present in the car to minimize UFP exposures from traffic. At the Center, participants first rested for 5 minutes before taking health measurements and questionnaires as a baseline reference. The study staff then gave the participants their PAPR, either with a sham filter or with the PM + VOC filter. Participants walked a set path around the perimeter of the Center for 90 minutes, resting every 15 minutes and taking health measurements every 30 minutes. Participants aimed to keep their heart rate at target 50% for their age to ensure they were maintaining a moderate physical activity level. Table 1 shows an example schedule from zero to 90 minutes. All walking sessions were conducted midday, from ~ 10 AM- 1 PM to control for diurnal variations in biological measures as well as exposure. Figure 5 shows an example of the walking path that was taken by the participants.

The study protocol was submitted to and approved by the University of Washington Institutional Review Board.

Table 1. Schedule for Participants, Repeated until 90 Minutes of Health Measurements

Baseline Health Measurements	15 Min Walk	2 Min Rest	15 Min Walk	2 Min Rest	30 Min Health Measurements

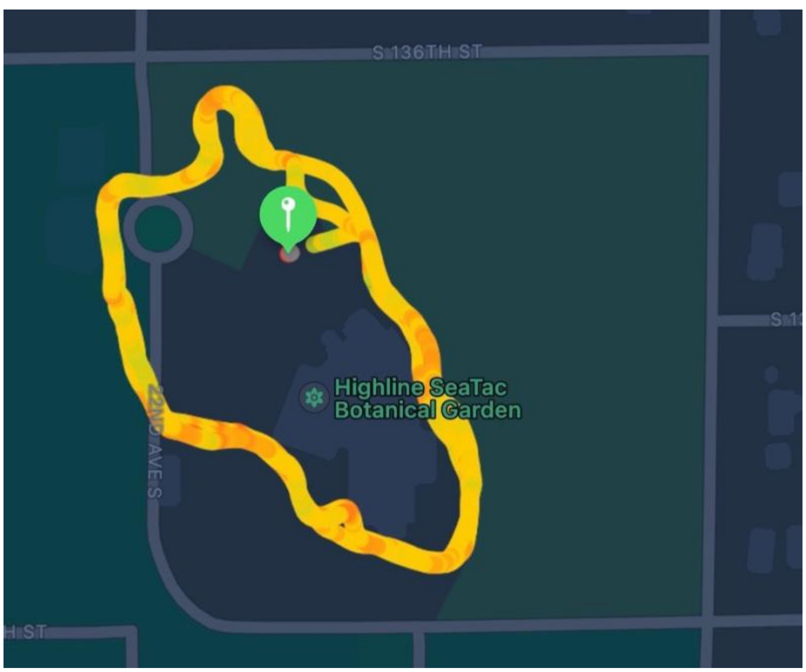

Figure 5. Walking path taken by the participants shown in yellow around the perimeter of the Community Center (green marker)

During baseline and measurement periods, direct reading air measurement instruments were collecting ambient exposure data at a central measurement location in the SeaTac Garden.

Data Collection and Field Work

Exposure data were collected with direct reading air measurement instruments. All instruments were plugged into extension cords that were powered by a 12V marine battery and 2200W DC to 120V AC pure sine wave inverter (Giandel PS-2200KSC). This set up is shown in Figure 4. To measure 0.3 to 10 µm particles, we used the TSI Optical Particle Sizer (OPS) 3330. OPS 3330 uses optics with 120° light collection and sheath air technology improves resolution and lowers maintenance (TSI OPS, 2022). The instrument is NIST factory calibrated in February 2022 to ensure accuracy. The OPS 3330 was set to take measurements every second (1 Hz) and ran as soon as we arrived at the site until the end of the experiment. The particles are measured and recorded in particle count per cubic centimeter (#/cc) for multiple size bins within the 0.3 to 10 µm size range. 13 size bins were utilized for this project.

To measure 10 to 420 nm particles, we used the TSI NanoScan SMPS Nanoparticle Sizer 3910 (NanoScan). The NanoScan is a lightweight, portable instrument, often used for exposure monitoring. The NanoScan has an isopropyl alcohol container that allows the alcohol to be used in the internal Condensation Particle Counter (CPC) that ensures use in sensitive environments (TSI NanoScan, 2022). This instrument takes measurements every minute, reported in #/cc, from the beginning of our arrival at the site to the end of the sampling period. The particle counts are provided for 13 size bins. The particle size range of the TSI NanoScan overlaps the sizes measured by the TSI 3330, however the instruments use different operating principles and therefore may differ slightly in their measurements of 0.3-0.4 µm sized particles. TSI provides software that smooths the differences in particle counts in the overlapping sizes, however, no correction was applied to the data in this study.

Both the OPS 3330 and NanoScan use automatic data logging, which was then saved on a USB drive to import to our computers at the end of each sampling period. Due to lack of charging cords on the first day, the OPS 3330 and the NanoScan were run for approximately an hour at a time, switching back and forth until the end of the sampling period.

To measure black carbon, we used the microAeth AE51. The AE51 is a real-time black carbon aerosol measurement instrument. The AE51 is a small, pocket-sized instrument that collects air samples on Teflon coated glass fiber (T60) filter media (Aeth Labs, 2022). The instrument records attenuation of an 880 nm wavelength light beam as it passes through the filter. This attenuation is converted to mass (ng/m^3) using the known optical absorbance per unit mass of Black Carbon material. The instrument was set up on arrival to the site and ran until the end of the sampling period.

To measure nitrogen dioxide (NO_2), we used the Aerodyne CAPS NO_2 (CAPS) monitor. The CAPS uses direct measurements through visible absorption at 450 nm (Aerodyne, 2022). CAPS differs from a standard chemiluminescence-based monitor, in that it is based on Cavity Attenuated Phase Shift (CAPS) technology to directly measure NO_2 concentrations and does not depend on photolysis of NOx species to NO making it less sensitive to other nitro-containing species. This instrument takes readings every 1 second and reports the NO_2 concentrations in ppb. The data was automatically stored on the laptop connected to the CAPS instrument and was moved over to our own laptops to prepare for data analysis.

Each day during the middle of the sampling period, we took a 10-minute average noise measurement. We used the 3M (SoundDetector SD-200). This instrument was set to slow, one second response time, and A-weighted measurements. This was to ensure the instrument would not pick up on fast and loud sounds, such as the car door slamming, especially since we were monitoring in the parking lots. The A-weighted covers the full frequency range of 20 Hz to 20 kHz, which covers the community noise, inclusive of airplanes, ranging from 50 Hz to 5,000 Hz (Oakland International, 2006). The sound level meter was field calibrated to a 114 dB 1 kHz tone before each measurement.

Figure 4. Direct reading measurement instruments set up for measuring environmental exposures at the site.

Commercially available PAPRs, such as those from 3M are designed to be worn continuously as personal protective equipment for work tasks that require a steady stream of filtered air in the breathing zone in high particulate laden environments (Figure 5). Unlike N95 Particulate Filtering Facepiece Respirators (N95 respirators), which require careful fitting and no facial hair to avoid leaking to be effective, PAPRs provide forced air into the breathing zone, and thus due to positive air pressure, are highly effective. Moreover, the design of PAPRs consist of a separate filter housing, which allows for replaceable filters. Because the filter is hidden inside this housing, study participants in a crossover study are blinded to their exposure assignment: they do not know whether there is a real or sham filter in the PAPR. Because the system is battery operated and portable, PAPRs may be used in a variety of scripted exposure studies, such as those that involve activities (e.g., sitting, standing, walking, bicycling, etc.) that could alter respiratory rates and inhaled dose if needed for the study design (Han et al., 2019; Han et al., 2021). PAPRs are feasible for studies of short-term exposures, and related acute health effects. In our study, we used two 3M™ Versaflo™ Easy Clean PAPR Kit TR-600-ECK.

Figure 5. 3M Versaflo Easy Clean PAPR Kit (3M.com)

Measurements of neuropsychological and cardiorespiratory parameters for this study are listed in Table 2. Neuropsychological data were collected from stress surveys and the Stroop effect test (Stroop, 1935), taken at the baseline and end of the 90 minutes monitoring. The ecological momentary assessment (EMA) stress survey asked participants to answer on a scale from 0 to 100 their tenseness/anxiety, anger/hostility, depression, frustration, and unhappiness (Scott, et al., 2017). After completing the stress survey, the Stroop effect test gave congruent (color words written in the same color of the word) and incongruent (color words written in the different color of the word) response, with the Stroop effect result being the congruent subtracted from the incongruent. All responses were reported in milliseconds (ms). The Stroop effect measures the selective attention capacity, processing speed, and can evaluate processing abilities (Lesley University). We used a computerized Stroop test administered on a laptop computer (https://www.psytoolkit.org/experiment-library/stroop.html).

At baseline, 30 minutes, 60 minutes, and 90 minutes a pulse oximeter, blood pressure, Apple Watch, and spirometer measurements were taken. The pulse oximeter measured blood oxygen percentage, heart rate (HR), and perfusion index (PI). The PI indicates the strength of the pulsatile signal, which is an indicator of peripheral perfusion. PI is the pulsatile signal (AC) divided by the nonpulsatile signal (DC) and ranges from 0.02% to 20%. A higher PI value indicates a stronger pulsatile signal, indicating better peripheral circulation (Yamazaki et al., 2012). The blood pressure measurements included systolic blood pressure (SBP), diastolic blood pressure (DBP), and HR. SBP and DBP are measured in millimeters of mercury (mmHg). The Apple Watch took HR and heart rate variability (HRV) measurements. HRV measurements are taken in ms, measuring how the amount of time between the heartbeats fluctuate. HRV measurements on the Apple Watch were triggered by conducting a “Breathe” mindfulness session on the watch. Apple’s HRV is summarized according to the SDNN metric, which is the standard deviation of the inter-heartbeat R-R intervals (Apple, 2022). We did not download the R-R interval data from the watches to calculate other HRV metrics. A study by Hernando, et al., (2018) validated the Apple Watch’s HRV against a chest strap HRV monitor and found, that while the watch missed some R-R intervals, which biased the HRV measures, the HRV reflected changes induced by mild mental stress in healthy subjects.

Table 2. Order of Health Measurement According to Protocol

Instrument/Measurement	**Health Outcome**
Stress EMA	tense/anxious, anger/hostility, depression, frustration, unhappiness
Stroop Test	Congruent, incongruent, Stroop effect
Pulse Oximeter	%SpO2, HR, PI
Omron BP	SBP, DBP, HR

Apple Watch	HR, HRV
Spirometer	FEV_1, FEVC, PEF, FEV_1/FVC

Data Analysis

The exposure data was analyzed using descriptive statistics, including the mean, standard deviation, median, and 25^{th} and 75^{th} percentiles. We chose to report the upper and lower percentiles rather than minimum or maximum as the direct-reading environmental exposure data tends to be very noisy and may not be representative of the trends. The AE51 black carbon data was run through R using the Optimized Noise-Reduction Algorithm (ONA) to reduce noise and smooth the data (Hagler, et al., 2011). The 3330 OPS time series also had a 10-second moving average calculated by Excel on the plot. This was done since the 3330 recorded a data point every second, the data was very noisy and hard to visualize a trend on the original plot.

The human health measurements were imported from the field sheets into Excel. They were then baseline adjusted to calculate within-person day-specific baseline differences. This was to adjust for any differences in the baseline between days. Ideally, baselines for the same person on both days of sampling would be the same, however that is not the case in our data due to external factors we cannot account for. At each time point, 30, 60, and 90 minutes, we subtracted the baseline in both the exposed and unexposed days. These differences were then examined to look at the difference between the exposure time points and non-exposed time points. These differences were then averaged for the asthmatic and healthy population. We also calculated relative baseline adjusted differences, which were the baseline adjusted differences scaled by the non-exposed baseline values. Conceptual equations are listed below.

The difference of a health measure at each timepoint t between when the subject was exposed vs non-exposed:

$$\text{difference}_t = (\text{health}_{\text{exposed},t} - \text{health}_{\text{non-exposed},t})$$

The baseline-adjusted difference in a health measure at each timepoint t between when the subject was exposed vs non-exposed:

$$\text{baseline\_adj\_difference}_t = (\text{Health}_{\text{exposed},t} – \text{Health}_{\text{exposed,baseline}}) - (\text{Health}_{\text{non-exposed},t} - \text{Health}_{\text{non-exposed,baseline}})$$

The baseline-adjusted relative difference at each timepoint t between when the subject was exposed vs non-exposed, where the reference is the health measure when non-exposed at baseline:

$$\text{relative\_baseline\_adj\_difference}_t = [(\text{Health}_{\text{exposed},t} – \text{Health}_{\text{exposed,baseline}}) - (\text{Health}_{\text{non-exposed},t} - \text{Health}_{\text{non-exposed,baseline}})] / [\text{Health}_{\text{non-exposed,baseline}}]$$

Results

Preliminary Exposure Data Results

The exposure data from our initial site visit was used to test if our site showed elevated levels of aircraft UFP and if our protocols using the PAPR were effective. Our data from the NanoScan, with particles sizes associated with aircraft UFPs, size bins 11.5 nm to 36.5 nm, with and without the PAPR is shown below in Figure 6. These data showed the levels of aircraft UFPs to be elevated at the Community Center site and that the PAPR had a very effective removal of the UFPs.

