Exploring Aerosol Exposure from Motorsport Events and Routine Activities

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ABSTRACT

Exposure to particulate matter (PM) is a health risk everyone experiences nearly on a daily basis. However, for motorsport fans, especially drifting fans, this risk seems to be elevated at a large scale due to the massive amounts of smoke drift cars can make. While it's widely understood that aggressive driving and alterations to emissions equipment can elevate PM levels in the air, there is a lack of data regarding the potential health and environmental impacts of drifting. Therefore, this study aims to address some of the gaps in knowledge in the drifting world by asking: How does aerosol exposure during drift events compare to other routine activities? I used a Particles Plus 8000 Series Handheld Particle Counter to measure concentrations of particle number (PN) and mass concentrations of fine and coarse PM ($PM_{2.5}$ and PM_{10}, respectively) at two types of drift events and during routine activities such as cooking, occupational hazards such as sanding, and recreational activities such as bonfires. Average PN, $PM_{2.5}$, and PM_{10} concentrations o were calculated and compared across all activities to look for statistically significant differences. Activities like cooking and grilling resulted in higher concentrations than almost all drift scenarios. These more everyday activities likely contribute to a person's overall aerosol exposure more than infrequently attending a drift event as a typical spectator Measured exposure concentrations were X–Y times lower with increasing distance from the emission source and up to Z times lower under racing conditions when the track surface was wet rather than dry. Overall, the PN and PM concentrations measured for a typical spectator during drifting events was comparable to those that most participants might experience from other common sources on a more daily basis.

KEYWORDS

Particle Number (PN), Fine Particulate Matter ($PM_{2.5}$), Coarse Particulate Matter (PM_{10}), Grassroots Drift Event (G.D.E), Professional Drift Event (P.D.E)

INTRODUCTION

Over the past decade, California has enacted a series of rigorous environmental policies with the primary goal of protecting human health and mitigating the human impact on the environment. These policies have particularly focused on the transportation sector, driven by compelling reasons. The transportation sector in the United States stands as the highest contributor to greenhouse gas emissions, responsible for a substantial 27% of the nation's total emissions, with electric power and industry following closely at 25%, according to the Environmental Protection Agency's data from 2022. These anthropogenic greenhouse gas emissions constitute the most prominent driving force behind climate change in the last century, as underscored by the Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6). In response to this pressing issue, California has introduced several pivotal policies, including Executive Order N-79, which mandates that all vehicles sold in the state by 2035 must be electric-powered, thereby producing zero tailpipe emissions. In addition, there is also Executive Order B-55-18, which mandates the state to be run on clean energy by 2045, further decreasing transportation emissions by using renewable energy to charge electric vehicles.

Prior work has found that traffic is responsible for approximately 35% of the PM2.5 and PM10 pollution in cities, including tailpipe and non-tailpipe emission (Karagulian et al., 2015). As policies have reduced tailpipe emissions from on-road vehicles, the contribution of non-tailpipe emissions from this sector become more important. Such emissions include brake and tire wear, which emit fine and coarse particulate matter (PM2.5 and PM10). Exposure to PM is of important concern and the focus of many studies and policy decisions, given the significant associated human health risks. Current research suggests cars emit coarse and fine particulate matter (PM_{10} and $PM_{2.5}$) by simply driving their car and slowly wearing down the tire into particulate matter (Woo et al., 2022). Exposure to PM is important to consider as they pose a significant danger to human health. Current research suggests there is a "significant association between exposure to particle pollution and health risks, including premature death," and these potential health effects include cardiovascular issues like cardiac arrhythmias and heart attacks, as well as respiratory ailments such as asthma attacks and bronchitis (EPA 2020). Furthermore, another study found that over 7% of premature deaths resulting from $PM_{2.5}$ exposure in the United States can be attributed to on-road transportation (Li & Managi 2022). This underscores the imperative for comprehensive policies that address not only tailpipe emissions but also often-overlooked non-tailpipe emissions from vehicles, which have a tangible and substantial impact on both public health and the environment. Although some only see automobiles simply as a tool to get them from place to place and a source of pollution, many also see them as a source of enjoyment and development through motorsport racing. One particular motorsport that has risen in popularity in the last two decades is drifting. A study researching the optimal control for drifting defines drifting as "a cornering technique with a large angle of sideslip where rear tires encounter extremely combined slip in both lateral and longitudinal directions" (Chaichaowarat 2013). It is not clear with current literature how much particulate matter, the size of particulate matter, and its concentration that drifting emits. However, we do know the result of this cornering technique puts immense stress on the rear tires, creating enough friction between the road and tire to make plumes of white smoke and loud screeching noises. Tire studies have indicated that increased slip angle and longitudinal forces produce more ultrafine particles than regular driving and ultrafine particles can be more toxic due to their high surface area and their ability to enter the bloodstream (Foitzik et al., 2018; Kwon et al., 2020). Thus, drifting may pose a health liability for its spectators and drivers. When evaluating aerosol exposure, it is important to consider different particle sizes, given the difference in respiratory deposition efficiency and associated health effects. PN is the total number of particles per volume of air (# cm^{-3}), and is dominated by smaller particles that are thought to have greater health impacts than $PM_{2.5}$ and PM_{10} by mass (µg m^{-3}) (Ohlwein et al., 2019). Fine particulate matter ($PM_{2.5}$) includes particles with diameters less than , particulate matter that is 2.5 µm in diameter, and can stay in the air for extended durations and cover substantial distances, sometimes reaching hundreds of miles (EPA 2018). Coarse particulate matter (PM_{10}) with diameters less than 10 µm, are less persistent in the air than $PM_{2.5}$ and ultrafine particles. Their spatial influence is usually confined because these particles tend to settle on the ground downwind of where they are emitted due to their bigger size (EPA 2018).

In this study, I ask, how does aerosol exposure during drift events compare to other routine activities? This overarching question guides the research and serves as the foundation for the investigation of aerosol exposure at drift events in California. Specifically, I ask: (1) What are the PM concentrations people are exposed to during grassroots drift events? (2) How could PM exposure be reduced to make it safer for participants? (3) What are the PM concentrations people are exposed to during other routine activities? Based on existing knowledge from the primary literature and the concerns raised by these sub-questions, the working hypothesis for this research is that the PM emissions would put participants' health at risk but at varying degrees. My hypothesis is solely based on the visible particles and smoke coming from the vehicles at these events. To address these research questions and test the hypothesis, the data collection objectives will involve gathering comprehensive data on particulate emissions from drifting, conducting comparative analyses with emissions data from other sources, and exploring potential emission reduction strategies and their feasibility within the motorsports community. Through rigorous data collection and analysis, this research aims to provide valuable insights into the aerosol risk of drifting and other common activities a person might experience. As the sport continues to grow, it is crucial to know what the possible impact that drifting can have on its participants so policymakers can make informed decisions on future regulations they may impose on motorsports.

METHODS

Study sites

For the investigation into drift motorsport exposure in California, I conducted measurements at two most popular drift tracks in the state. The first track I recorded was at Balcony, one of the six tracks at Willow Springs International Raceway. Balcony is considered by most as a “skid-pad” which is a flat oval track covered in asphalt resembling a big parking lot. This track at Willow Springs is typically used to develop and test vehicle handling and suspension dynamics, but it also serves as a good spot to host drifting competitions due to the close proximity of the pit areas and spectator stands to the cars driving. The pit area is immediately next to the track with additional parking for cars above and below the track (Figure 1). The second track I recorded was at Irwindale Speedway. Irwindale Speedway is a big oval track with a banked surface and typically holds big professional motorsport events. There is a main grandstands that goes through the length of the track, with smaller stands farther out on the sides, and a pit area behind the stands (Figure 2).

Figure 1. Balcony measurement points. The numbers associated with the locations are in relation to their distance with G1 being the closest and G3 being the farthest. These locations represent the common areas spectator would be in which are the main spectator area (G1), pit area (G2), and parking for other vehicles (G3). Image from Google Maps Satellite.

