Developing a Mask Containing Nanofiber Filtration Methods for Optimal Breathability and Comfort for Professional and Recreational Runners

Grant Proposal

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Executive Summary

With the COVID-19 Pandemic secluding the population in their homes, a desire was sparked amongst them to find a new hobby to keep themselves entertained. The most popular hobby that arose was running. However, since COVID is an air-borne disease, runners were required to wear masks to maintain their health. The most common masks, the surgical and KN95 mask, have detrimental effects on the runner. The material the surgical mask uses are too thick, which inhibits the runner's breathing, making it difficult to inhale oxygen and exhale the carbon dioxide back into the atmosphere. This significantly reduces the runner's comfort and health. However, if runner's use a mask that has a thinner material, a harmful pollutant such as particulate matter under the size of 2.5 microns (PM 2.5) will enter the lungs and may cause severe respiratory diseases. This study strives to create and design a mask that will effectively filter out PM 2.5 in the atmosphere, while also providing maximum comfort for the runner. Filters that were designed electrospinning methods will be implemented in this study's mask. The characteristics of this filter will prevent the smallest of harmful particles from entering the runner while also maintaining the regular amount of oxygen intake and carbon dioxide outtake. Additionally, the mask will consist of a 2-valve system for proper distribution of the oxygen and carbon dioxide intake and outtake. This mask will be conducted in a light-transmittance test to determine the effectiveness of this mask. This research and engineering project has the potential to revolutionize the way runners can perform in densely polluted environments.

Keywords: Air Pollution, PM 2.5, Minute Ventilation, Electrospinning, Nanofibers, Pace, 2-Valve Design

Developing a Mask Containing Nanofiber Filtration Methods for Optimal Breathability and Comfort for Professional and Recreational Runners

One of the most popular pastimes in the modern world is to go running outdoors (Aydin et al., 2013). However, there are extreme threats that endanger the safety of runners, such as air pollution released from industrial and economical causes. (Wen et al., 2024).

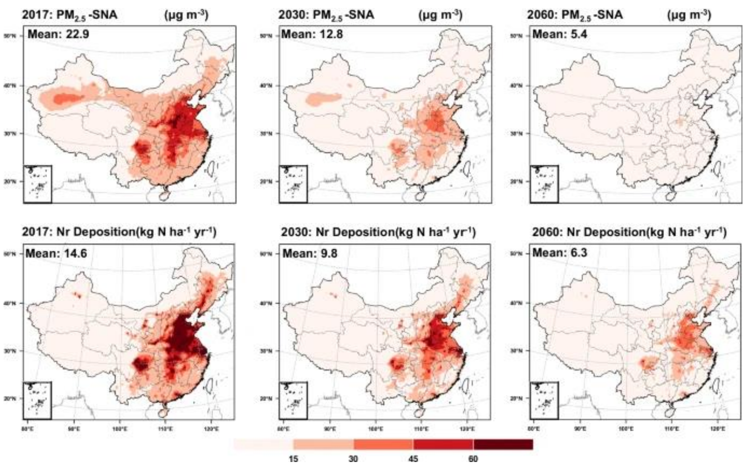


Figure 1: A figure from the study of Wen et al (2024). Shows the average levels of PM2.5 and Nitrogen in China. These pollutants come from the growing air pollution from industrial exhaust.

The most prevalent pollutant in the atmosphere is particulate matter under the size of 2.5 micrometers (PM 2.5). PM 2.5 comes from industrial exhaust such as car and factory emissions. Inhaling an excessive amount of PM 2.5 could put the runner at risk of suffocation, asthma, or developing heart or lung diseases (Department of Health and Human Services, 2018). Air pollution significantly increases the pace for a runner, in terms of the time it takes to run a certain distance (Guo & Fu, 2019). Competitive runners will be heavily effected by the potential fluctuations in pace. Exposure to high levels of PM 2.5 could lead to health and performance implications in the runner.

Previous Studies

In response, multiple studies have taken different directions to tackle this obstacle. One is to create or use a mask. Originally, past methods were to use standard masks like the surgical and KN95 models (Velasco et al., 2022). A study conducted by Runergy displayed the effects of running in surgical and KN95 masks. The major criteria for this study were for the masks to be able to protect the runner from pollutants while also providing satisfactory breathability. However, they found that both masks caused discomfort and suffocation (Runergy, 2020). They experienced shortness of breath as well.

However, there is a mask specifically designed for runners exercising in densely polluted areas, and that mask is the Airinum Urban Mask 2.0. Although this mask offers high-tech filtration methods consisting of two ventilation valves, the lack of comfort is a big issue. Reviews on this mask written by consumers stated that the filter was too big on the face and the material used was somewhat scratchy (Airinum, 2021). Thus, proving it still has some flaws that need to be fixed for the ideal criteria of balancing comfort, filtration, and breathability.