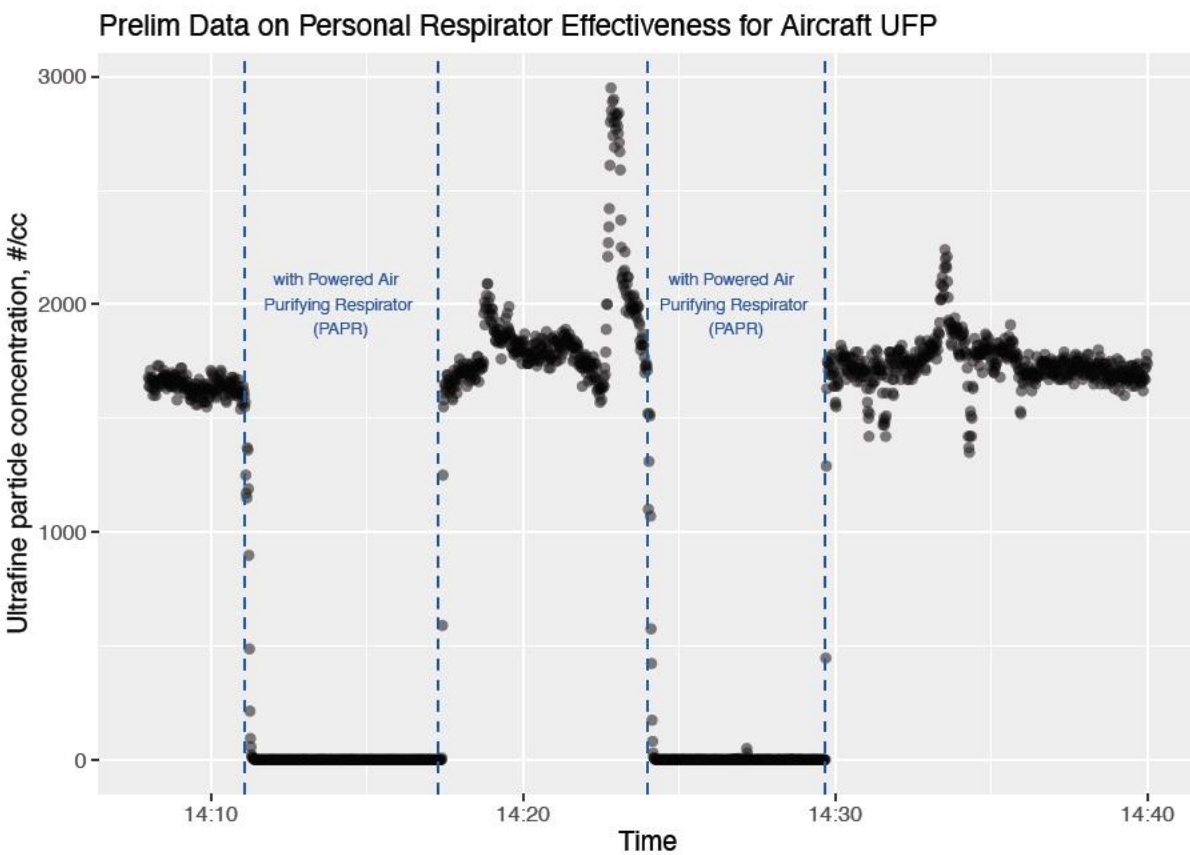

Figure 6. Preliminary Data on PAPR Effectiveness for Aircraft UFP

Exposure Data

The site conditions for each day of sampling are described in Table 3. On the first three days, the planes were landing over the site, with only the last day having flights taking off. The first day was only international, larger, aircraft, the second and third day were domestic, international, and shipping flights, and the last day was only domestic smaller flights. The last day of sampling seemed to have the most volume of flights, and the third day had the fewest, however flight counts were not conducted by the researchers during the study.

Table 3. Site Conditions

Date	**Take off/Landing Overhead**	**Flight Type**
5/17	Landing	International
5/19	Landing	Domestic, International, Shipping
5/20	Landing	Domestic, International, Shipping
5/21	Take off	Domestic

The environmental conditions are described in Table 4 for each day of sampling. The first, second, and last days of sampling were similar, with the third day being the most different, with the slowest wind speed and highest humidity. The winds were blowing in the northern direction for the first two days and switched to the south the last two days. The third day of sampling was the coldest at 48 F° and the last day being the warmest at 61 F°. All days of sampling were cloudy.

Table 4. Environmental Conditions

	Day 1	Day 2	Day 3	Day 4
Date	5/17	5/19	5/20	5/21
Wind Speed (mph)	10	8	3	10
Direction	NE	NE	SW	SE
Humidity	47%	63%	77%	50%
Temp (F°)	58	50	48	61
Conditions	cloudy	cloudy	cloudy	partly cloudy

The 10-minute noise measurements taken each day are presented in Table 5. The equivalent continuous sound level (L_{EQeq}), minimum, and maximum readings were recorded.

Ambient background noise in urban areas typically ranges from 60 to 70 dBA while suburban neighborhoods ambient noise levels range from 45 to 50 dBA (US EPA, 1974). The OSHA 8-hour PEL is 90 dBA. All our noise measurements were under the OSHA PEL, included the maximum noises. Only on day 4 the L_{eq} was above the EPA ambient urban background levels, while the rest fell into the typical range. All L_{eq}'s were above the ambient suburban background levels.

Table 5. Noise Measurements

Date	**Start time**	**Stop time**	**L_{eq} (dBA)**	**Min (dBA)**	**Max (dBA)**
Day 1 5/17	13:00	13:10	61	76.8	48.7
Day 2 5/19	12:54	13:05	66.8	55.3	81.6
Day 3 5/20	12:11	12:21	63.8	62.4	73.3
Day 4 5/21	11:15	11:26	71	61.5	87.2

Table 6 and Figures 7 to 22 shows the exposure air monitoring data. Table 6 shows the descriptive statistics for each instrument, as well as the size bins for the 3330 and the NanoScan. The summary statistics for the CAPS NO_2 data are slightly biased lower, as the CAPS instrument auto-zeros every few minutes, resulting in a few seconds of near-zero data. The downward spikes in Figures 19 to 22 show the occasional auto-zero periods. For our particle results from the 3330, we saw greater particle counts for our smaller sized particles (0.4 µm and below), with very few particles for 0.45 to 10 µm. The greatest particle counts we saw were for the smallest bin (0.3 µm). The averages in this size bin for the four days ranged from 52.99 to 177.85 particles per cc. On day two, there were fewer fine particles in comparison to the other days, (52.99 versus 102.12 to 177.75 particles per cc), however around the same count of larger particles (0.45 µm and above).

The NanoScan mainly observed UFPs in the smaller size bins as well, with the highest counts being 36.5 nm and below, and very few particles 205.4 nm and greater. The particles with the greatest counts were typically 11.5 and 20.5 nm, which we typically attribute to aircraft emissions. On day 3 however, we saw greater concentrations of larger sizes, 27.4 to 64.9 nm, rather than the smaller sizes. This size range we typically attribute to roadway traffic UFP. The AE51 BC and CAPS NO_2 also had the highest concentrations detected for this day, suggesting that there were other sources influencing our data to a greater extent than aircraft emissions. This day also lines up with the day that had the slowest wind speeds, another factor that could have been affecting the particle composition and pollutant mixture.

On day 4 we saw the highest amount of smaller size UFPs in comparison to the larger sizes. The averages were 1695.80 particles per cc for 11.5 nm and 1402.57 particles per cc for 15.4 nm, compared to only 237.30 particles per cc for 20.5 nm, the next largest size bin. While these were not the highest concentrations of the smaller size UFPs, these were the biggest differences in concentrations when comparing the UFPs less than and greater than 20 nm.

Table 6. Exposure Data Summary – BC data before ONA correction

	17-May				19-May				20-May				21-May			
	Mean	**STDEV**	**Median**	**[25,75]**	**Mean**	**STDEV**	**Median**	**[25,75]**	**Mean**	**STDEV**	**Median**	**[25,75]**	**Mean**	**STDEV**	**Median**	**[25,75]**
3330 OPS (#/cc)																
0.3 um	102.12	21.60	100	[89,117]	52.95	9.29	53	[47,59]	177.85	48.89	181	[137,210]	169.93	48.56	169	[139,208]
0.35 um	32.31	8.05	32	[27,37]	18.94	4.88	19	[16,22]	61.41	21.18	63	[43,76]	54.43	16.46	54	[44,66]
0.4 um	11.45	3.90	11	[9,14]	8.07	3.05	8	[6,10]	22.75	9.15	23	[16,29]	18.66	6.29	19	[14,23]
0.45 um	4.20	2.18	4	[3,6]	3.27	1.89	3	[2,4]	7.94	3.92	8	[5,10]	6.18	2.84	6	[4,8]
0.5 um	4.80	2.33	5	[3,6]	4.38	2.20	4	[3,6]	8.91	3.85	9	[6,11]	6.87	3.05	7	[5,9]
0.55 um	4.93	2.38	5	[3,6]	4.71	2.28	5	[3,6]	8.52	3.55	8	[6,11]	6.84	3.07	7	[5,9]
0.6 um	1.88	1.41	2	[1,3]	1.58	1.27	1	[1,2]	2.79	1.81	3	[1,4]	2.14	1.54	2	[1,3]
0.65 um	1.24	1.13	1	[0,2]	1.07	1.05	1	[0,2]	1.92	1.46	2	[1,3]	1.47	1.26	1	[1,2]
0.7 um	1.90	1.42	2	[1,3]	1.73	1.33	2	[1,3]	3.15	1.91	3	[2,4]	2.46	1.69	2	[1,3]
0.75 um	7.07	2.91	7	[5,9]	5.68	2.49	6	[4,7]	9.98	3.85	10	[7,12]	8.05	3.46	8	[6,10]
1 um	8.77	3.28	9	[7,11]	6.45	2.71	6	[5,8]	14.15	4.77	14	[11,17]	11.48	4.66	11	[8,15]
2.5 um	1.00	1.27	1	[0,2]	0.60	0.82	0	[0,1]	1.86	1.49	2	[1,3]	1.26	1.20	1	[0,2]
5 um	0.18	0.87	0	[0,0]	0.11	0.42	0	[0,0]	0.36	0.66	0	[0,1]	0.23	0.51	0	[0,0]
10 um	0.03	0.46	0	[0,0]	0.02	0.19	0	[0,0]	0.036	0.20	0	[0,0]	0.02	0.22	0	[0,0]
NanoScan (#/cc)																
11.5 nm	1050.53	461.96	1031.51	[837.52,1346.93]	1483.63	1022.74	1227.94	[961.64,1687.69]	528.55	198.54	485.26	[386.58,618.2]	1695.80	2005.38	772.52	[338.78,2275.49]
15.4 nm	1225.30	649.11	1182.28	[887.23,1423.05]	2338.95	1101.94	2160.09	[1589.89,2996.12]	923.53	289.27	887.62	[778.57,1046.75]	1402.57	1422.47	788.89	[461.19,1795.47]
20.5 nm	527.67	464.55	398.61	[235.16,628.06]	1735.72	1170.03	1557.11	[809.16,2388.78]	756.00	295.21	803.62	[558.06,964.08]	237.30	154.81	231.96	[155.68,329.17]
27.4 nm	504.85	316.71	431.07	[327.13,577.22]	1791.20	1197.56	1527.46	[917.55,2452.80]	1052.77	518.22	1134.57	[560.86,1397.29]	583.83	232.38	558.87	[438.72,731.36]
36.5 nm	413.94	178.18	407.26	[331.30,468.33]	1279.50	779.92	1067.80	[710.09,1702.77]	1150.05	596.11	1237.20	[590.6,1503.05]	902.84	387.19	779.15	[604.36,1139.86]
48.7 nm	194.69	76.97	204.70	[162.96,238.88]	474.10	272.61	402.30	[310.39,584.03]	994.01	536.96	1026.53	[550.21,1239.43]	855.54	250.92	816.09	[655.76,1080.49]
64.9 nm	42.30	33.03	34.65	[17.06,63.85]	40.54	103.29	0	[0,70.19]	727.26	423.28	713.96	[452.11,848.15]	663.34	154.68	637.07	[575.56,746.78]
86.6 nm	53.16	31.98	49.03	[36.06,69.03]	41.64	53.01	10.02	[0,77.45]	509.52	316.09	492.27	[359.13,559.08]	544.80	106.25	530.98	[482.00,612.12]
115.5 nm	113.24	40.23	110.98	[99.37,135.94]	184.39	67.85	183.49	[151.67,214.53]	306.43	186.65	274.67	[237.29,339.88]	402.09	120.56	390.68	[324.67,472.19]
154 nm	113.84	37.54	117.34	[103.25,131.29]	228.66	118.93	216.53	[146.54,290.49]	105.86	52.34	100.53	[80.41,123.49]	183.32	122.12	143.04	[107.34,221.33]
205.4 nm	53.08	19.49	56.67	[45.39,64.66]	104.32	79.94	84.19	[44.08,147.12]	1.46	11.38	0	[0,0]	10.45	31.07	0	[0,0]
273.8 nm	0.63	2.03	0	[0,0]	2.50	24.21	0	[0,0]	1.15	16.14	0	[0,0]	0.035	0.47	0	[0,0]
365.2 nm	0.13	1.03	0	[0,0]	1.72	23.17	0	[0,0]	0.96	9.91	0	[0,0]	0.23	3.09	0	[0,0]
AE51 BC (ng/cm3)	161.38	4428.93	128	[-1123,1398]	203.15	5748.79	185	[-1695,2105.5]	426.24	5658.38	409.50	[-798,1611]	373.64	12844.62	326	[-2098.25,2715.75]
CAPS NO2 (ppb)	2.01	3.90	1.68	[0.74, 2.84]	1.91	1.78	2.06	[0.75,3.19]	7.94	3.68	9.05	[4.02,10.96]	6.02	4.37	5.08	[1.88,10.48]

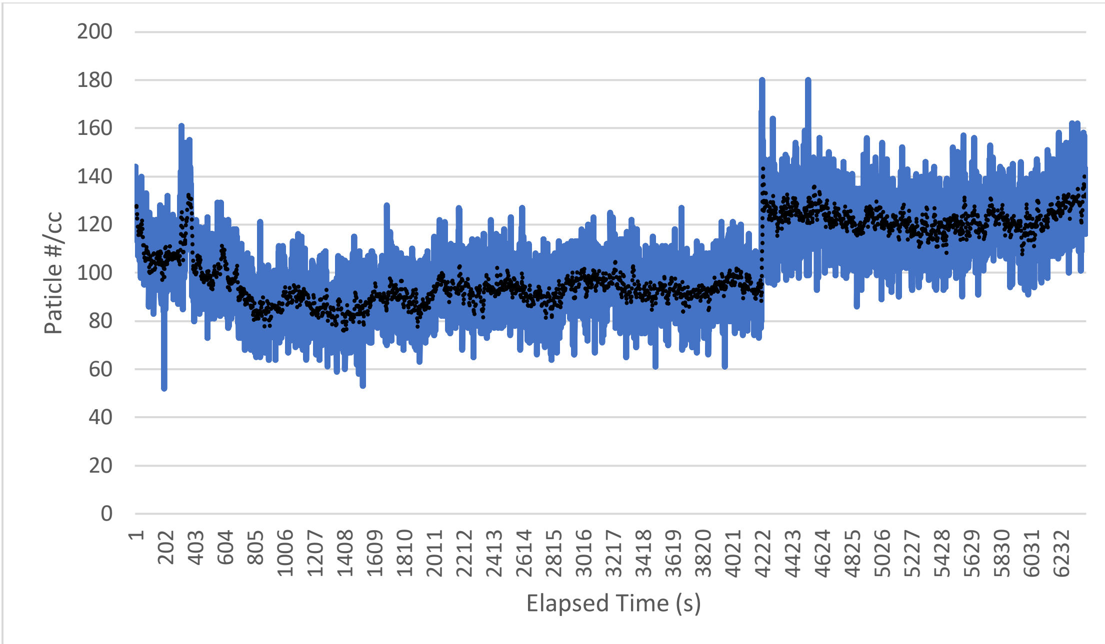

Figure 7. TSI 3330 OPS Time Series Plot for Bin 1 (0.3 µm) on 5-17; the black dotted line is the moving average.