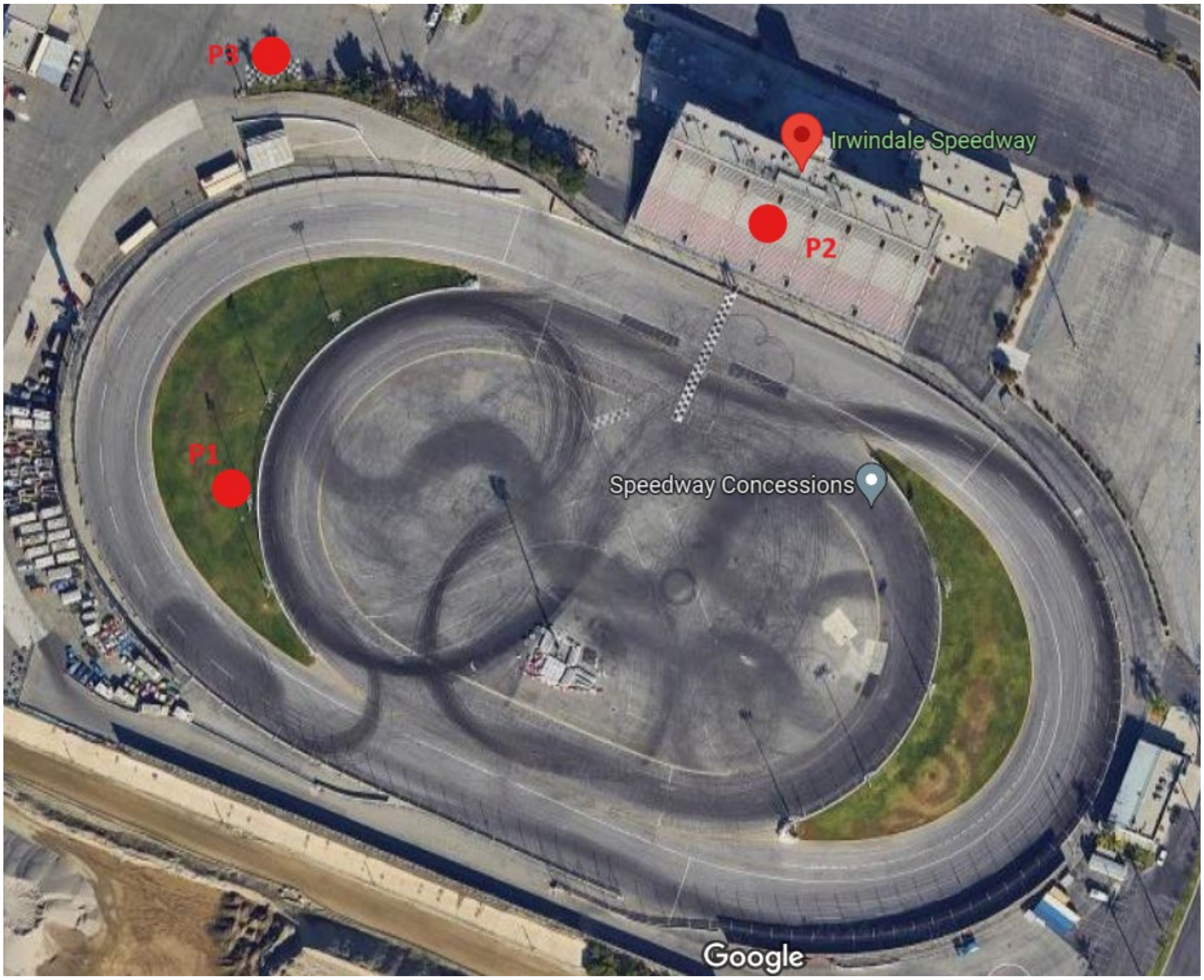

Figure 2. Irwindale Speedway measurement points. P1 is the inner track area and serves as a reference point to compare to G1 due to their similar distance from emissions source. P2 and P3 are stands where spectators tend to watch. Image from Google Maps Satellite.

For assessing exposure in other activities, an array of locations served as the backdrop for data collection. These encompassed locations such as a small office on UC Berkeley's campus for "clean air" recordings. For outdoor commercial cooking, I sampled at Dollar Hits in Los Angeles, a small outdoor restaurant with its tables and charcoal grills set in a parking lot. My backyard was used for propane grilling exposure along with my apartment kitchen for cooking and candle exposure. I recorded at Fiesta Island, a small beach island in San Diego, for bonfire exposure. I also used the Joe Customs shop, my personal business, to test auto body and wood-working exposure. While these sites were selected based on accessibility and feasibility, it is essential to acknowledge that they may not precisely mirror someone else's exposure to the same activities.

Data Collection

With these particle size characteristics in mind, I used a Particles Plus 8000 Series Particle Counter to measure concentrations of PN, $PM_{2.5}$, and PM_{10}. This optical counter counts particles in different size bins (0.3, 0.5, 1.0, 2.5, 10 µm), from which total PN counts for particles between 0.3 and 25 µm in diameter can be determined. Assuming spherical particles of unit density, the particle counter also reports mass concentrations for $PM_{2.5}$ and PM_{10}. A standard operating procedure was used in every sampling set: the counter is set upright at breathing height for each activity, the isoprobe is not obstructed by any object, and sample timing is set every 7 seconds.

Drift motorsport exposure

Willow Springs International Raceway and Irwindale Speedway vary greatly in size and layout. Spectator areas, pit areas, and the track itself are situated in unique locations for each track. Aerosol exposure can vary heavily depending on which track and where you are on the track. At each track, I recorded from three different locations. It's important to acknowledge that these locations are not necessarily at the same distances, but rather recorded from the most common locations a spectator would find themselves at these drift events. Another important difference between the track recordings is the different types of cars driving at these events. The event at Balcony was a grassroots drifting competition event with less modified vehicles, while the event at Irwindale Speedway was a professional drifting competition event with heavily modified and dedicated race cars. Pro-drift cars do not have any type of emission-reduction equipment and make over twice the power of the cars at the grassroots drifting competition with an exception of one vehicle. As a result of the increased power, they are visibly going much faster and create a lot more smoke than the grassroots cars. Recording at these two completely different events was to gather data on the variance in exposure a person may encounter at each track and corresponding type of event, rather than a direct comparison between the two.

I recorded with the particle counter at the following three locations for Willow Springs Raceway (Figure 1). G1 is the spectator area and is less than 5 meters away when cars pass by. G2 is in the pit area about 25 meters from the emission source, and G3 is in the parking lot that is around 70 meters away from the emission source. The recordings at Willow Springs Raceway are meant to represent a grassroots drifting event (GDE) in Southern California. Most, if not all, events held in Balcony are grassroots events and grassroots events are the most common event a typical driver would attend. There are usually less spectators at G.D.Es, but they have distinct differences as mentioned before that would be interesting to compare with professional events.

For Irwindale Speedway, I measured at the following three locations. P1 is in the inner track area that is only accessible to drivers and their team and is less than 5 meters away from the cars passing by. P2 is in the main grandstand, where most spectators sit and about 80 meters away from the emissions source. P3 is in the pit area, about 100 meters away from the emission source (Figure 2). Irwindale Speedway only hosts professional drifting events (PDEs) with hundreds of spectators and drivers with serious race teams. My recordings here are meant to represent professional drift events in Southern California and these are the types of events that a typical spectator would attend more frequently.

Both events followed a 32 driver competition format. All recordings were done during the practice and Top 32 session of the competition, so this was when the most amount of laps were happening during the day and recorded for at least 30 minutes per location. I did, however, record for two days at Irwindale Speedway as it was a two-day event. On the second day, it rained in the morning before practice and I was not able to access P1 for wet data.

Other activity exposure

The emission of tire smoke during drifting events may raise concerns about spectator health, yet various activities also present risks of PM exposure. I also assess exposure levels in several common activities: cooking (encompassing cooking breakfast with bacon and eggs, charcoal and propane grilling), bonfires, and occupational risk such as auto body work. I wanted to record bonfires and cooking as they are very common domestic and recreational activities people do, and would serve as a relatable reference point of risk when assessing the risk of drifting. In addition, I chose auto body work and woodworking as a part of my data set to put activities that are well known to cause respiratory issues and typically call for the use of personal protective equipment (PPE) during the activity, which would serve as a reference point to compare if PPE should be worn during drift events.

To quantify aerosol exposure from cooking, I employed multiple methods to compare aerosol emissions and exposure. Daily exposure during cooking breakfast was measured by placing a particle counter next to the electric stovetop, recording data with the exhaust on and off, and preparing bacon and eggs for each sample set. Grilling exposure was measured at about a meter away from the grill. This was done with a 4 burner propane grill, and a 20 cm x 80 cm charcoal grill at a Filipino BBQ restaurant, cooking beef skewer sticks (Figure 3). I also measured a bonfire event about one meter away using Duraflame logs and began with a 4 log base and continued to add more logs as time went on.

Figure 3. Particle counter in action. The top-left image is charcoal grilling, bottom-left image is auto body work, and the right image is the grassroot event at WSIR. Photos by author.

I used my automotive shop for my occupational recordings. The counter was placed in my working area to get an accurate exposure recording for the auto body activity. I sanded the quarter panel of the vehicle continuously for 5 minutes with a 40 cm block of 400 grit sandpaper. In addition to all these activities, I recorded inside a typical campus office without any obvious emission sources to simulate a "clean environment" test that can be used to compare to drifting and the other activities.

Data analysis

This study systematically investigated PM exposure across diverse activities, locations, and times. Since the data was collected at regular intervals during each activity, it allowed for the calculation of average and median PN, $PM_{2.5}$ and PM_{10} for each activity and is represented graphically through frequency histograms and bar charts by using the Particles Plus Software and Microsoft Excel.

95% confidence interval test

In order to determine the significance of exposure differences between various activities, I used a table and bar graph with 95% confidence intervals. 95% confidence intervals allow for the comparison of means across multiple groups, in this case, different activities and their different variation per activity. I graphed the data with the confidence intervals, checked for overlap, and identified whether there are statistically significant differences in PM exposure among the studied activities.

RESULTS

Once the data was collected, it was imported into Microsoft Excel where the following graphs were created. As noted above, PN results are presented in units of number per cubic centimeter (# cm^{-3}), and $PM_{2.5}$ and PM_{10} are given in units of micrograms per cubic meter (µg m^{-3}). All reported results are mean values ± 95% confidence intervals for each sampling event/activity unless otherwise noted.

Particle concentrations from drifting

Drifting events led to increased concentrations of average PN, $PM_{2.5}$, and PM_{10} across all monitored locations, as illustrated in Figure 4, Figure 5, and Figure 6. Specifically, Figure 3 details PN concentrations during different types of drifting events at three locations along each track. The average PN concentrations for G3, G2, and G1 were 35 ± 10 , 82 ± 12, and 190 ± 25 # cm^{-3}, respectively. Comparatively, PN concentrations for P3, P2, and P1 were 188 ± 26, 264 ± 6, and 426 # cm^{-3} ± 58, respectively. Notably, these values from the professional event were consistently higher than those observed during grassroots events (Figure 4).

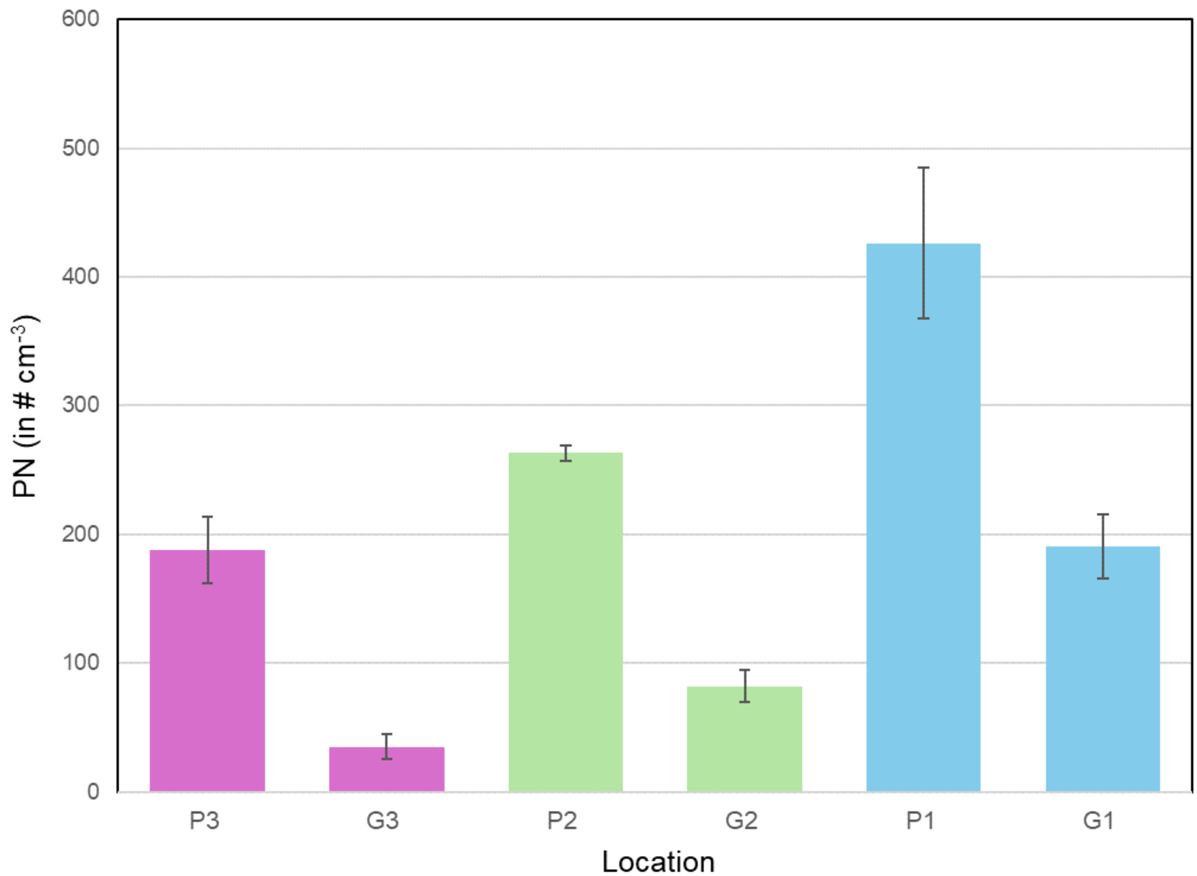

Figure 4. Average PN concentrations from drifting events. The colors are associated with their distance ranking. Blue is for the closest recording, Green is the middle distance recording, and Pink is for the farthest recordings. There are two bars for each distance, one for the recording at the professional event (P1–3) and the grassroots event (G1–3).

$PM_{2.5}$ levels during grassroots events were measured at G3, G2, and G1, yielding values of 6 ± 1 , 18 ± 3, and 42 ± 9 μg m^{-3}, respectively. Conversely, levels during professional events (P3, P2, P1) were significantly higher, measuring at 45 ± 8, 41 ± 1, and 162 ± 33 μg m^{-3}, respectively (Figure 5, Figure 6). These results parallel the trend observed with PN concentrations, showing consistently elevated levels during professional events compared to grassroots events. In addition, the location of recording seems to correspond with the concentrations measured.

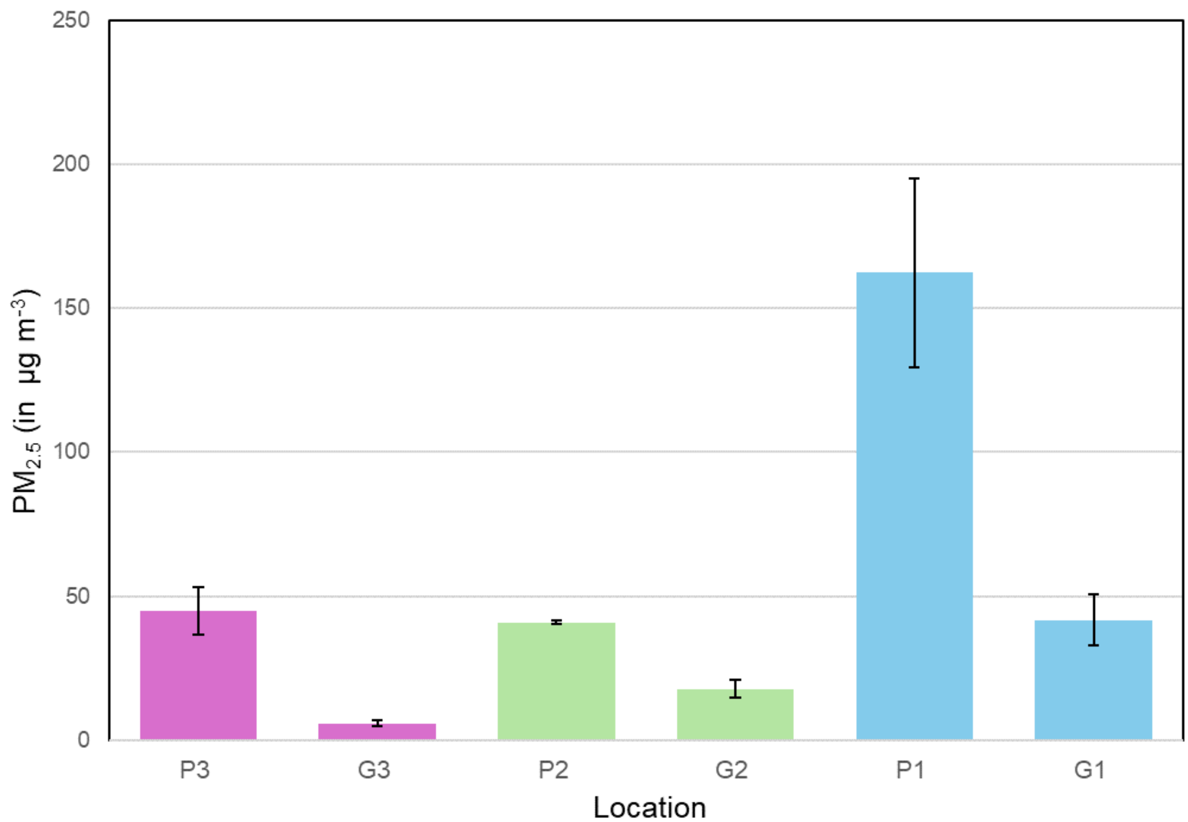

Figure 5. Average $PM_{2.5}$ concentrations from drifting events. The colors are associated with their distance ranking. Blue is for the closest recording, Green is the middle distance recording, and Pink is for the farthest recordings. There are two bars for each distance, one for the recording at the professional event (P1–3) and the grassroots event (G1–3).

PM_{10} concentrations were assessed at G1, G2, and G3, resulting in measurements of 54 ± 2, 142 ± 10, and 114 ± 12 µg m^{-3}, respectively. Similarly, measurements for P1, P2, and P3 were recorded at 64 ± 9, 55 ± 1, and 205 ± 34 µg m^{-3} respectively (Figure 6). Interestingly, PM_{10} concentrations during drifting events did not increase with the ranking of location unlike the other concentrations.