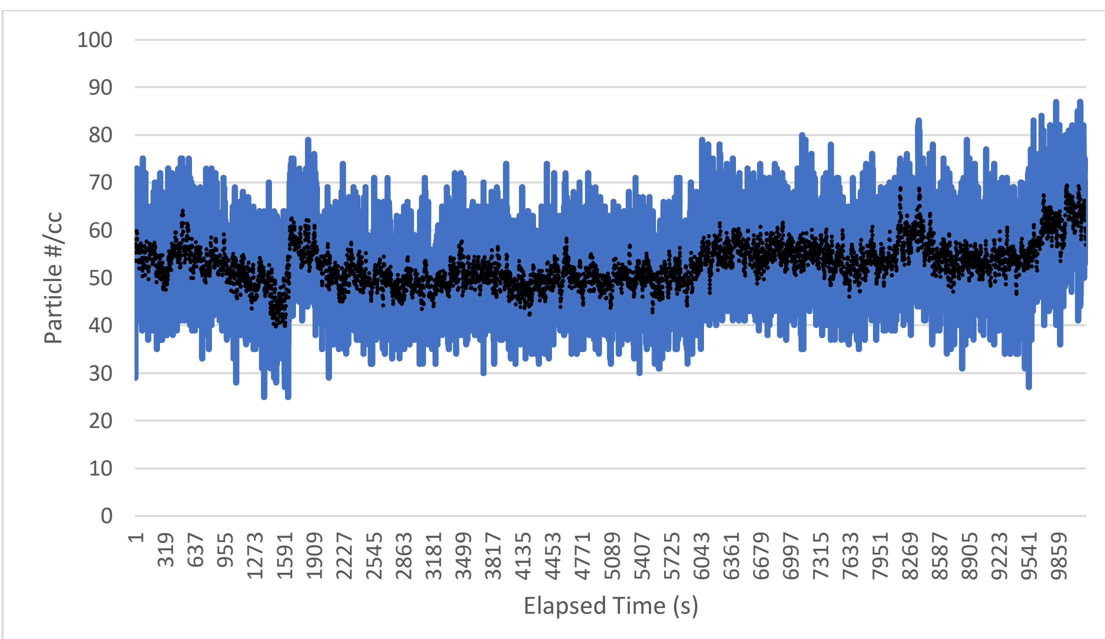

Figure 8. TSI 3330 OPS Time Series Plot for Bin 1 (0.3 µm) on 5-19; the black dotted line is the moving average.

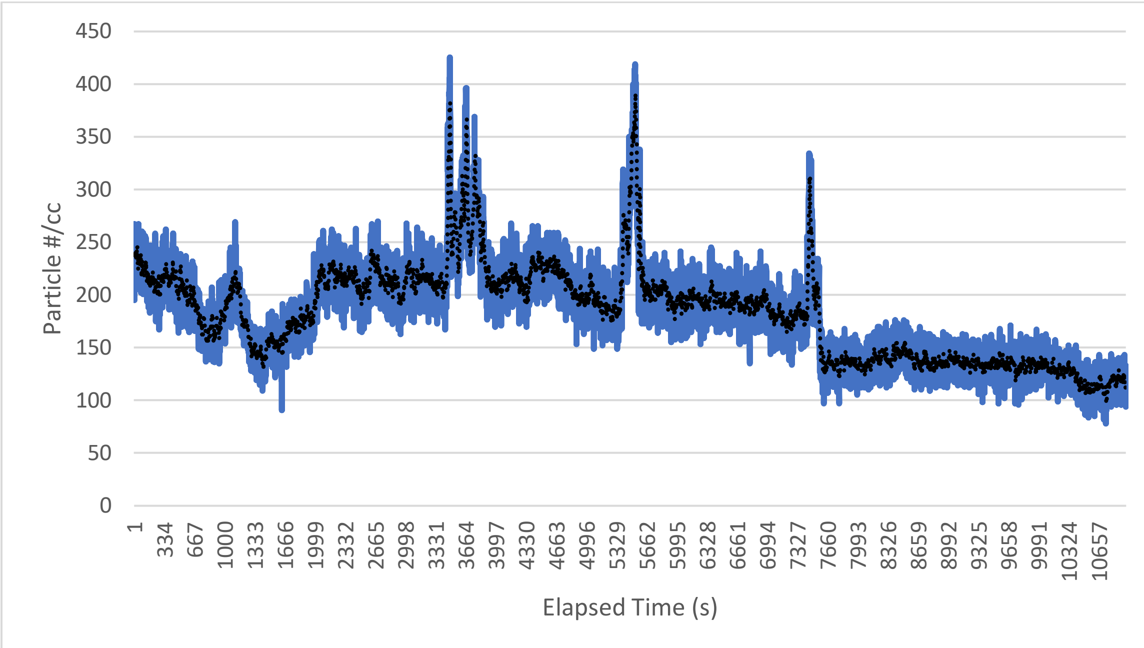

Figure 9. TSI 3330 OPS Time Series Plot for Bin 1 (0.3 µm) on 5-20; the black dotted line is the moving average.

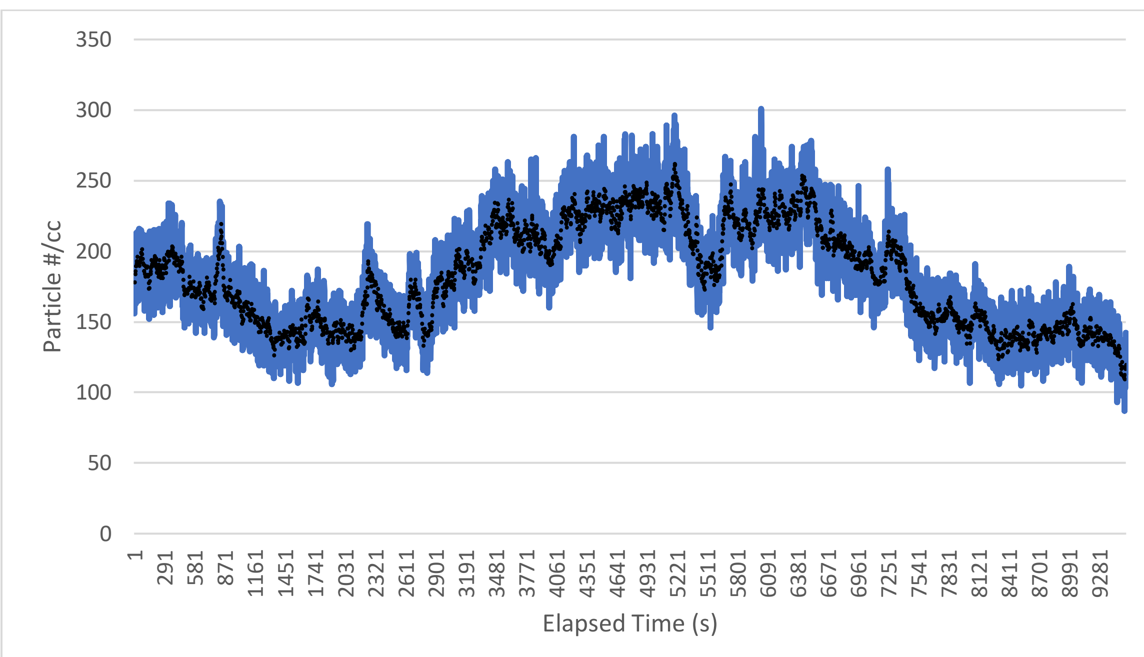

Figure 10. TSI 3330 OPS Time Series Plot for Bin 1 (0.3 µm) on 5-21; the black dotted line is the moving average.