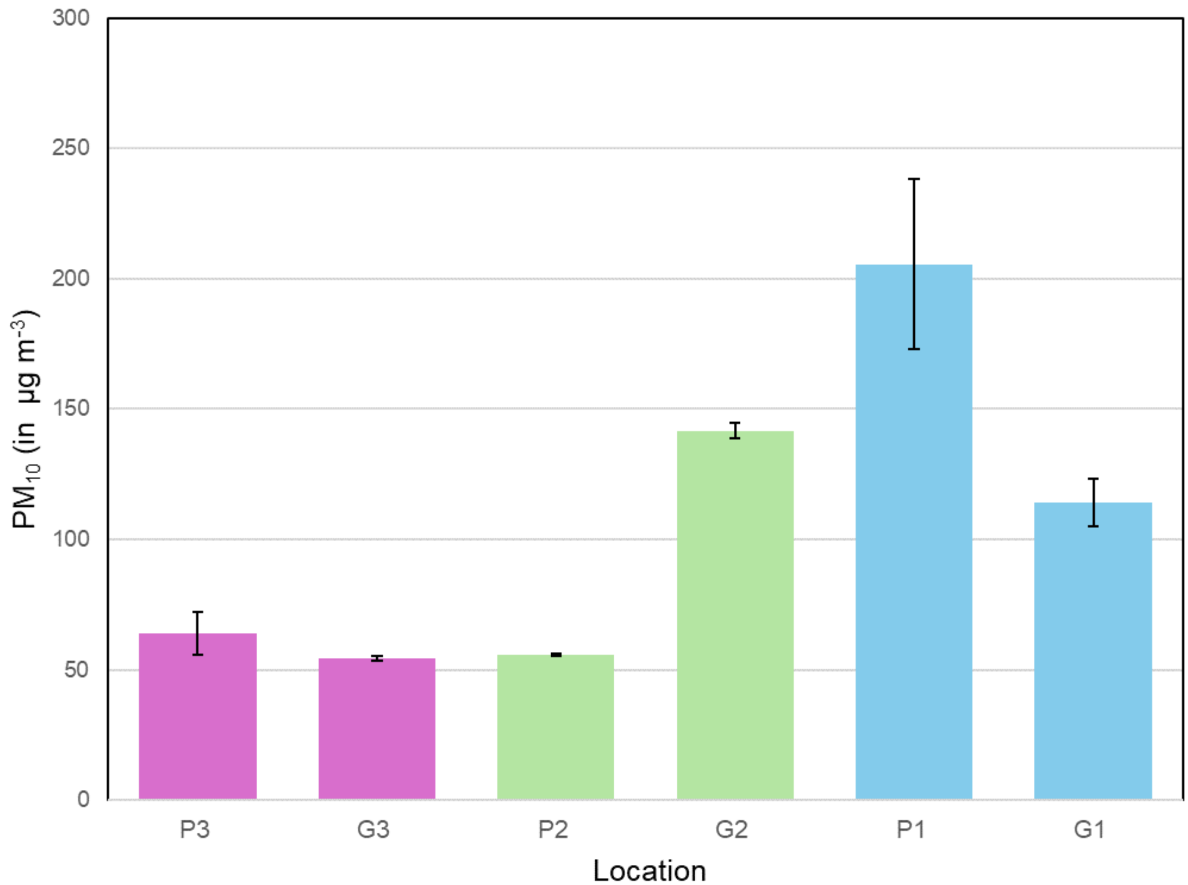

Figure 6. Average PM_{10} concentrations from Drifting Events. The colors are associated with their distance ranking. Blue is for the closest recording, Green is the middle distance recording, and Pink is for the farthest recordings. There are two bars for each distance, one for the recording at the professional event (P1–3) and the grassroots event (G1–3).

Since it rained during one of my testing days, I also compared measurements for when the track surface was wet versus dry (Figure 7, Figure 8). The PN of P3 and P2 in wet conditions are 5 ± 1 and 40 ± 6 # cm^{-3}, respectively (Figure 7). PM2.5 concentrations followed a similar trend in heavy reduction for wet and dry conditions at P3 and P2 as well. However, PM10 concentrations remained relatively higher in P3 and P2 during wet conditions at 22 ± 2 and 31 ± 1 µg m^{-3} (Figure 8).

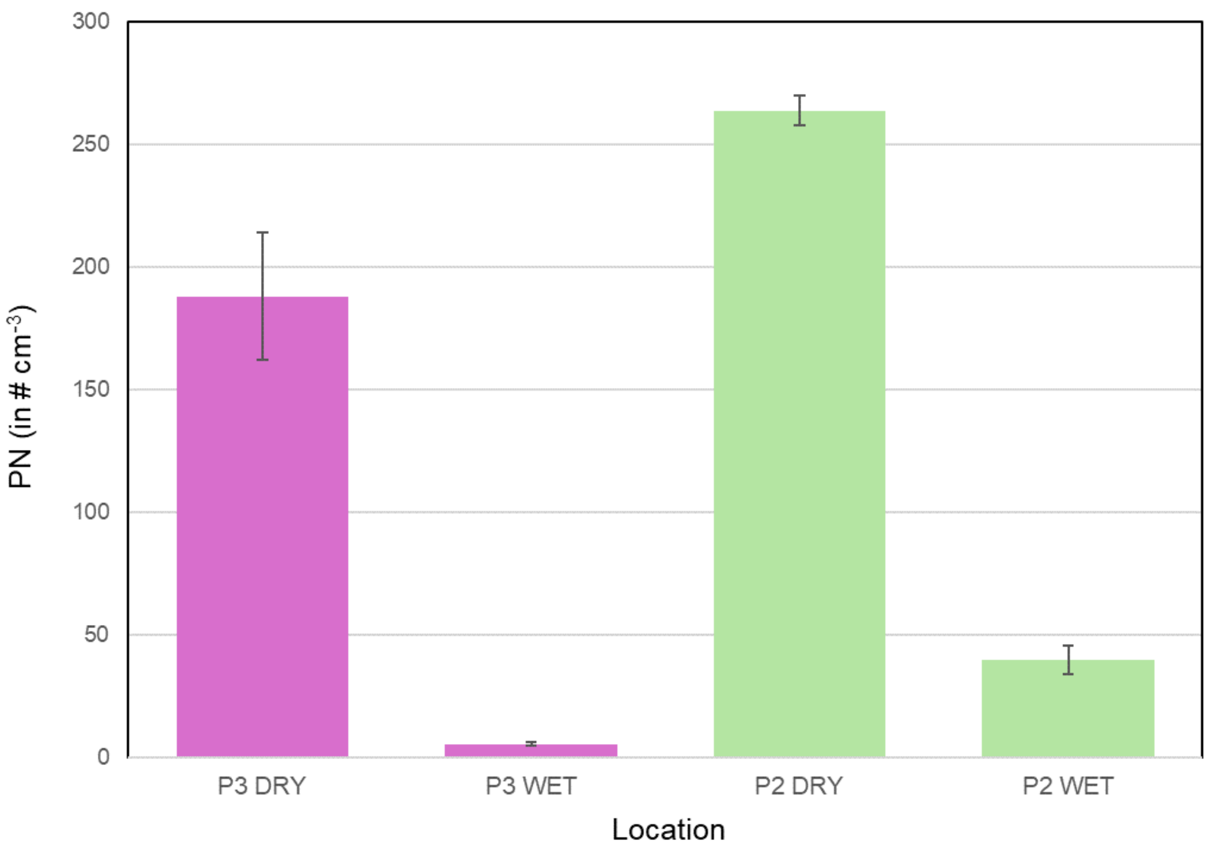

Figure 7. Average PN concentrations from P.D.Es in Wet and Dry conditions. The colors are associated with their distance ranking, where the farthest distance is shown in pink and the middle distance in green. There are two bars in the same color representing the same recording location, but one is for dry and one is for wet conditions.

Overall, attending a drift event can expose you to a range of PN from low background concentrations around 5 # cm^{-3} to 426 # cm^{-3}. It is important to note that my recording for a "clean environment" averaged to 0 # cm^{-3} for PN, 9 ± 1 μg m^{-3} for $PM_{2.5}$, and 26 ± 7 μg m^{-3} for PM_{10}.

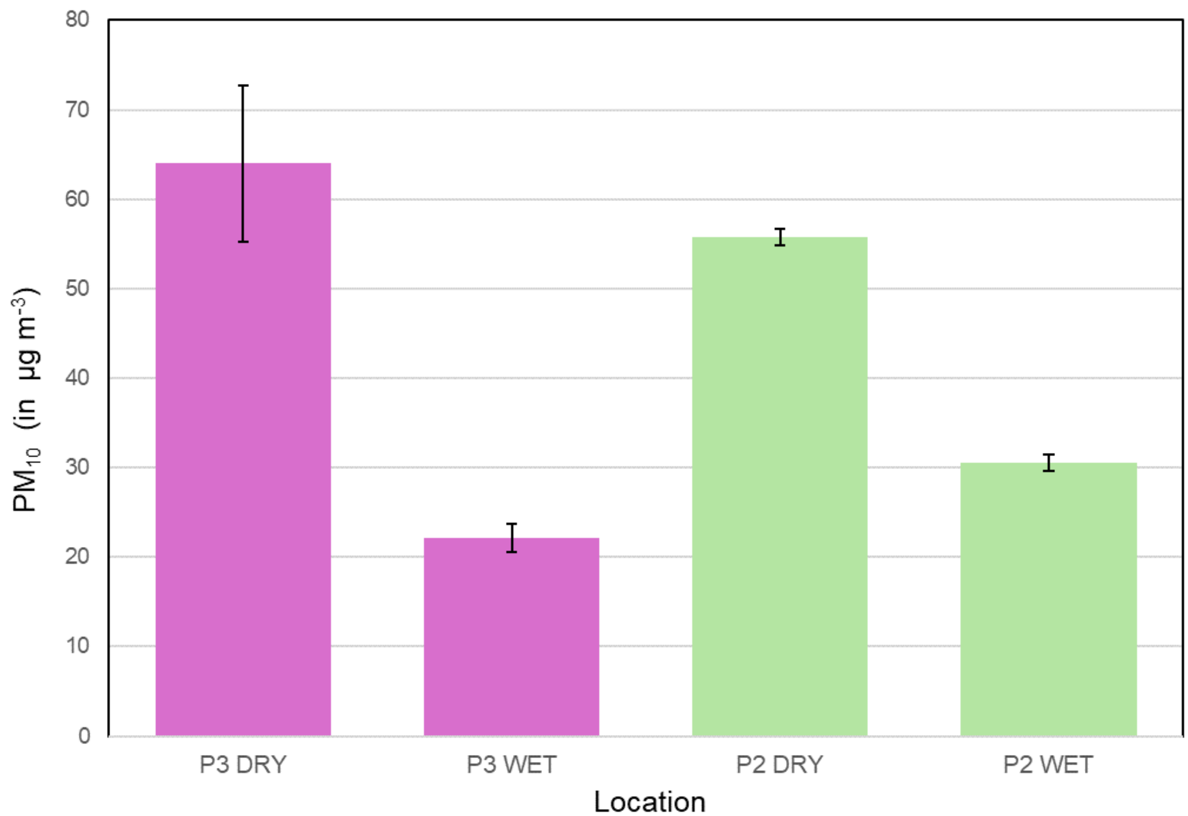

Figure 8. Average PM10 concentrations from P.D.Es in Wet and Dry conditions. The colors are associate d with their distance ranking. There are two bars in the same color representing the same recording location, but one is for dry and one is for wet conditions.

Exposure from Other Activities

Starting with auto body work, relatively low average PN levels of 29 ± 1 # cm^{-3} were recorded, Propane or gas grilling exhibited higher average PN levels at 215 ± 18 # cm^{-3}. displaying variability in emissions. Charcoal grilling had the highest average PN levels at 559 ± 41 # cm^{-3}, indicating more emission variability. Bonfire activities showed average PN levels at 199 ± 15 # cm^{-3}. Cooking breakfast resulted in elevated PN levels, with and without the overhead vent van on or off, with respective averages of 461 ± # cm^{-3} and 516 # cm^{-3}(Figure 9).

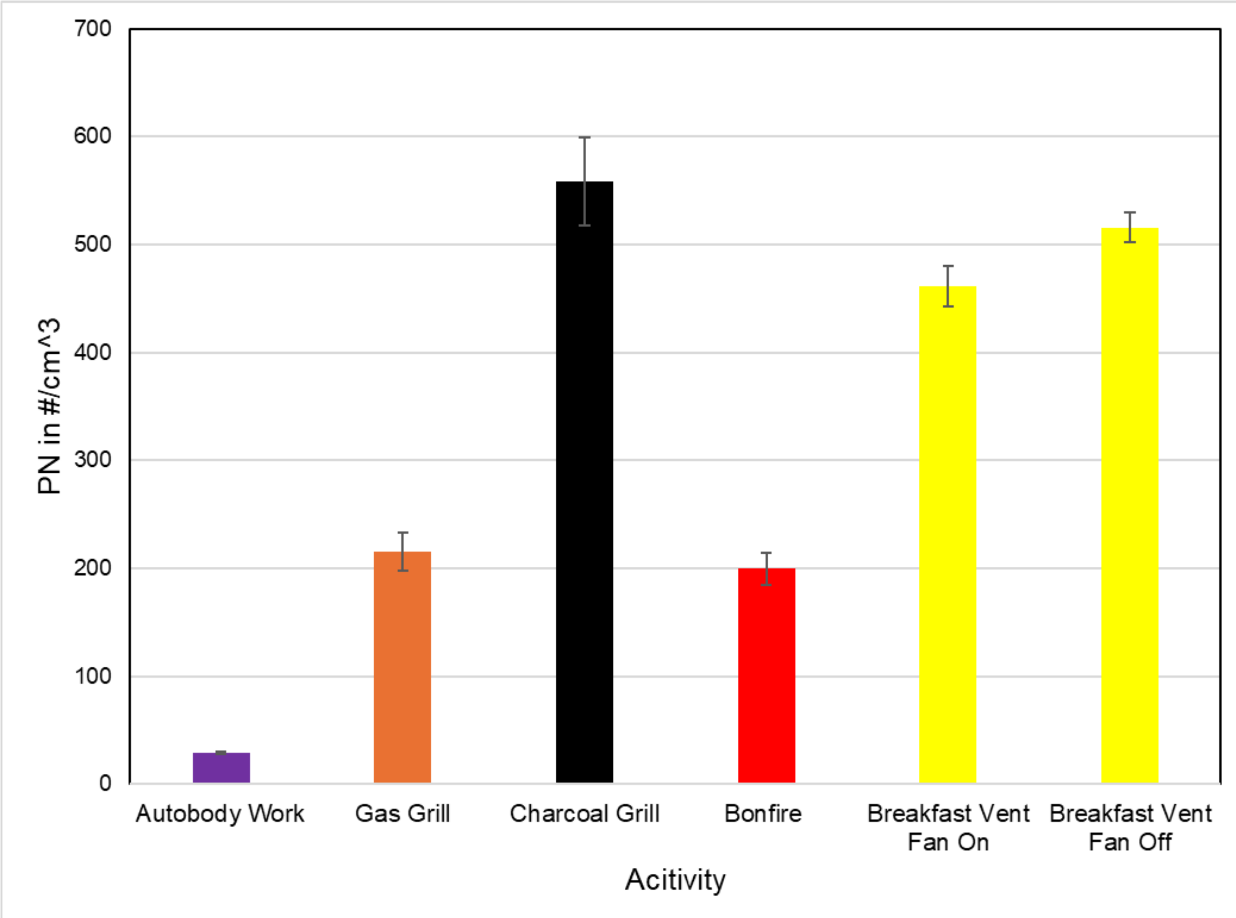

Figure 9. Average PN from Common Activities. The colors are associated with the type of activity. Purple represents auto body work, orange represents gas or propane grilling, black represents charcoal grilling, red represents bonfires, and yellow represents cooking breakfast. There are two yellow bars, one is for when data was recorded with vent fan on and the other is with vent fan off.

Auto body work showed lower $PM_{2.5}$ levels at 22 ± 1 µg m^{-3}, contrasting with the higher levels and more variable concentrations seen in gas grilling at 56 ± 7 µg per m^3. Charcoal grilling exhibited higher $PM_{2.5}$ levels at 159 ± 18 µg pm^{-3}. The bonfire activity displayed moderate $PM_{2.5}$ levels at 46 ± 4 µg m^{-3}, while the cooking breakfast with and without the vent fan had elevated $PM_{2.5}$ levels, averaging 103 ± 9 µg m^{-3} and 102 ± 4 µg m^{-3}, respectively (Figure 10).