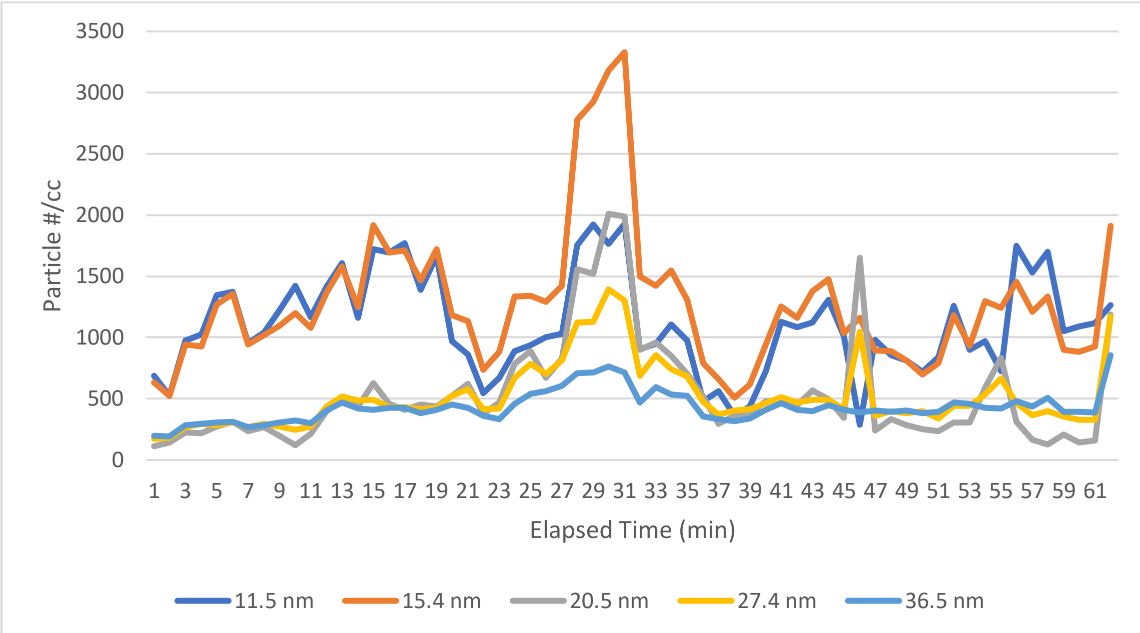

Figure 11. TSI NanoScan Plot for UFPs on 5-17

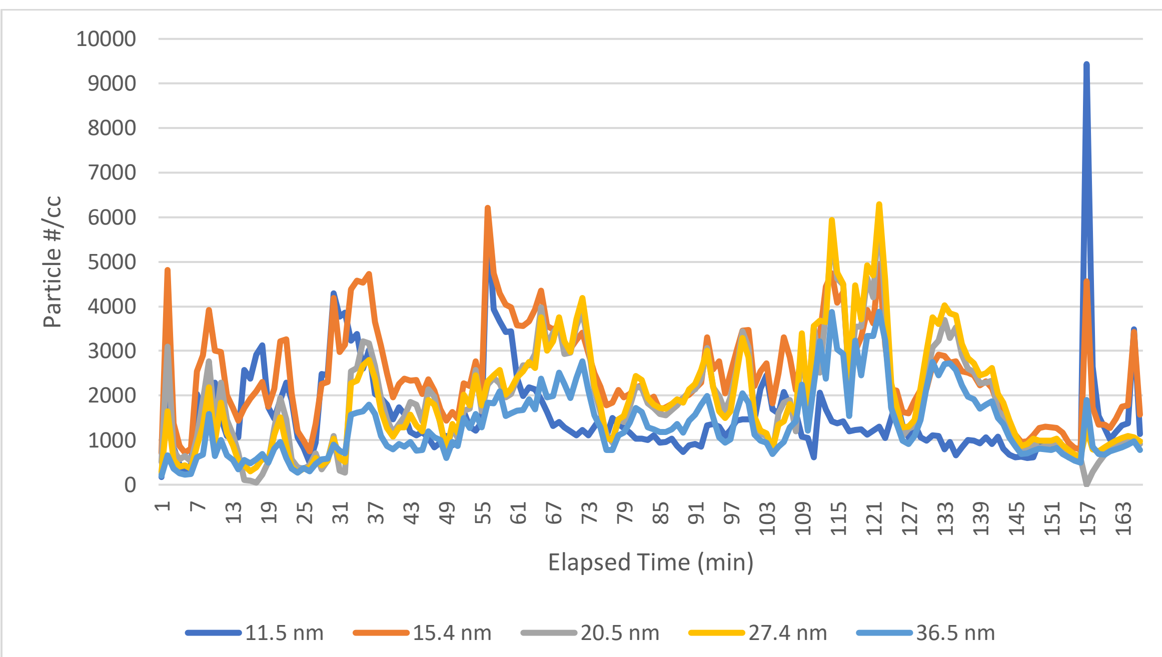

Figure 12. TSI NanoScan Plot for UFPs on 5-19

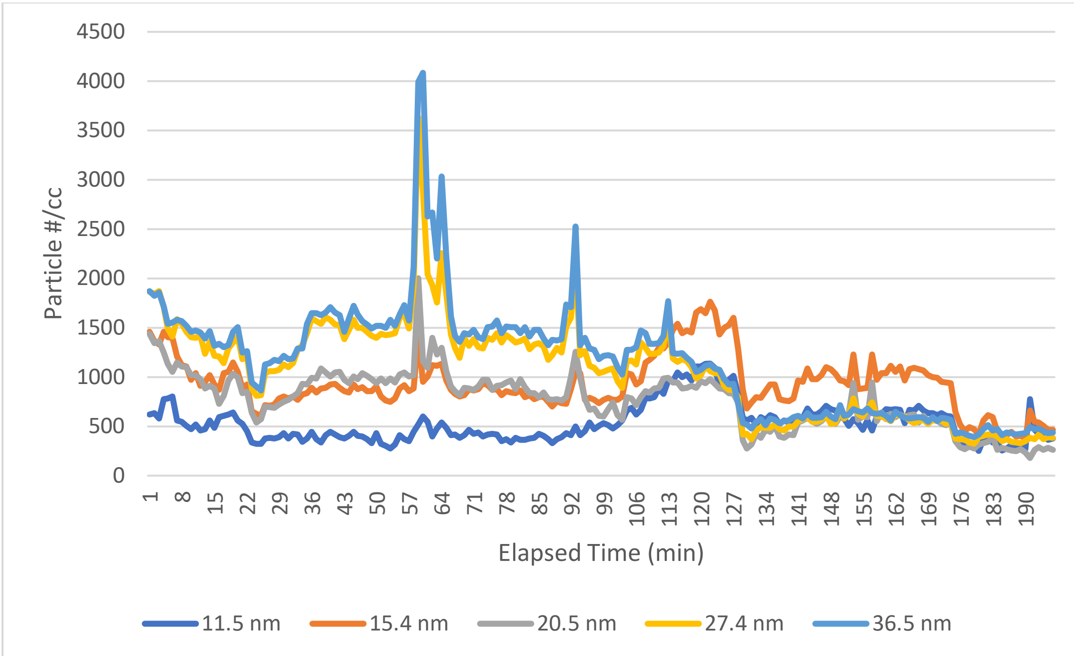

Figure 13. TSI NanoScan Plot for UFPs on 5-20

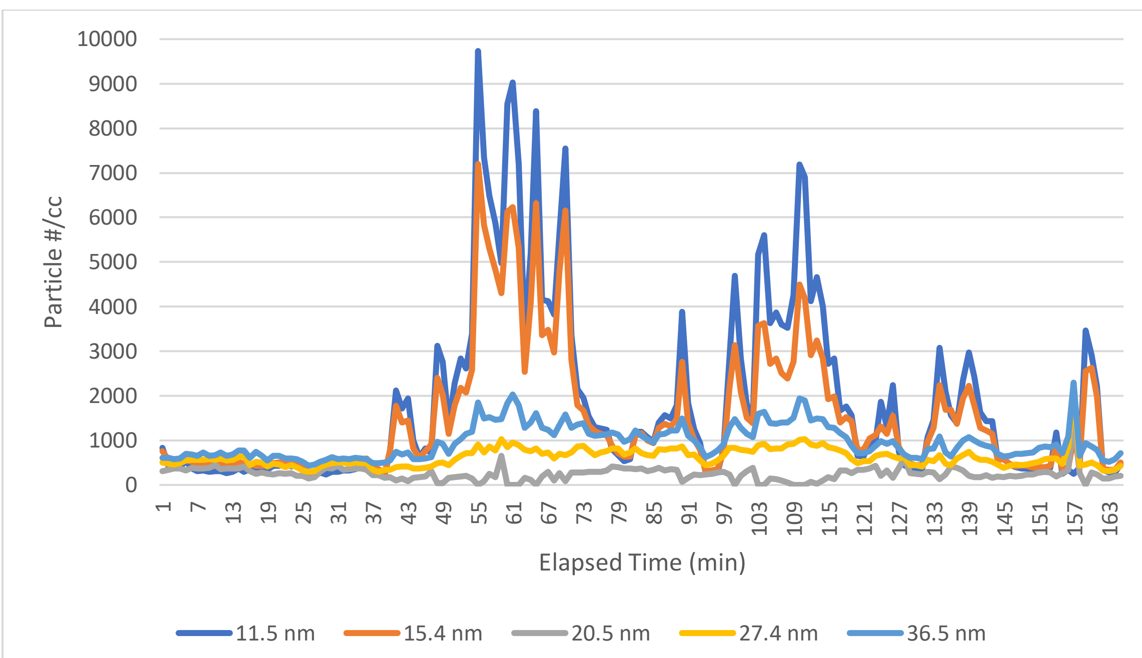

Figure 14. TSI NanoScan Plot for UFPs on 5-21

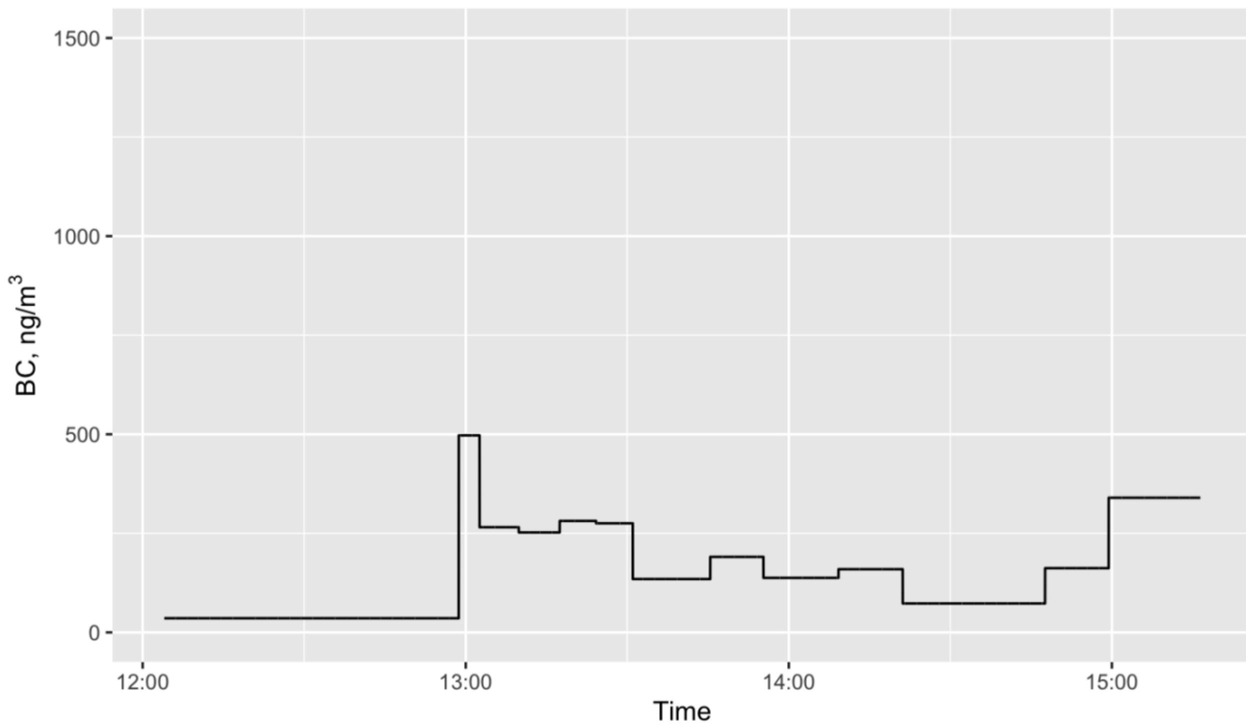

Figure 15. AE51 Black Carbon Time Series Plot After ONA Correction on 5-17

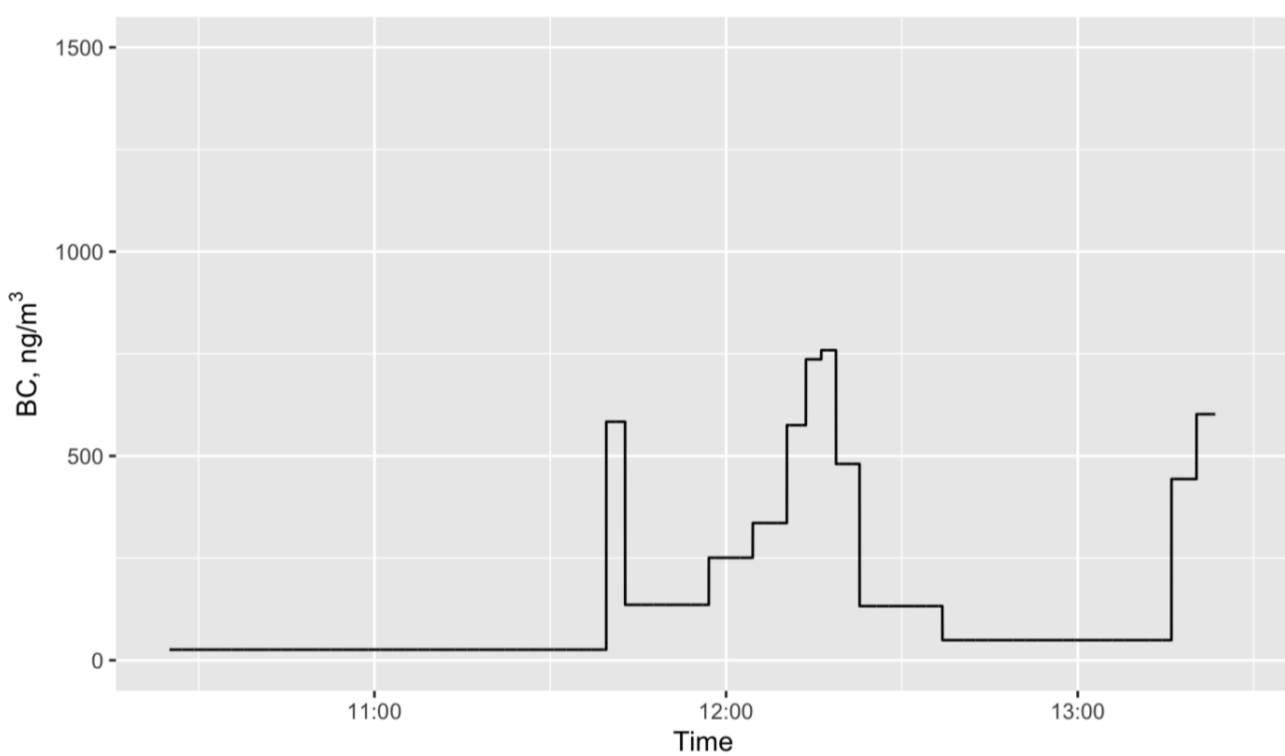

Figure 16. AE51 Black Carbon Time Series Plot After ONA Correction on 5-19

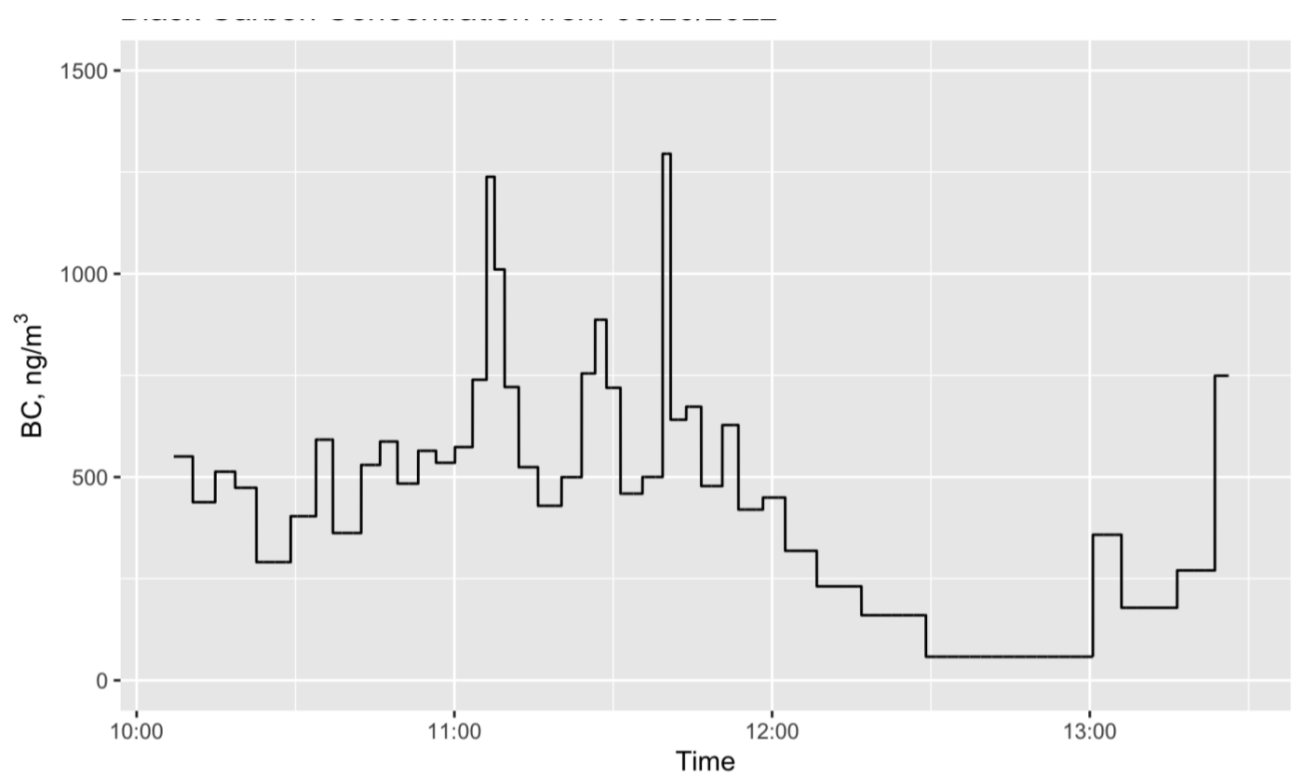

Figure 17. AE51 Black Carbon Time Series Plot After ONA Correction on 5-20

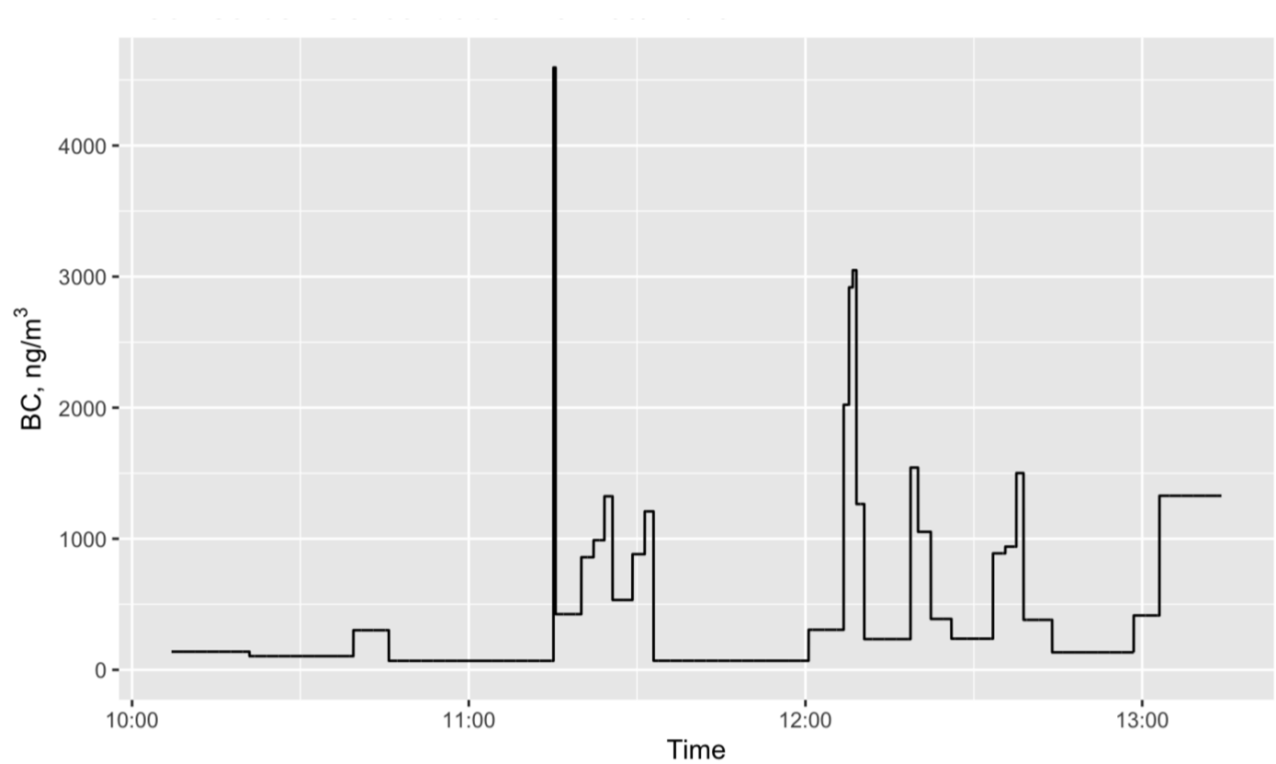

Figure 18. AE51 Black Carbon Time Series Plot After ONA Correction on 5-21

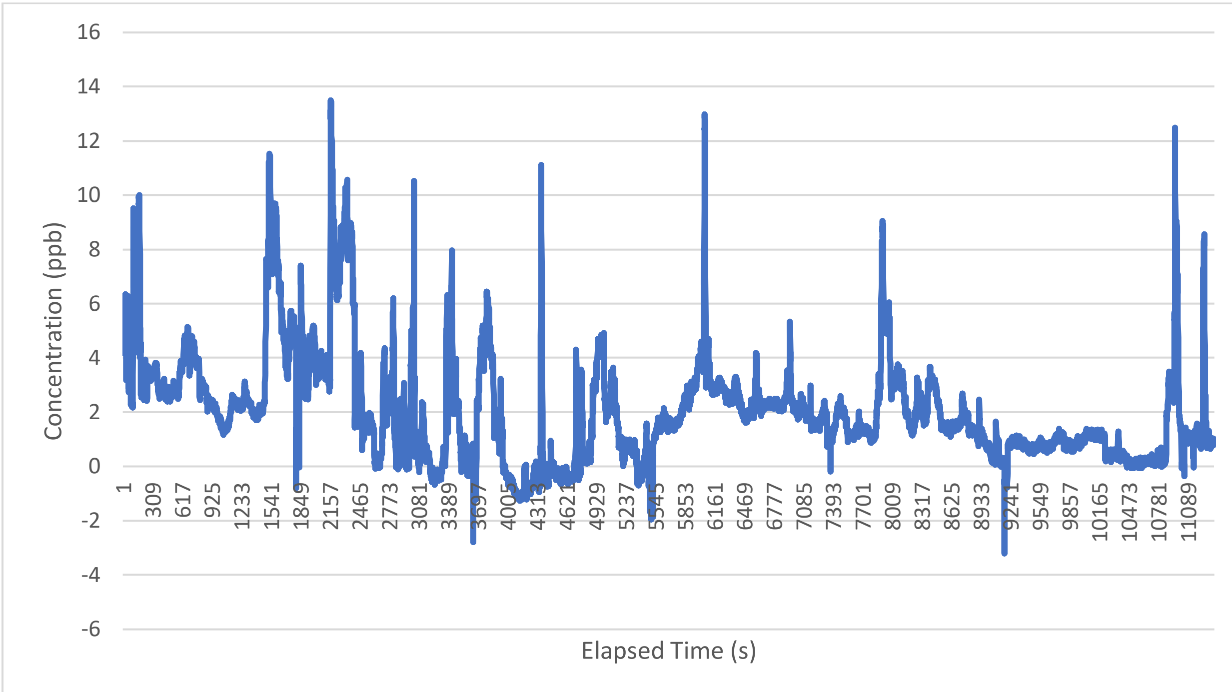

Figure 19. Aerodyne CAPS NO_2 Time Series Plot on 5-17

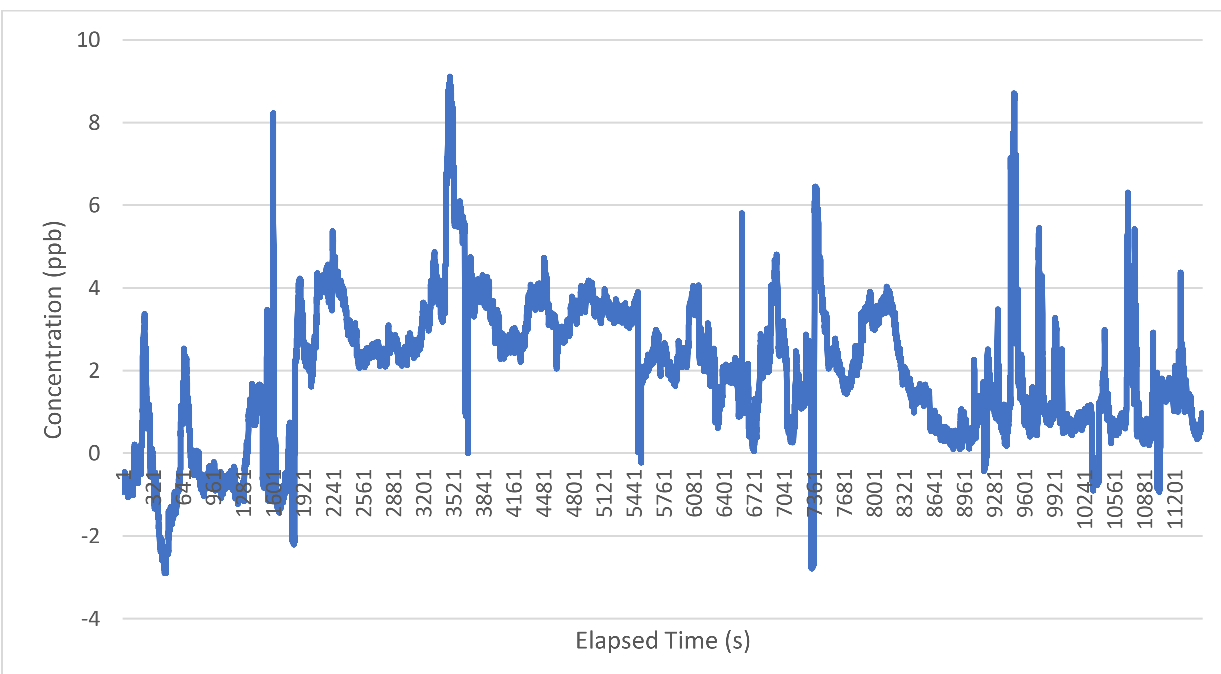

Figure 20. Aerodyne CAPS NO_2 Time Series Plot on 5-19

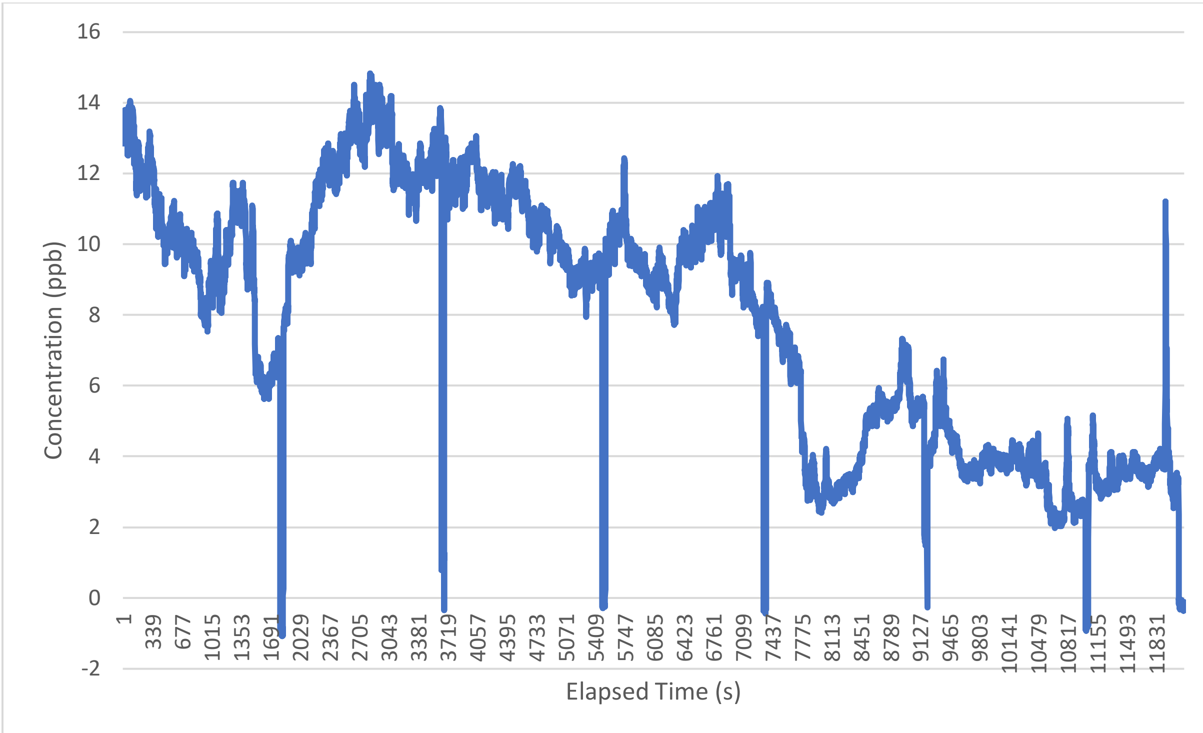

Figure 21. Aerodyne CAPS NO_2 Time Series Plot on 5-20

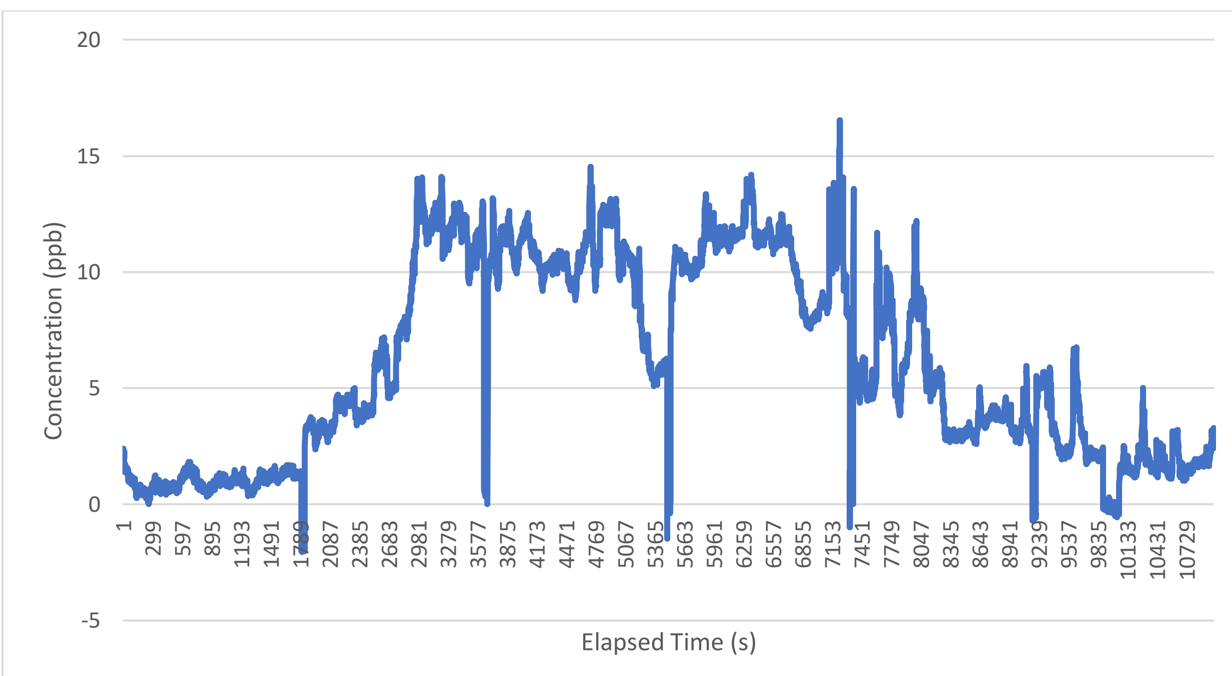

Figure 22. Aerodyne CAPS NO_2 Time Series Plot on 5-21

Health Data

The majority of the 4 participants were in their mid 20s (75%) and female (75%). Both asthmatics were diagnosed with asthma at a young age. A more detailed demographic breakdown is in Table 7. All health measures, including baseline measures on exposure and non-exposure days are presented in the Appendix.

Table 7. Subject Demographics. Numbers and types of participants or mean [min, max] of demographic variables

	Healthy	**Asthmatic**
N	2	2
Age (years)	37 [25, 49]	25.5 [24, 27]
Sex	1 M, 1 F	2 F
Weight (kg)	68.5 [61, 76]	55 [54, 56]
Height (cm)	172.5 [170, 175]	163 [161, 165]

Tables 8 through 10 show the average of within-person relative difference in effects. This was the exposure minus the non-exposure results at same time point, that were baseline-adjusted, relative to baseline non-exposed measure. When the baseline non-exposure measure is 0, the value 1 was used to avoid division by 0 (which only potentially occurs in the stress questionnaire responses).

Heart rate, HRV, FEV_1, and FVC is where we saw the biggest effects in our asthmatic group. For heart rate and HRV, we saw opposite effects when comparing our healthy and asthmatic groups. For all three time points, the heart rate showed a negative scale, or decrease in the relative difference for the healthy group while the asthmatic group showed a positive scale, or increase. On the Omron BP, the heart rate decreased by 4% at 90 minutes in the healthy group compared to the 9.5% increase in the asthmatic group. For all three time points, the HRV increased or remained the same for the healthy group while the asthmatic group decreased. The healthy group's HRV increased by 35% while the asthmatics group decreased by 149% at 90 minutes.