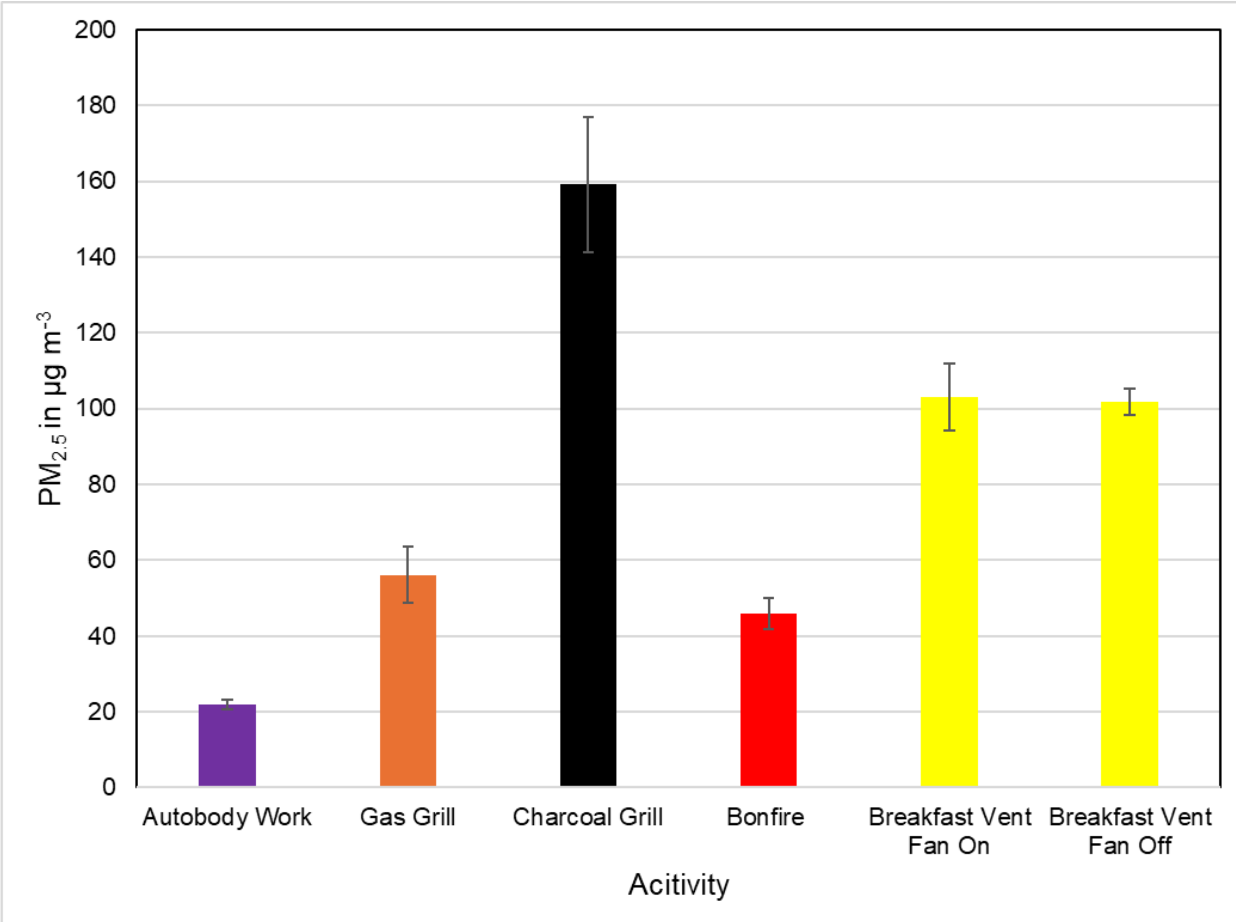

Figure 10. Average $PM_{2.5}$ from Common Activities. The colors are associated with the type of activity. Purple represents auto body work, orange represents gas or propane grilling, black represents charcoal grilling, red represents bonfires, and yellow represents cooking breakfast. There are two yellow bars, one is for when data was recorded with vent fan on and the other is with vent fan off.

In terms of PM_{10} concentrations, auto body work showed notably higher levels at 1238 ± 217 µg m^{-3}. Gas grilling exhibited lower PM10 levels at 243 ± 30 µg m^{-3}, contrasting with the higher levels seen in charcoal grilling at 345 ± 50 µg m^{-3}. Bonfire activities contributed moderately to PM_{10} concentrations, averaging 107 ± 8 µg m^{-3}. Cooking breakfast with and without the vent fan demonstrated elevated PM_{10} levels, averaging 310 ± 67 µg m^{-3} and 224 ± 9 µg m^{-3}, respectively (Figure 11).

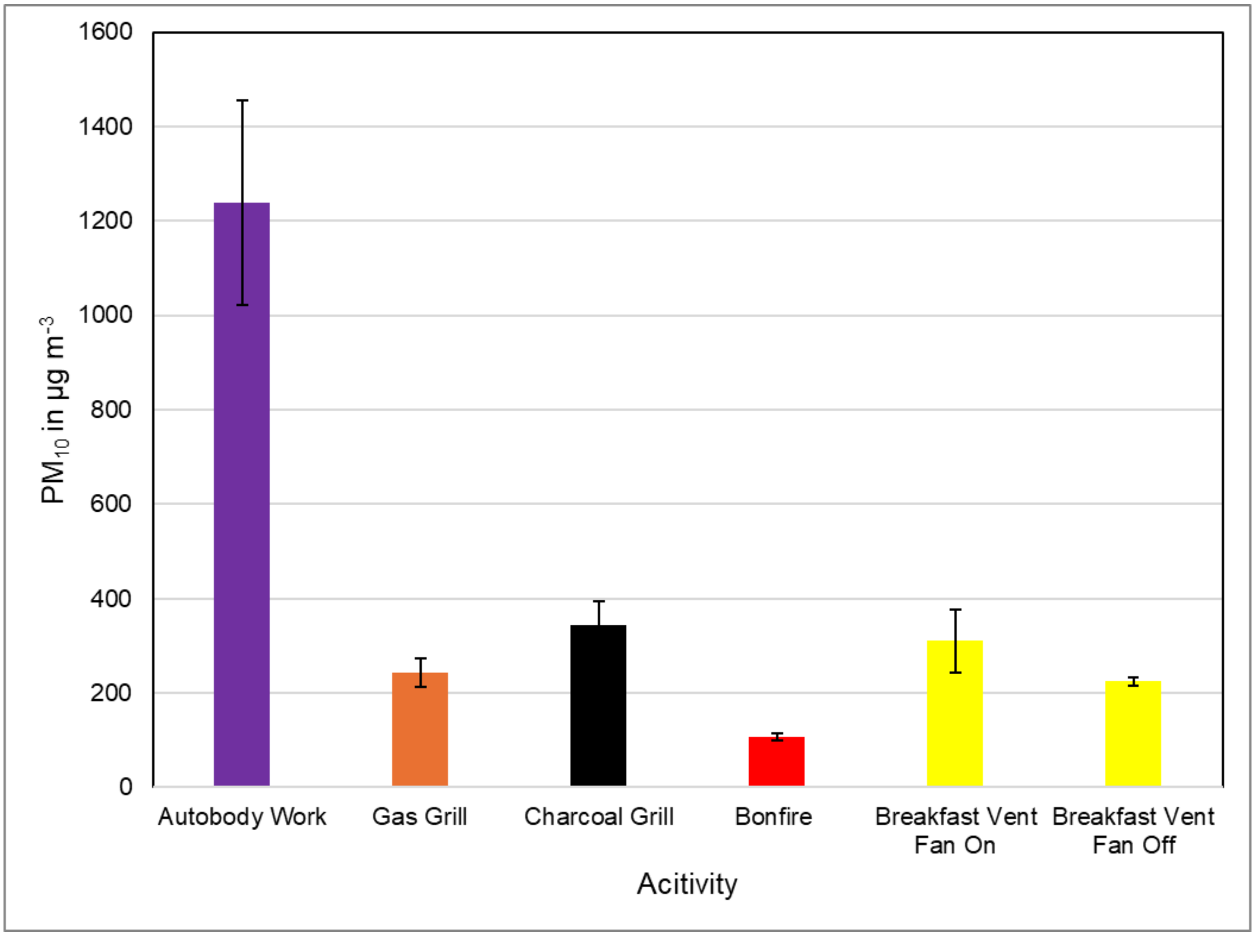

Figure 11. Average PM_{10} from Common Activities. The colors are associated with the type of activity. Purple represents auto body work, orange represents gas or propane grilling, black represents charcoal grilling, red represents bonfires, and yellow represents cooking breakfast. There are two yellow bars, one is for when data was recorded with vent fan on and the other is with vent fan off.

The ranges of average PN exposure at the track varied from 5.23 # cm^{-3} to 426 # cm^{-3}, $PM_{2.5}$ exposure at the track varied from 3.67 µg pm^{-3} to 162.38 µg m^{-3}, and the PM_{10} exposure minute at the track varied from 22.13 µg m^{3} to 205.54 µg m^{-3}.

DISCUSSION

Across nearly all activities, a participant would be putting themselves at statistically significant levels of elevated PN in comparison to a "clean" environment. However, when comparing risks for each activity, there are certain activities that stand out as higher risk.

Drifting

To put $PM_{2.5}$ and PM_{10} results into a more relatable perspective that the public may be more familiar with, I converted these event-average concentrations to the Air Quality Index (AQI). The EPA represents the health hazards or air quality with the AQI, which can be calculated separately for $PM_{2.5}$ and PM_{10}. An AQI value of 0-50 is considered "good" air quality according to the EPA, followed by "moderate" at 51-100, "unhealthy for sensitive groups" at 101-150, "unhealthy" at 151-200, "very unhealthy" at 201-300, and finally "hazardous" at 301-500. The AQI of $PM_{2.5}$ at a drift event ranged from 15 to 213, meaning a drift event can have "healthy" and "very unhealthy" levels of $PM_{2.5}$, depending on your proximity to the race. In addition, the AQI of PM_{10} ranged from 21 to 126, meaning a drift event can have "healthy" and "unhealthy for sensitive groups" levels of PM_{10}.