On our spirometer, our FEV_1 and FVC results showed similar trends, the healthy and asthmatic increased and decreased at the same time points. For FVC, the healthy group increased 9 % at 30 minutes and decreased 17% at 90 minutes while the asthmatic group increased 14% at 30 minutes and decreased 32% at 90 minutes. The FEV_1 showed the healthy group to increase decrease 1% and the asthmatic group decreased 3.5% at 60 minutes.

Table 8. Average of within-person relative difference in effects for Healthy Group

		30 mins	60 mins	90 mins
Stress Test				
Tense/Anxious				1.00
Angry/hostile				-3.00
Depressed/blue				0.00
Frustrated				-2.50
Unhappy				0.00
Stroop Test				
Congruent (ms)				0.07
Incongruent (ms)				0.06
Stroop Effect (ms)				-0.95
Pulse Oximeter				
%SpO2		-0.02	-0.02	-0.02
HR		-0.11	0.04	0.05
PI		-0.43	-1.93	-1.00
Blood Pressure				
SBP		-0.04	-0.04	0.09
DBP		-0.02	0.10	0.07
HR		-0.06	-0.07	-0.04
Apple Watch				
HR		0.09	0.03	0.08
HRV (ms)		0.13	0.00	0.35
Spirometry				
FEV_1 (L)		0.00	-0.01	0.01
FVC (L)		0.09	-0.09	-0.17
PEF (L/s)		0.09	0.15	0.12
FEV_1/FVC		-0.05	0.08	0.14

Table 9. Average of within-person relative difference in effects for Asthmatic Group

		30 mins	60 mins	90 mins
Stress Test				
Tense/Anxious				2.25
Angry/hostile				0.00
Depressed/blue				0.00
Frustrated				0.00
Unhappy				0.00
Stroop Test				
Congruent (ms)				0.25
Incongruent (ms)				0.22
Stroop Effect (ms)				1.72
Pulse Oximeter				
%SpO2		0.01	-0.01	-0.01
HR		0.13	0.18	0.16
PI		0.43	-0.65	0.34
Blood Pressure				
SBP		-0.11	-0.02	-0.08
DBP		-0.08	-0.05	-0.03
HR		0.08	0.09	0.10
Apple Watch				
HR		-0.02	-0.04	0.07
HRV (ms)		-0.87	-0.79	-1.49
Spirometry				
FEV_1 (L)		-0.01	-0.04	0.00
FVC (L)		0.14	-0.16	-0.32
PEF (L/s)		0.08	0.01	0.00
FEV_1/FVC		-0.11	0.10	0.23

Table 10. Average of within-person relative difference in effects for All

		30 mins	60 mins	90 mins
Stress Test				
Tense/Anxious				1.63
Angry/hostile				-1.50
Depressed/blue				0.00
Frustrated				-1.25
Unhappy				0.00
Stroop Test				
Congruent (ms)				0.16
Incongruent (ms)				0.14
Stroop Effect (ms)				0.39
Pulse Oximeter				
%SpO2		-0.01	-0.01	-0.01
HR		0.01	0.11	0.11
PI		0.00	-1.29	-0.33
Blood Pressure				
SBP		-0.07	-0.03	0.01
DBP		-0.05	0.03	0.02
HR		0.01	0.01	0.03
Apple Watch				
HR		0.03	-0.01	0.08
HRV (ms)		-0.37	-0.40	-0.57
Spirometry				
FEV_1 (L)		0.00	-0.02	0.00
FVC (L)		0.11	-0.13	-0.24
PEF (L/s)		0.08	0.08	0.06
FEV_1/FVC		-0.08	0.09	0.19

Discussion

Findings from Aim 1

As shown from our exposure data results, we were able to successfully collect all data for our air monitoring. We were able to take instruments with size bins, 3330 and NanoScan, to see the size distributions of particles and UFPs from the emissions. As expected, most days we mainly saw smaller size UFPs, less than 35 nm, which are attributed to aircraft emissions. We also saw some larger UFPs, greater than 50 nm, which we attribute to roadway pollution. This makes sense as we were sampling in a parking lot and could not account for the cars driving around. We also measured PM, and saw that the smaller size particles, especially the smallest at 0.3 µm, had the highest particle counts. On the days that the roadway-sized UFP concentrations and larger PM were higher, BC and NO_2 concentrations were also higher.

Findings from Aim 2

As shown from our results from our initial day of testing, we were able to test the efficiency of our PAPR. As we saw in Figure 6, the PAPR had an almost 100% particle and UFP removal efficiency with the HEPA + Organics filter installed. While some of our measurements under the PAPR were greater than 0 in concentration, we also noted that the seal around the sampling tube was not as tight as the seal would be around the participant's face. We wrapped our hand around the tube to put it under the PAPR, which would not be as tight as fit with a tight elastic band.

This could account for some of the particles that got under the PAPR while sampling for removal efficiency.

Findings from Aim 3

As shown from our results in the human health data, we were able to collect preliminary data for changes in cardiorespiratory measures in our two populations. We also successfully collected neuropsychological data with our stress EMA and Stroop test. The most notable changes we saw were heart rate, HRV, FEV_1, and FVC. Heart rate and HRV showed opposite changes in the healthy and HRV population, with the healthy population showing positive health changes and the asthmatics showing an adverse health change. The FEV_1 and FVC showed the same changes, just a larger scale on the asthmatic population.

Previous Studies

In comparison to previous similar studies, our study had some similarities and differences. For human health data, previous studies showed an association between aircraft UFPs and IL-6. We cannot make a comparison without data, as we did not collect blood measurements. The same study from Habre et al. showed an association with roadway UFPs and sTNFrII, which is also a blood measure and therefore we cannot compare. The study also showed an association between roadway traffic UFPs and decreased FEV_1 in asthmatics. The study found counterintuitive increases in FEV_1 and FVC with exposure to aircraft UFPs, but these increases were not statistically significant. Based on our data, we saw suggestions of a relationship between aircraft

UFPs and FEV_1 as well as FVC. Further testing would be needed to confirm this relationship, as we did not calculate the strength of association nor confidence between our exposures and health outcomes given the small number of subjects in this feasibility study. For exposure data, previous studies showed that aircraft UFPs were higher in particle counts on the days where planes were landing. This was due to the engines not fully running while planes are landing, causing incomplete combustion, being less efficient and not burning as clean. All these factors generally lead to more particle emission (Austin et al., 2021; Graeme and Raper, 2006). In comparisons, while planes are taking off, they use more power and thrust. Both landing and take-offs push air down.

Strengths and Limitations

One of our study's strengths was that we successfully collected all our exposure and human health data. We had well scripted and tested protocols that lead to us successfully carrying out our experiment. Often there are issues with the instruments, the setting, and subjects, so we were fortunate to not run into any issues that prevented us from collecting our data. We observed that the use of Apple Watches was successful for helping study participants maintain consistent heart rate during the walking activity of the study. Another strength is that smaller sized UFP toxicity is very new. While we did see other sources of UFP emissions, conducting air sampling at the site while our subjects were there helped create a better understanding of the potential relationships between exposure to smaller size UFPs and their health effects, especially at varying time-points of short-term exposure. An additional strength is that we are not aware of any PAPR-related aircraft UFP studies. While it may not be feasible for port workers or people in the community to wear PAPRs outside, seeing how adverse health effects may occur even in acute exposure settings could lead to further research on how to provide more protection from these emissions. Further testing would help determine if this trend is true at our study location, or if other environmental factors were affecting the particle counts that day. Should future studies reinforce the relationship between exposure and health effects, and the role of PPE, alternative forms of respiratory protection such as more cost-effective particulate-only N95 respirators could be evaluated and considered for occupational protection.

A limitation to this study was our small sample size. We did not have a very large sample, and therefore did not perform any statistical testing. If we had been able to, we could have assessed the magnitude of associations between the exposure and the outcomes and calculate confidence intervals for the associations. Another limitation was our short sampling period. There could have been a need for a longer washout period, as ours was 24 to 48 hours. This could have affected baseline measurements, as well as the time points on the second day the participants were measured, especially if the smaller UFPs could have had additive, synergistic, or even antagonistic effects in the body. Another reason for a longer sampling period would be to consider another type of filter in the PAPR, e.g., the HEPA filter without organics removal. While we used just a sham or a HEPA + Organics filter, it would have been nice to include the HEPA filter to see if just removing particulates alone made a difference in comparison to removing particles plus VOCs and the sham (no filtration) condition. A longer sampling period would have provided more exposure data as well. We saw some differences in exposure data, and it is hard to determine whether it was due to changes in weather or flight path, which collecting more data would help us analyze the trends.

For future research, we would like to create a larger sample size and have a longer sampling period. Having a larger sample size would increase our human health data and address some of the concerns discussed in our limitations. Having a longer sampling period would increase our exposure data which would also address some of our concerns discussed in our limitations. We would also like to include blood work measurements, that could then be compared to and expand upon the blood work results from previous studies. It would also be beneficial to potentially find a less road traffic heavy site, as we could see on the third day that the road traffic potentially impacted our exposure data. If the site was also further west, so it would be closer to the more used runway, it may also help ensure that the health effects we see are mainly related to aircraft.

Conclusion

Jet fuel emissions are common at and in areas surrounding airports. The typical combustion emissions produce VOCs, CO_2, CO, NO_x, SO_x, PAHs, and PM, with incomplete combustion products measured as BC and UFP. While we measured multiple combustion byproducts, our study focused on UFPs and their size distribution. Previous studies have reported aircraft combustion UFPs to range from 5 to 40 nm, in comparison to roadway UFPs typically being greater than 35 nm. Exposure to UFPs has been associated with decreased lung function and increased inflammation in those with asthma. A study conducted near LAX also showed an association between aircraft specific UFPs and IL-6. A previous study conducted around SeaTac Airport observed elevated levels of small UFPs, less than 20 nm, attributable to downwind plumes of emissions from aircrafts. Our aims in this study were to characterize particles concentrations and sizes at a community center under the flight path near SeaTac Airport, to characterize the particle exposure reduction with PAPR for HEPA + Organics filter, and to collect preliminary data on changes in cardiorespiratory measure with and without the use of PAPRs to control exposures at the community site.

Our results showed that the site did have elevated level of smaller sized UFPs, attributable to aircraft emissions. The exposure data also showed results of smaller sizes of PM as well. On days where the larger sized UFPs were greater in concentration, so were BC, NO_2, and larger size PMs, which are attributable to roadway traffic exposures. Our data also showed the highest results of small sized UFPs to be the day when planes were taking off rather than landing. Our small, randomized crossover study employing the PAPR to control exposure found baseline adjusted relative differences to be opposite and greater in effects for heart rate and HRV when comparing the healthy population. It also showed relative differences for FEV_1 and FVC to have the same directionality in effects, but also greater differences in asthmatic when compared to our healthy population. While we did not test confidence or association in this feasibility study, based on our data we saw relative differences changes between the healthy and asthmatic populations after a short-term exposures lasting 90 minutes or less, which indicate the need for further study of acute health effects from exposures.

We hope to use this study, including using the now tested protocols and controls, to create a larger study. A larger sample size will help us create a stronger association and confidence between exposure and health outcomes, and a longer sampling period will help us determine trends in the exposure data. We hope to keep our protocols, while adding potentially more health determinants, including blood work, for future studies.

This study only assessed short term exposures near airport runways, outside of airport working grounds. Airport workers and community residents may experience both higher or longer-term exposures and be exposed more chronically at closer locations to runways, that should be considered for future research. While our study helped characterize and quantify potential exposures to aircraft emissions and their health outcomes, specifically UFPs, continued research would help address occupational and public health concerns.

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Appendix

Health Data Tables

AU1:

Non-exposure day

	Baseline	**30 mins**	**60 mins**	**90 mins**	**Avg**	**SD**
Stress Test						
Tense/Anxious	10			5	**7.50**	**3.54**
Angry/hostile	0			3	**1.50**	**2.12**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	810			821	**815.50**	**7.78**
Incongruent (ms)	993			962	**977.50**	**21.92**
Stroop Effect (ms)	183			141	**162.00**	**29.70**
Pulse Oximeter						
%SpO2	96	97	96	97	**96.50**	**0.58**
HR	76	88	79	74	**79.25**	**6.18**
PI	2.2	9.6	7.9	3.5	**5.80**	**3.52**
Blood Pressure 1						
SBP	167	151	156	145	**154.63**	**9.39**
DBP	109	100	97	105	**102.75**	**5.32**
HR	68	76	78	82	**75.88**	**5.89**
Apple Watch						
HR	76.33	79.67	77	78.33	**77.83**	**1.48**
HRV (ms)	34	33	31	31	**32.25**	**1.50**
Spirometry						
FEV_1 (L)	2.8	2.74	2.81	2.8	**2.79**	**0.03**
FVC (L)	3.27	3.41	3.41	3.48	**3.39**	**0.09**
PEF (L/s)	8.21	7.49	6.94	7.72	**7.59**	**0.53**
FEV_1/FVC	86	80	82	80	**82**	**2.83**

Exposure day

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	30			40	**35**	**7.07**
Angry/hostile	20			20	**20**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	20			15	**17.5**	**3.54**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	586			620	**603**	**24.04**
Incongruent (ms)	765			897	**831**	**93.34**
Stroop Effect (ms)	179			277	**228**	**69.30**
Pulse Oximeter						
%SpO2	99	96	96	98	**97.25**	**1.50**
HR	76	80	89	74	**79.75**	**6.65**
PI	5.4	12.9	7.2	2.3	**6.95**	**4.45**
Blood Pressure 1						
SBP	171.5	156	156.5	173.5	**164.38**	**9.42**
DBP	107	101.5	107.5	104.5	**105.13**	**2.75**
HR	76.5	76.5	77	76.5	**76.63**	**0.25**
Apple Watch						
HR	78.33	79	78	76.67	**78**	**0.98**
HRV (ms)	45	33	23	42	**35.75**	**9.91**
Spirometry						
FEV_1 (L)	2.79	2.76	2.75	2.89	**2.80**	**0.06**
FVC (L)	3.66	3.54	4.12	4.18	**3.88**	**0.32**
PEF (L/s)	8.01	8.02	8.57	8.97	**8.39**	**0.47**
FEV_1/FVC	76	78	67	69	**72.50**	**5.32**

Within-person difference

(Exposure - Non-exposure at the same time point)