These ranges included both grassroots and professional-level drifting events. Although there are differences in the sampling conditions between these two events, including the types of vehicles used, the racetrack topography, distances from emission source, and local meteorology, there were similar trends found between the two. For instance, the recordings at the farthest distance from the emissions source had the lowest PN, $PM_{2.5}$, and PM_{10} concentrations and alternatively, the recordings at the closest distance had the highest values. This result is expected, as concentrations typically decrease with distance from the emission source as a result of dispersion of particles in the air. Under stagnant wind conditions, on the other hand, PM can instead accumulate around the pollution source (Uugwanga 2021). The results found in the present study align with previous research on the decay of particulate pollution from freeways, which have been shown to drop by 70% within 500 feet downwind from the source. For this reason, California Senate Bill (SB) 352 requires specific responses assessing health risk for schools within 500 feet (150 m) of busy roadways (SCAQMD 2005).

Despite the distances of the professional event being greater for 2nd and 3rd distance recordings than the grassroots event, I originally hypothesized that the aerosol concentrations would still be higher at the professional event. The main reason for this hypothesis is that the vehicles at professional events were all purpose-built race cars or "Pro-cars", making double to triple the amount of horsepower in comparison to vehicles at grassroots events. The increased power from Pro-Cars allows the vehicles to spin, volatilize, and carry more speed and increase forces on their tires much easier and faster resulting in bigger plumes of smoke, aligning with previous findings that increased slip angle and longitudinal forces on the tires creates more PM (Foitzik et al., 2018; Kwon et al., 2020). The plumes of tire smoke were much smaller visually during grassroots events and this was evident in my data. G1 and P1 were supposed to represent the closest possible distance a spectator would be from the emissions point, around 5 meters. The average PN of the professional event was more than double the amount a person would be exposed to at a grassroots level (G1).

Across all locations, the average PN and $PM_{2.5}$ were around double the amount in a professional event in comparison to a grassroots event. The converted AQI value for the average $PM_{2.5}$ at P1 and G1 was 115 and 213, suggesting that $PM_{2.5}$ concentrations when standing as close as possible to the cars is "unhealthy for sensitive groups" at a grassroots event and "very unhealthy" at a professional event. In addition, the AQI for PM_{10} for P1 was "moderate" and "unhealthy for sensitive groups" for G1. However, the difference between the average PM_{10} was not statistically significant between events except for P3 and G3. It is important to note that during the recording at P1, the PN concentrations exceeded the operational range of the particle counter during some of the Pro-car passes. The data dropouts during these moments may have affected my data, such that the average results reported here for P1 may be lower than actual concentrations experienced. When considering wet drift event data, the risk for exposure is significantly less than the dry, which I expected in my hypothesis. The recordings in the professional drift event at Irwindale Speedway were done on two consecutive days and on the second day it rained. Unfortunately, I was unable to record from P1 in the wet due to the lack of access during the competition day. Current research suggests that precipitation can lower ambient aerosol concentrations as rainwater extracts particles and dissolved gaseous pollutants from the atmosphere and transports aerosols to the ground (Wang et al., 2023). For the measurements of the wet and dry tracks presented here, the 50% to 90% reductions in average PN, $PM_{2.5}$, and PM_{10} concentrations measured at P2 and P3 may instead be due to the dynamics of drifting rather than atmospheric dynamics. My assumptions are that the wet track surface does not allow the tire to volatilize due to the lack of friction between the ground and the tire, and the cooling of the tires from the water. This lack of volatilization is evident in the absence of visible smoke plumes from vehicles drifting under the wet conditions, explaining the significant reduction of particulate exposure a participant would experience at the track. My findings go against one of the studies in

China on wet road PM concentrations, which were reported to have an increase in PM (Tan et al. 2021). Another study done in London, however, reported to have lower PM concentrations in the wet (Fussell et al. 2022). The disparity between my findings and the first study likely stems from the difference in driving style, as the tires on drift cars are pushed to their absolute limit in the dry and the data they recorded is for regular driving. These differences merit further study, however. During the professional drift event under wet conditions, the AQI value of 37 for $PM_{2.5}$ and 28 for PM_{10} for P2, which are considered to be "healthy". In contrast, during dry conditions, the corresponding AQI values of the same distances are "unhealthy for sensitive groups" for $PM_{2.5}$ at a value of 125 and "moderate" for PM_{10} at a value of 55. In summary, a person's exposure to aerosols at a drift event can be minimized to a "healthy" and "moderate" standard by distancing themselves from the emissions point, going to an event when it's raining, or attending a grassroots event.

Domestic, Recreational, and Occupational Risk

I hypothesized that my other recordings would result in comparable average PN, $PM_{2.5}$, and PM_{10} concentrations to drifting, and for most of the activities, the data suggests that this is true. Cooking food can range anywhere from an average total PN of 2.38 # cm^{-3} to 559 # cm^{-3}, which is even higher than drifting. $PM_{2.5}$ values when cooking breakfast are comparable with and without the vent fan, with average concentrations of 101 and 103 $\mu g\ m^{-3}$. These elevated values are expected due to the byproducts of incomplete combustion during cooking (Lachowicz et al. 2022). When converted to AQI values, the $PM_{2.5}$ value is 175, meaning the $PM_{2.5}$ levels for cooking breakfast are considered to be "unhealthy". and the PM_{10} AQI values were 134 with the vent fan on and 178 with the vent fan off. In contrast, the difference between average PM_{10} and average PN between the vent fan settings are statistically significant from each other (Figures 9, Figure 10). For PM_{10}, the difference in average concentration with the fan on was 28% lower than when the fan was off, and using the fan dropped the AQI from 178 to 134, corresponding to slight improvement from being "unhealthy" for everyone to "unhealthy for sensitive groups." Although cooking bacon and eggs may not be representative of all cooking situations in the kitchen, the difference between the settings of the vent fan is statistically significant and is an important tool for reducing someone's daily aerosol exposure. Another air quality study analyzing air quality in an apartment when cooking also found that mechanical ventilation did make a significant difference similar to my findings, but also found that with a combination of natural ventilation, such as opening windows, there would be more improvement in air quality (Kim et al. 2018).

The results presented here also suggest that someone's aerosol exposure while grilling outdoors at home with propane is significantly less than cooking indoors and grilling with charcoal. AQI levels for $PM_{2.5}$ and PM_{10} were considered to be "unhealthy for sensitive groups" when grilling with propane, compared to "very unhealthy" when grilling with charcoal. In general, charcoal grilling is considered to be a bigger source of PM emissions due to the incomplete combustion that is characteristic of using charcoal as a fuel, compared to the more complete combustion that is achieved while using propane (Alves et al. 2022). The results reported in Figure 9, 10, and 11 support this conclusion. Charcoal grilling resulted in the highest average PN measured across all activities in this study, more than 300% larger than the average PN measured during propane grilling (Figure 9). Similarly, average PM_{10} for charcoal grilling was nearly 300% greater than that for grilling with propane gas, and average $PM_{2.5}$ was 145% greater. Converted to AQI values, the $PM_{2.5}$ and PM_{10} averages per minute are considered to be "very unhealthy" and "unhealthy" respectively. These elevated concentrations during cooking and grilling show the importance of considering everyday activities when considering personal aerosol exposure. Using proper precautions for ventilation and opting for cleaner cooking methods are critical for mitigating the potential negative health outcomes associated with these more routine exposures.

The average PN, $PM_{2.5}$, and PM_{10} are comparable for bonfires and attending a grassroots drift event and standing as close as possible to the vehicles. There was no statistically significant difference in average concentrations or AQI categories between these recreational activities. Notably, the $PM_{2.5}$ and PM_{10} concentrations measured here were significantly lower than those reported in another study, which found concentrations that were more than two times greater. These differences could be due to experimental conditions, however, with differences in the combustion conditions, fuel burned, and local meteorology (Gautam 2018).

When considering occupational risks such as auto body work, these activities have a low PN and $PM_{2.5}$ in comparison to most activities. However, PM_{10} was the highest out of any activity, a 600% increase over a professional drift event and a 360% increase over a charcoal barbeque. The $PM_{2.5}$ AQI levels were considered to be "healthy", while the PM_{10} levels were labeled as "hazardous". One study specifically focusing on $PM_{2.5}$ and PM_{10} from auto body work also found extremely elevated PM_{10} concentrations (Sneha et al. 2024). In addition, these results in general were not surprising as the Occupational Safety and Health Administration warns that this type of work does expose you to particulate matter and chemical hazards (OSHA 2024).

In comparing drifting activities to other routine activities, several noteworthy observations were made. Specifically, certain drifting scenarios exhibited no statistically significant differences when contrasted with other activities. For instance, the average particle number (PN) levels from Group 1 (G1) drifting sessions did not significantly differ from those generated during bonfires and gas grilling activities. Conversely, the average PN levels from Group 2 (G2) drifting sessions conducted in dry conditions were notably higher than those observed during bonfires and gas grilling. Notably, all PN measurements recorded during drifting events, except for those at Position 1 (P1), were significantly lower than those observed during breakfast cooking and charcoal grilling. P1 PN levels were not statistically different from those during breakfast cooking. Similar trends were identified concerning PM2.5 concentrations. The average PN and PM2.5 levels during auto body work were significantly lower than all recorded values during drifting. However, it is noteworthy that the average PM10 concentrations during auto body work were 600% higher than the maximum PM10 concentrations recorded during drifting. These findings collectively suggest that the exposure levels experienced during grassroots drifting events are comparable, if not lower, than those encountered during most routine activities. While professional drifting events at their closest proximity (P1) did demonstrate higher concentration levels than some activities, it is important to note that spectators typically maintain a greater distance from vehicles during professional events, particularly at venues like Irwindale Speedway.