	Baseline	**30 mins**	**60 mins**	**90 mins**	**Avg**	**SD**
Stress Test						
Tense/Anxious	20			35	**27.50**	**10.61**
Angry/hostile	20			17	**18.50**	**2.12**
Depressed/blue	0			0	**0**	**0**
Frustrated	20			15	**17.50**	**3.54**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	-224	0	0	-201	**-106.25**	**123.05**
Incongruent (ms)	-228	0	0	-65	**-73.25**	**107.62**
Stroop Effect (ms)	-4	0	0	136	**33**	**68.69**
Pulse Oximeter						
%SpO2	3	-1	0	1	**0.75**	**1.71**
HR	0	-8	10	0	**0.50**	**7.37**
PI	3.2	3.3	-0.70	-1.2	**1.15**	**2.43**
Blood Pressure 1						
SBP	4.5	5.5	0.5	28.50	**9.75**	**12.69**
DBP	-2	1.5	10.5	-0.50	**2.38**	**5.60**
HR	8.5	1	-1	-5.50	**0.75**	**5.84**
Apple Watch						
HR	2	-0.67	1	-1.67	**0.17**	**1.64**
HRV (ms)	11	0	-8	11	**3.50**	**9.26**
Spirometry						
FEV_1 (L)	-0.01	0.02	-0.06	0.09	**0.01**	**0.06**
FVC (L)	0.39	0.13	0.71	0.70	**0.48**	**0.28**
PEF (L/s)	-0.20	0.53	1.63	1.25	**0.80**	**0.81**
FEV_1/FVC	-10	-2	-15	-11	**-9.50**	**5.45**

Within-person difference

(Exposure - Non-exposure at the same time point, baseline-adjusted)

		30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious				15		
Angry/hostile				-3		
Depressed/blue				0		
Frustrated				-5		
Unhappy				0		
Stroop Test						
Congruent (ms)				23		
Incongruent (ms)				163		
Stroop Effect (ms)				140		
Pulse Oximeter						
%SpO2		-4	-3	-2	-3	1
HR		-8	10	0	0.67	9.02
PI		0.10	-3.90	-4.40	-2.73	2.47
Blood Pressure 1						
SBP		1	-4	24	7	14.93
DBP		3.50	12.50	1.50	5.83	5.86
HR		-7.50	-9.50	-14	-10.33	3.33
Apple Watch						
HR		-2.67	-1	-3.67	-2.44	1.35
HRV (ms)		-11	-19	0	-10	9.54
Spirometry						
FEV_1 (L)		0.03	-0.05	0.10	0.03	0.08
FVC (L)		-0.26	0.32	0.31	0.12	0.33
PEF (L/s)		0.73	1.83	1.45	1.34	0.56
FEV_1/FVC		8	-5	-1	0.67	6.66

Within-person relative differences
(Exposure - Non-exposure at the same time point, baseline-adjusted, relative to baseline non-exposed measure*)

		30 mins	60 mins	90 mins
Stress Test				
Tense/Anxious				1.5
Angry/hostile				-3
Depressed/blue				0
Frustrated				-5
Unhappy				0
Stroop Test				
Congruent (ms)				0.028
Incongruent (ms)				0.164
Stroop Effect (ms)				0.765
Pulse Oximeter				
%SpO2		-0.042	-0.031	-0.021
HR		-0.105	0.132	0
PI		0.045	-1.773	-2
Blood Pressure 1				
SBP		0.006	-0.024	0.144
DBP		0.032	0.115	0.014
HR		-0.110	-0.140	-0.206
Apple Watch				
HR		-0.035	-0.013	-0.048
HRV (ms)		-0.324	-0.559	0
Spirometry				
FEV_1 (L)		0.011	-0.018	0.036
FVC (L)		-0.080	0.098	0.095
PEF (L/s)		0.089	0.223	0.177
FEV_1/FVC		0.093	-0.058	-0.012

AU2:

Non-exposure day

	Baseline	**30 mins**	**60 mins**	**90 mins**	**Avg**	**SD**
Stress Test						
Tense/Anxious	10			5	**7.50**	**3.54**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	843			609	**726**	**165.46**
Incongruent (ms)	791			675	**733**	**82.02**
Stroop Effect (ms)	-52			66	**7**	**83.44**
Pulse Oximeter						
%SpO2	98	96	99	97	**97.50**	**1.29**
HR	104	82	96	108	**97.50**	**11.47**
PI	5.30	9.90	4.50	3.40	**5.78**	**2.86**
Blood Pressure						
SBP	112.50	113.50	119.50	119.50	**116.25**	**3.77**
DBP	75	75.50	84	81.50	**79**	**4.45**
HR	99	91.50	97	103	**97.63**	**4.78**
Apple Watch						
HR	97.33	97.67	99.33	107.67	**100.50**	**4.86**
HRV (ms)	18	36	28	18	**25**	**8.72**
Spirometry						
FEV_1 (L)	3.22	3.15	3.07	3.11	**3.14**	**0.06**
FVC (L)	4.05	4.06	5.09	5.69	**4.72**	**0.81**
PEF (L/s)	6.89	6.07	5.77	6.04	**6.19**	**0.48**
FEV_1/FVC	80	78	60	55	**68.25**	**12.61**

Exposure day

	Baseline	**30 mins**	**60 mins**	**90 mins**	**Avg**	**SD**
Stress Test						
Tense/Anxious	30			45	**37.50**	**10.61**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	810			839	**824.50**	**20.51**
Incongruent (ms)	849			855	**852.00**	**4.24**
Stroop Effect (ms)	39			16	**27.50**	**16.26**
Pulse Oximeter						
%SpO2	97	96	97	97	**96.75**	**0.50**
HR	78	85	92	96	**87.75**	**7.93**
PI	6.90	13.90	5.60	4.50	**7.73**	**4.23**
Blood Pressure						
SBP	114.50	110.50	127.50	120.50	**118.25**	**7.41**
DBP	78	72.50	74.50	87.50	**78.13**	**6.65**
HR	82	84.5	89	93.50	**87.25**	**5.07**
Apple Watch						
HR	91.33	99.33	89.67	101.67	**95.50**	**5.89**
HRV (ms)	50	34	34	35	**38.25**	**7.85**
Spirometry						
FEV_1 (L)	3.20	3.12	3.02	3.07	**3.10**	**0.08**
FVC (L)	4.13	5.2	4.04	4.04	**4.35**	**0.57**
PEF (L/s)	7.59	7.36	6.97	7.13	**7.26**	**0.27**
FEV_1/FVC	77	60	75	76	**72**	**8.04**

Within-person difference
(Exposure - Non-exposure at the same time point)

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	20			40	**30**	**14.14**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	-33	0	0	230	**49.25**	**121.50**
Incongruent (ms)	58	0	0	180	**59.50**	**84.86**
Stroop Effect (ms)	91	0	0	-50	**10.25**	**58.77**
Pulse Oximeter						
%SpO2	-1	0	-2	0	**-0.75**	**0.96**
HR	-26	3	-4	-12	**-9.75**	**12.45**
PI	1.60	4	1.10	1.10	**1.95**	**1.39**
Blood Pressure						
SBP	2	-3	8	1	**2**	**4.55**
DBP	3	-3	-9.50	6	**-0.88**	**6.86**
HR	-17	-7	-8	-9.50	**-10.38**	**4.53**
Apple Watch						
HR	-6	1.67	-9.67	-6	**-5**	**4.77**
HRV (ms)	32	-2	6	17	**13.25**	**14.73**
Spirometry						
FEV_1 (L)	-0.02	-0.03	-0.05	-0.04	**-0.03**	**0.01**
FVC (L)	0.08	1.14	-1.05	-1.65	**-0.37**	**1.24**
PEF (L/s)	0.70	1.29	1.20	1.09	**1.07**	**0.26**
FEV_1/FVC	-3	-18	15	21	**3.75**	**17.73**

Within-person difference

(Exposure - Non-exposure at the same time point, baseline-adjusted)

		30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious				20		
Angry/hostile				0		
Depressed/blue				0		
Frustrated				0		
Unhappy				0		
Stroop Test						
Congruent (ms)				263		
Incongruent (ms)				122		
Stroop Effect (ms)				-141		
Pulse Oximeter						
%SpO2		1	-1	1	0.33	1.15
HR		29	22	14	21.67	7.51
PI		2.40	-0.50	-0.50	0.47	1.67
Blood Pressure						
SBP		-5	6	-1	0	5.57
DBP		-6	-12.5	3	-5.17	7.78
HR		10	9	7.5	8.83	1.26
Apple Watch						
HR		7.67	-3.67	0	1.33	5.78
HRV (ms)		-34	-26	-15	-25	9.54
Spirometry						
FEV_1 (L)		-0.01	-0.03	-0.02	-0.02	0.01
FVC (L)		1.06	-1.13	-1.73	-0.60	1.47
PEF (L/s)		0.59	0.5	0.39	0.49	0.10
FEV_1/FVC		-15	18	24	9	21

Within-person relative differences
(Exposure - Non-exposure at the same time point, baseline-adjusted, relative to baseline non-exposed measure*)

		30 mins	60 mins	90 mins
Stress Test				
Tense/Anxious				2
Angry/hostile				0
Depressed/blue				0
Frustrated				0
Unhappy				0
Stroop Test				
Congruent (ms)				0.31
Incongruent (ms)				0.15
Stroop Effect (ms)				2.71
Pulse Oximeter				
%SpO2		0.01	-0.01	0.01
HR		0.28	0.21	0.13
PI		0.45	-0.09	-0.09
Blood Pressure				
SBP		-0.04	0.05	-0.01
DBP		-0.08	-0.17	0.04
HR		0.10	0.09	0.08
Apple Watch				
HR		0.08	-0.04	0
HRV (ms)		-1.89	-1.44	-0.83
Spirometry				
FEV_1 (L)		0.00	-0.01	-0.01
FVC (L)		0.26	-0.28	-0.43
PEF (L/s)		0.09	0.07	0.06
FEV_1/FVC		-0.19	0.23	0.30

AU3:

Non-exposure day

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	10			5	**7.50**	**3.54**
Angry/hostile	0			3	**1.50**	**2.12**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	909			746	**827.50**	**115.26**
Incongruent (ms)	967			921	**944**	**32.53**
Stroop Effect (ms)	58			185	**121.50**	**89.80**
Pulse Oximeter						
%SpO2	97	97	96	98	**97**	**0.82**
HR	65	69	72	68	**68.50**	**2.89**
PI	2.30	9	9.40	2.20	**5.73**	**4.02**
Blood Pressure						
SBP	126	132	128	118	**126**	**5.89**
DBP	88	93	80	76.50	**84.38**	**7.50**
HR	68	68	67.50	68.50	**68**	**0.41**
Apple Watch						
HR	83.67	73.33	80	67.33	**76.08**	**7.23**
HRV (ms)	90	83	92	82	**86.75**	**4.99**
Spirometry						
FEV_1 (L)	3.22	3.15	3.07	3.11	**3.14**	**0.06**
FVC (L)	4.05	4.06	5.09	5.69	**4.72**	**0.81**
PEF (L/s)	6.89	6.07	5.77	6.04	**6.19**	**0.48**
FEV_1/FVC	80	78	60	55	**68.25**	**12.61**

Exposure day

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	0			0	**0**	**0**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	629			568	**598.50**	**43.13**
Incongruent (ms)	860			773	**816.50**	**61.52**
Stroop Effect (ms)	231			204	**217.50**	**19.09**
Pulse Oximeter						
%SpO2	98	98	97	98	**97.75**	**0.50**
HR	62	59	65	72	**64.50**	**5.57**
PI	1.20	5.80	3.50	1.10	**2.90**	**2.23**
Blood Pressure						
SBP	126.50	122	122	123.50	**123.50**	**2.12**
DBP	77.50	75.50	76.50	77	**76.63**	**0.85**
HR	63.50	63	63.50	72.50	**65.63**	**4.59**
Apple Watch						
HR	68.33	75.33	70.67	69.67	**71**	**3.04**
HRV (ms)	28	74	80	83	**66.25**	**25.77**
Spirometry						
FEV_1 (L)	3.20	3.12	3.02	3.07	**3.10**	**0.08**
FVC (L)	4.13	5.20	4.04	4.04	**4.35**	**0.57**
PEF (L/s)	7.59	7.36	6.97	7.13	**7.26**	**0.27**
FEV_1/FVC	77	60	75	76	**72**	**8.04**

Within-person difference
(Exposure - Non-exposure at the same time point)

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	-10			-5	**-7.50**	**3.54**
Angry/hostile	0			-3	**-1.50**	**2.12**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	-280	0	0	-178	**-114.50**	**138.62**
Incongruent (ms)	-107	0	0	-148	**-63.75**	**75.49**
Stroop Effect (ms)	173	0	0	19	**48**	**83.81**
Pulse Oximeter						
%SpO2	1	1	1	0	**0.75**	**0.50**
HR	-3	-10	-7	4	**-4**	**6.06**
PI	-1.10	-3.20	-5.90	-1.10	**-2.83**	**2.28**
Blood Pressure						
SBP	0.50	-10	-6	5.50	**-2.50**	**6.87**
DBP	-10.50	-17.50	-3.50	0.50	**-7.75**	**7.93**
HR	-4.5	-5	-4	4	**-2.38**	**4.27**
Apple Watch						
HR	-15.33	2	-9.33	2.33	**-5.08**	**8.72**
HRV (ms)	-62	-9	-12	1	**-20.50**	**28.22**
Spirometry						
FEV_1 (L)	-0.02	-0.03	-0.05	-0.04	**-0.03**	**0.01**
FVC (L)	0.08	1.14	-1.05	-1.65	**-0.37**	**1.24**
PEF (L/s)	0.70	1.29	1.20	1.09	**1.07**	**0.26**
FEV_1/FVC	-3	-18	15	21	**3.75**	**17.73**

Within-person difference

(Exposure - Non-exposure at the same time point, baseline-adjusted)

		30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious				5		
Angry/hostile				-3		
Depressed/blue				0		
Frustrated				0		
Unhappy				0		
Stroop Test						
Congruent (ms)				102		
Incongruent (ms)				-41		
Stroop Effect (ms)				-154		
Pulse Oximeter						
%SpO2		0	0	-1	-0.33	0.58
HR		-7	-4	7	-1.33	7.37
PI		-2.10	-4.80	0.00	-2.30	2.41
Blood Pressure						
SBP		-10.50	-6.50	5	-4.00	8.05
DBP		-7	7	11	3.67	9.45
HR		-0.50	0.50	8.50	2.83	4.93
Apple Watch						
HR		17.33	6	17.67	13.67	6.64
HRV (ms)		53	50	63	55.33	6.81
Spirometry						
FEV_1 (L)		-0.01	-0.03	-0.02	-0.02	0.01
FVC (L)		1.06	-1.13	-1.73	-0.60	1.47
PEF (L/s)		0.59	0.50	0.39	0.49	0.10
FEV_1/FVC		-15	18	24	9	21