Limitations and Future Directions

One notable limitation of this study lies in its sample size, which encompassed only two events held at different tracks under distinct weather conditions, and one event each for the more routine activities that were compared. Moreover, the unique characteristics of each vehicle and driver, including varying tires, engine setups, and driving styles, contributed to the lack of control in the data. This variability extends to the other activities surveyed, making it challenging to provide precise measurements of exposure. Weather conditions, particularly wind direction and precipitation, also played a significant role in exposure levels, yet were not fully accounted for in the methodology. Furthermore, the accuracy of measurements at one of the locations (P1) was affected by concentrations that exceeded the operational range of the particle counter at times and likely resulted in an underestimation of the actual concentrations experienced during those times. In the future, it would be ideal if additional replicate measurements were conducted for each activity to enhance the characterization of exposure concentration variability across various conditions. Improvements will also be necessary to the sampling methodology to ensure that measured concentrations consistently fall within the operational range of the particle counter. Additionally, it will be essential to validate the particle counter response across different aerosol types. This optical measurement method relies on certain assumptions regarding typical aerosol properties, which may not hold true for specific emission sources. Verifying this response across a range of aerosols will help refine the accuracy of the measurements.

Broader Implications

Despite the perception of drifting as a high-risk activity for respiratory health due to its smokey nature, a comparative analysis reveals that its associated risks are comparable to those of everyday activities such as cooking and grilling. This study aimed to provide a rough estimation of aerosol exposure in motorsport and common activity settings, highlighting the lack of literature on motorsports and the resulting negative assumptions made by the public and policymakers. While drifting events indeed demonstrate notable aerosol concentrations, particularly in professional settings, the data shows that combustion activities yield similar levels of particulate matter and fall under similar AQI categories. . Findings suggest that spectator exposure to aerosols is not significantly higher compared to more commonplace activities, emphasizing the importance of considering exposure not only in drifting but also in other everyday activities. Therefore, while drifting may not be entirely benign for respiratory health, its risks are not disproportionate when compared to other common activities, underscoring the importance of considering overall exposure levels and mitigation strategies in assessing health impacts.

ACKNOWLEDGEMENTS

Thank you to these people who helped me immensely in my thesis. Chelsea Preble for taking all this time to guide me through the process of doing this project and being extremely patient with me. I was so incredibly excited to work with her as she was a previous ES student and wrote so many interesting studies. I am honored to be her mentee for my thesis and I would not have had it any other way. My father and Carrie Thang, who helped me record some of my drifting data when I was preoccupied during the drift events and supported me throughout the whole process. Thank you to my mentors for this class, Patina Mendez and Jessica Craigg, for being wonderful instructors over the past year. This would not be possible without these people and I appreciate everything they have done for me.

REFERENCES

Alves, C. A., M. Evtyugina, E. Vicente, A. Vicente, C. Gonçalves, A. I. Neto, T. Nunes, and N. Kováts. 2022. Outdoor Charcoal grilling: Particulate and gas-phase emissions, organic speciation and Ecotoxicological Assessment. Atmospheric Environment 285:119240.

Air Quality Issues in School Site Selection. (n.d.). . http://www.aqmd.gov/docs/default-source/planning/air-quality-guidance/school_guidance.pdf.

Autobody repair and refinishing - hazards and solutions. (2024). https://www.osha.gov/autobody/hazards-solutions.

AQI Basics. (n.d.). . AirNow.gov, U.S. EPA. https://www.airnow.gov/aqi/aqi-basics/.

CA E.D. [State of California Executive Department]. 2018. Executive Order B-55-18. CA E.D. Sacramento, C.A., USA

CA E.D. [State of California Executive Department]. 2020. Executive Order N-79-20. CA E.D. Sacramento, C.A., USA

Chaichaowarat, R., and W. Wannasuphoprasit. 2013a. Optimal control for steady state drifting of RWD Vehicle. IFAC Proceedings Volumes 46:824–830.

EPA [Environmental Protection Agency]. 2020. Fast Facts: U.S. Transportation Sector

Greenhouse Gas Emissions. A Report of the EPA Science Advisory Board (EPA-420-F-22-018). EPA, Washington, D.C., USA.

EPA [Environmental Protection Agency]. 2020. How Does PM Affect Human Health?. A Report of the EPA Science Advisory Board. EPA, Washington, D.C., USA.

EPA [Environmental Protection Agency]. 2018 Report on the Environment: Particulate Emissions Report of the EPA Science Advisory Board. EPA, Washington, D.C., USA.

Foitzik, M.-J., H.-J. Unrau, F. Gauterin, J. Dörnhöfer, and T. Koch. 2018. Investigation of Ultra Fine Particulate Matter Emission of Rubber Tires. Wear 394–395:87–95.

Fussell, J. C., M. Franklin, D. C. Green, M. Gustafsson, R. M. Harrison, W. Hicks, F. J. Kelly, F. Kishta, M. R. Miller, I. S. Mudway, F. Oroumiyeh, L. Selley, M. Wang, and Y. Zhu. 2022. A Review of Road Traffic-Derived Non-Exhaust Particles: Emissions, Physicochemical Characteristics, Health Risks, and Mitigation Measures. Environmental Science & Technology 56:6813–6835.

Gautam, S., A. Talatiya, M. Patel, K. Chabhadiya, and P. Pathak. 2020. Personal Exposure to Air Pollutants from Winter Season Bonfires in Rural Areas of Gujarat, India. Exposure and Health 12:89–97.

IPCC [The Intergovernmental Panel on Climate Change]. 2023. Sixth Assessment Report (AR6). United Nations. New York, N.Y., USA

Kang, K., H. Kim, D. D. Kim, Y. G. Lee, and T. Kim. 2019. Characteristics of cooking-generated PM10 and PM2.5 in residential buildings with different cooking and ventilation types. Science of The Total Environment 668:56–66.

Karagulian, F., C. A. Belis, C. F. Dora, A. M. Prüss-Ustün, S. Bonjour, H. Adair-Rohani, and M. Amann. 2015. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. Atmospheric Environment 120:475–483.

Kim, H., K. Kang, and T. Kim. 2018. Measurement of Particulate Matter (PM2.5) and Health Risk Assessment of Cooking-Generated Particles in the Kitchen and Living Rooms of Apartment Houses. Sustainability 10:843.

Kwon, H.-S., M. H. Ryu, and C. Carlsten. 2020. Ultrafine particles: Unique physicochemical properties relevant to health and disease. Experimental & Molecular Medicine 52:318–328.

Lu, F., D. Xu, Y. Cheng, S. Dong, C. Guo, X. Jiang, and X. Zheng. 2015. Systematic review and meta-analysis of the adverse health effects of ambient PM2.5 and PM10 pollution in the Chinese population. Environmental Research 136:196–204.

Mourao, P. 2018. Smoking gentlemen—how formula one has controlled CO2 emissions. Sustainability 10:1841.

Ohlwein, S., R. Kappeler, M. Kutlar Joss, N. Künzli, and B. Hoffmann. 2019. Health effects of ultrafine particles: A systematic literature review update of epidemiological evidence. International Journal of Public Health 64:547–559.

Particles Plus (2022). Instrument Management Software. Retrieved from https://particlesplus.com/ims/

Sneha, M., S. Indushri, N. Ramsundram, A. Gandhimathi, H. Arul, and S. Prasanth. 2024. Elemental characterization of PM10 and PM2.5 and exposure risk assessment: Auto-repair garage. International Journal of Environmental Science and Technology 21:6373–6388.

Tan, F., Y. Guo, W. Zhang, X. Xu, M. Zhang, F. Meng, S. Liu, S. Li, and L. Morawska. 2021. Large-Scale Spraying of Roads with Water Contributes to, Rather Than Prevents, Air Pollution. Toxics 9:122.

Uugwanga, M. N., and N. A. Kgabi. 2021. Dilution and dispersion of particulate matter from abandoned mine sites to nearby communities in Namibia. Heliyon 7:e06643.

Wang, R., K. Cui, H.-L. Sheu, L.-C. Wang, and X. Liu. 2023. Effects of precipitation on the air quality index, PM2.5 levels, and on the dry deposition of PCDD/Fs in the ambient air. Aerosol and Air Quality Research 23:220417.

Woo, S.-H., H. Jang, S.-H. Mun, Y. Lim, and S. Lee. 2022. Effect of treadwear grade on the generation of tire PM emissions in laboratory and real-world driving conditions. Science of The Total Environment 838:156548.

Xu, C., J. Chen, X. Zhang, K. Cai, C. Chen, and B. Xu. 2023. Emission characteristics and quantitative assessment of the health risks of cooking fumes during outdoor barbecuing. Environmental Pollution 323:121319.