Within-person relative differences
(Exposure - Non-exposure at the same time point, baseline-adjusted, relative to baseline non-exposed measure*)

		30 mins	**60 mins**	**90 mins**
Stress Test				
Tense/Anxious				0.500
Angry/hostile				-3
Depressed/blue				0
Frustrated				0
Unhappy				0
Stroop Test				
Congruent (ms)				0.112
Incongruent (ms)				-0.042
Stroop Effect (ms)				-2.655
Pulse Oximeter				
%SpO2		0	0	-0.010
HR		-0.108	-0.062	0.108
PI		-0.913	-2.087	0.000
Blood Pressure				
SBP		-0.083	-0.052	0.040
DBP		-0.080	0.080	0.125
HR		-0.007	0.007	0.125
Apple Watch				
HR		0.207	0.072	0.211
HRV (ms)		0.589	0.556	0.700
Spirometry				
FEV_1 (L)		-0.003	-0.009	-0.006
FVC (L)		0.262	-0.279	-0.427
PEF (L/s)		0.086	0.073	0.057
FEV_1/FVC		-0.188	0.225	0.300

AU4:

Non-exposure day

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	10			5	**7.50**	**3.54**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	559			568	**563.50**	**6.36**
Incongruent (ms)	698			634	**666**	**45.25**
Stroop Effect (ms)	139			67	**103**	**50.91**
Pulse Oximeter						
%SpO2	98	97	98	99	**98**	**0.82**
HR	75	74	77	75	**75.25**	**1.26**
PI	5.50	4.80	13.20	3	**6.63**	**4.51**
Blood Pressure						
SBP	104.50	121.50	117	117.50	**115.13**	**7.36**
DBP	61	71.50	66.50	72	**67.75**	**5.14**
HR	76.50	66.50	70.50	75	**72.13**	**4.53**
Apple Watch						
HR	77	74	74	75.33	**75.08**	**1.42**
HRV (ms)	58	72	108	137	**93.75**	**35.71**
Spirometry						
FEV_1 (L)	2.86	2.83	2.88	2.88	**2.86**	**0.02**
FVC (L)	3.28	3.1	3.3	4.23	**3.48**	**0.51**
PEF (L/s)	6.96	6.7	7.08	7.34	**7.02**	**0.27**
FEV_1/FVC	87	91	87	68	**83.25**	**10.34**

Exposure day

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	10			0	**5**	**7.07**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	559			669	**614**	**77.78**
Incongruent (ms)	695			833	**764**	**97.58**
Stroop Effect (ms)	136			164	**150**	**19.80**
Pulse Oximeter						
%SpO2	99	99	99	98	**98.75**	**0.50**
HR	64	62	77	78	**70.25**	**8.42**
PI	2.40	3.90	3.50	4.20	**3.50**	**0.79**
Blood Pressure						
SBP	120	119	122.5	118	**119.88**	**1.93**
DBP	67	73	77	72	**72.25**	**4.11**
HR	72	66	73	79.5	**72.63**	**5.53**
Apple Watch						
HR	75	63	68.67	84.33	**72.75**	**9.15**
HRV (ms)	81	104	123	35	**85.75**	**37.94**
Spirometry						
FEV_1 (L)	2.91	2.83	2.75	2.92	**2.85**	**0.08**
FVC (L)	3.44	3.3	3.32	3.67	**3.43**	**0.17**
PEF (L/s)	6.57	6.8	6.28	6.51	**6.54**	**0.21**
FEV_1/FVC	85	86	83	80	**83.50**	**2.65**

Within-person difference
(Exposure - Non-exposure at the same time point)

	Baseline	30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious	0			-5	**-2.50**	**3.54**
Angry/hostile	0			0	**0**	**0**
Depressed/blue	0			0	**0**	**0**
Frustrated	0			0	**0**	**0**
Unhappy	0			0	**0**	**0**
Stroop Test						
Congruent (ms)	0	0	0	101	**25.25**	**50.50**
Incongruent (ms)	-3	0	0	199	**49**	**100.01**
Stroop Effect (ms)	-3	0	0	97	**23.50**	**49.02**
Pulse Oximeter						
%SpO2	1	2	1	-1	**0.75**	**1.26**
HR	-11	-12	0	3	**-5**	**7.62**
PI	-3.1	-0.90	-9.70	1.20	**-3.13**	**4.72**
Blood Pressure						
SBP	15.50	-2.50	5.50	0.50	**4.75**	**7.89**
DBP	6	1.50	10.50	0	**4.50**	**4.74**
HR	-4.50	-0.50	2.50	4.50	**0.50**	**3.92**
Apple Watch						
HR	-2	-11	-5.33	9	**-2.33**	**8.42**
HRV (ms)	23	32	15	-102	**-8**	**63.05**
Spirometry						
FEV_1 (L)	0.05	0	-0.13	0.04	**-0.01**	**0.08**
FVC (L)	0.16	0.2	0.02	-0.56	**-0.05**	**0.35**
PEF (L/s)	-0.39	0.10	-0.80	-0.83	**-0.48**	**0.44**
FEV_1/FVC	-2	-5	-4	12	**0.25**	**7.93**

Within-person difference

(Exposure - Non-exposure at the same time point, baseline-adjusted)

		30 mins	60 mins	90 mins	Avg	SD
Stress Test						
Tense/Anxious				-5		
Angry/hostile				0		
Depressed/blue				0		
Frustrated				0		
Unhappy				0		
Stroop Test						
Congruent (ms)				101		
Incongruent (ms)				202		
Stroop Effect (ms)				100		
Pulse Oximeter						
%SpO2		1	0	-2	-0.33	1.53
HR		-1	11	14	8	7.94
PI		2.20	-6.60	4.30	-0.03	5.78
Blood Pressure						
SBP		-18	-10	-15	-14.33	4.04
DBP		-4.50	4.50	-6	-2	5.68
HR		4	7	9	6.67	2.52
Apple Watch						
HR		-9	-3.33	11	-0.44	10.31
HRV (ms)		9	-8	-125	-41.33	72.95
Spirometry						
FEV_1 (L)		-0.05	-0.18	-0.01	-0.08	0.09
FVC (L)		0.04	-0.14	-0.72	-0.27	0.40
PEF (L/s)		0.49	-0.41	-0.44	-0.12	0.53
FEV_1/FVC		-3	-2	14	3	9.54

Within-person relative differences
(Exposure - Non-exposure at the same time point, baseline-adjusted, relative to baseline non-exposed measure*)

		30 mins	60 mins	90 mins
Stress Test				
Tense/Anxious				-0.5
Angry/hostile				0
Depressed/blue				0
Frustrated				0
Unhappy				0
Stroop Test				
Congruent (ms)				0.18
Incongruent (ms)				0.29
Stroop Effect (ms)				0.72
Pulse Oximeter				
%SpO2		0.01	0	-0.02
HR		-0.01	0.15	0.19
PI		0.40	-1.20	0.78
Blood Pressure				
SBP		-0.17	-0.10	-0.14
DBP		-0.07	0.07	-0.10
HR		0.05	0.09	0.12
Apple Watch				
HR		-0.12	-0.04	0.14
HRV (ms)		0.16	-0.14	-2.16
Spirometry				
FEV_1 (L)		-0.02	-0.06	0.00
FVC (L)		0.01	-0.04	-0.22
PEF (L/s)		0.07	-0.06	-0.06
FEV_1/FVC		-0.03	-0.02	0.16

Healthy Comparisons:

AU1 NE

	Averages				**Differences to Baseline**		
	Basline	**Time 30**	**Time 60**	**Time 90**	**T30-B**	**T60-B**	**T90-B**
Stroop Test							
Congruent (ms)	810	--	--	821	--	--	11
Incongruent (me)	993	--	--	962	--	--	-31
Stroop Effect	183	--	--	141	--	--	-42
Pulse Oximeter							
%SpO2	96	97	96	97	1	0	1
HR	76	88	79	74	12	3	-2
PI	2.2	9.6	7.9	3.5	7.4	5.7	1.3
Blood Pressure							
SBP	167	150.5	156	145	-16.5	-11	-22
DBP	109	100	97	105	-9	-12	-4
HR	68	75.5	78	82	7.5	10	14
Apple Watch							
HR	78.5	77.5	78.5	79	-1	0	0.5
HRV	34	33	31	31	-1	-3	-3

AU3 NE

	Averages				Differences to Baseline		
	Basline	Time 30	Time 60	Time 90	T30-B	T60-B	T90-B
Stroop Test							
Congruent (ms)	909	--	--	746	--	--	-163
Incongruent (me)	967	--	--	921	--	--	-46
Stroop Effect	58	--	--	185	--	--	127
Pulse Oximeter							
%SpO2	97	97	96	98	0	-1	1
HR	65	69	72	68	4	7	3
PI	2.3	9	9.4	2.2	9	9.4	2.2
Blood Pressure							
SBP	126	132	128	118	6	2	-8
DBP	88	93	80	76.5	5	-8	-11.5
HR	68	68	67.5	68.5	0	-0.5	0.5
Apple Watch							
HR	84.5	122	139	128	37.5	54.5	43.5
HRV	18	36	28	18	18	10	0

AU1 E

	Averages				Differences to Baseline		
	Basline	Time 30	Time 60	Time 90	T30-B	T60-B	T90-B
Stroop Test							
Congruent (ms)	586	--	--	620	--	--	34
Incongruent (me)	765	--	--	897	--	--	132
Stroop Effect	179	--	--	277	--	--	98
Pulse Oximeter							
%SpO2	99	96	96	98	-3	-3	-1
HR	76	80	89	74	4	13	-2
PI	5.4	12.9	7.2	2.3	10.7	5	0.1
Blood Pressure							
SBP	171.5	156	156.5	173.5	-15.5	-15	2
DBP	107	101.5	107.5	104.5	-5.5	0.5	-2.5
HR	76.5	76.5	77	76.5	0	0.5	0
Apple Watch							
HR	76.5	79	78.5	79	0.5	0	0.5
HRV	34	33	31	31	-1	-3	-3

AU3 E

	Averages				Differences to Baseline		
	Basline	**Time 30**	**Time 60**	**Time 90**	**T30-B**	**T60-B**	**T90-B**
Stroop Test							
Congruent (ms)	629	--	--	568	--	--	-61
Incongruent (me)	860	--	--	773	--	--	-87
Stroop Effect	231	--	--	204	--	--	-27
Pulse Oximeter							
%SpO2	98	98	97	98	0	-1	0
HR	62	59	65	72	-3	3	10
PI	1.2	5.8	3.5	1.1	5.8	3.5	1.1
Blood Pressure							
SBP	126.5	122	122	123.5	-4.5	-4.5	-3
DBP	77.5	75.5	76.5	77	-2	-1	-0.5
HR	63.5	63	63.5	72.5	-0.5	0	9
Apple Watch							
HR	66.5	132	128	121	65.5	61.5	54.5
HRV	18	36	28	18	18	10	0

Asthmatic Comparisons:

AU2 NE

	Averages				**Differences to Baseline**		
	Basline	**Time 30**	**Time 60**	**Time 90**	**T30-B**	**T60-B**	**T90-B**
Stroop Test							
Congruent (ms)	843	--	--	609	--	--	-234
Incongruent (me)	791	--	--	675	--	--	-116
Stroop Effect	-52	--	--	66	--	--	118
Pulse Oximeter							
%SpO2	98	96	99	97	-2	1	-1
HR	104	82	96	108	-22	-8	4
PI	5.3	99	4.5	3.4	99	4.5	3.4
Blood Pressure							
SBP	112.5	113.5	119.5	119.5	1	7	7
DBP	75	75.5	84	81.5	0.5	9	6.5
HR	99	91.5	97	103	-7.5	-2	4
Apple Watch							
HR	97.5	108	114	115	10.5	16.5	17.5
HRV	18	36	28	18	18	10	0

AU4 NE

	Averages				Differences to Baseline		
	Basline	Time 30	Time 60	Time 90	T30-B	T60-B	T90-B
Stroop Test							
Congruent (ms)	559	--	--	568	--	--	9
Incongruent (me)	698	--	--	634	--	--	-64
Stroop Effect	139	--	--	67	--	--	-72
Pulse Oximeter							
%SpO2	98	97	98	99	-1	0	1
HR	75	74	77	75	-1	2	0
PI	5.5	4.8	13.2	3	4.8	13.2	3
Blood Pressure							
SBP	104.5	121.5	117	117.5	17	12.5	13
DBP	61	71.5	66.5	72	10.5	5.5	11
HR	76.5	66.5	70.5	75	-10	-6	-1.5
Apple Watch							
HR	77.5	112	119	111	34.5	41.5	33.5
HRV	58	72	108	137	14	50	79

AU2 E

	Averages				Differences to Baseline		
	Basline	Time 30	Time 60	Time 90	T30-B	T60-B	T90-B
Stroop Test							
Congruent (ms)	810	--	--	839	--	--	29
Incongruent (me)	849	--	--	855	--	--	6
Stroop Effect	39	--	--	16	--	--	-23
Pulse Oximeter							
%SpO2	97	96	97	97	-1	0	0
HR	78	85	92	96	7	14	18
PI	6.9	13.9	5.6	4.5	13.9	5.6	4.5
Blood Pressure							
SBP	114.5	110.5	127.5	120.5	-4	13	6
DBP	78	72.5	74.5	87.5	-5.5	-3.5	9.5
HR	82	84.5	89	93.5	2.5	7	11.5
Apple Watch							
HR	90	118	110	132	28	20	42
HRV	50	34	34	35	-16	-16	-15

AU4 E

	Averages				Differences to Baseline		
	Basline	Time 30	Time 60	Time 90	T30-B	T60-B	T90-B
Stroop Test							
Congruent (ms)	559	--	--	669	--	--	110
Incongruent (me)	695	--	--	833	--	--	138
Stroop Effect	136	--	--	164	--	--	28
Pulse Oximeter							
%SpO2	98	98	97	98	0	-1	0
HR	62	59	65	72	-3	3	10
PI	1.2	5.8	3.5	1.1	5.8	3.5	1.1
Blood Pressure							
SBP	120	119	122.5	118	-1	2.5	-2
DBP	67	73	77	72	6	10	5
HR	72	66	73	79.5	-6	1	7.5
Apple Watch							
HR	75	121	114	124	46	39	49
HRV	81	104	123	35	23	42	-46