Another plausible method to address these issues is the use of an electro-spinner. Deng et al. (2022) attempted to electro-spin a polymer to create a nanofiber. This nanofiber was used as a filtration device, which successfully filtered and prevented nanoparticles from passing through, particularly PM 2.5. It also resulted in better air permeability and flexibility. However, this study did not try to implement the fiber into a mask.

Knowledge Gaps

In recent mask models, significant aspects of the mask are excluded in the design. The most important one is the balance between filtration and breathability efficiency. Surgical and KN95 masks are proficient in filtering out the larger-sized air pollutants (3.0 - 10.0 microns) encompassing the atmosphere (Wang et al., 2023). However, their breathability could be better (Wang et al., 2023). With these masks, the emitted carbon dioxide is trapped inside the mask and will cause suffocation to the user. Additionally, air pollutants vary in size, and those models do not account for the smaller particles. Throughout the economic market, there is a low number of masks that can adequately balance between the two. And the ones that do cost a significant amount of money, ranging from $40 to $60 (Airinum, 2024).

Another prominent issue in the mask industry is the negligence of filtering out the smaller air particles. Face protection devices often do not filter out the smaller air pollutants and only filters the more prominent pollutants, like the KN95 mask, and this mainly derives from the use of inefficient materials (Wang et al., 2023). Smaller particles can still cause heavy damage to the body, similar to the effects of the larger-sized particles (New York State Department of Health, 2024). So, mask models should heavily influence that aspect. To protect people from these hazards, the gaps in knowledge need to be addressed immediately, as the health of runners is at stake.

Justification

Current mask models utilize material that lacks the essential attributes that will efficiently help professional runners perform. To adequately protect runners, these gaps need to be resolved. This study aims to gain a comprehensive understanding of the risks in the air and develop a mask with nanofiber filtration methods that produce efficient breathability and comfort for the user, specifically for professional and recreational runners. This research has the potential to revolutionize the way we protect runners from air pollution, significantly improving their performance and health. Filters that contain electrospinning techniques will be the target filter for the designed mask.

Nakai and Enoki (2019) used light scattering tests to test the filtration of specific masks and analyze the air permeability.

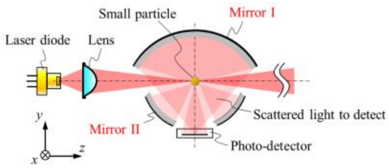


Figure 2: A diagram of the photosensor Nakai and Enoki (2019) used in their study. This shows the laser directing light at a particle, and the photodetector gathering the scattered light data.

They found that the light test was high-quality and provided significant data, which brings a new path of testing for this study. Solving these issues will allow runners to perform at their best while staying the healthiest they can be with a mask. We hypothesize that a nanofiber-based mask will support runners and rid them of the burdens of the polluted environment.

Section II: Specific Aims

This study aims to develop a mask for runners performing in densely air-polluted areas. Our long-term goal is to ensure that runners experience comfort without worrying about airborne hazards in the atmosphere. Our central hypothesis for this proposal lies within these specific aims, where our rationale for the aims lies in the hope that each one will help progress our designed mask. Considering this objective, our work will consist of the following aims:

Specific Aim #1: Finding a mask filter that uses electrospinning technology

Specific Aim #2: Testing the filter in a light-transmittance test to accurately quantify the efficiency of the mask

Specific Aim #3: Computer-assisting designing (CAD) two exhalation valves for the mask

The outcome of these aims will accurately reflect the efficiency of the overall mask, from its filtration capabilities to its general satisfaction in terms of comfort. The tests will be comprehensive, providing a detailed understanding of the mask's performance and identifying any areas for improvement. The findings will give the audience confidence in the project's methodology and its validity.

Section III: Project Goals and Methodology

Relevance/Significance

The project aims to develop a mask for runners that holds significance for their health, safety, and performance. During exercise, the participants air intake increases, resulting in more and bigger air pollutants entering the lungs. This can further the risk of respiratory damage like, heart and lung diseases, heart attacks, seizures, and more (EDA, 2024). When performing, a runner's minute ventilation will increase, which is the amount of air a person intake in 1 minute (Giles & Koehle, 2013). As a result, the runner will be intaking more air pollution per minute. It can diminish a runner's pace by 2-5 minutes, which may affect their personal best or their place in an official race (Guo & Fu, 2019). Consequently, developing a comfortable and filtration-efficient mask is crucial to prevent these detriments from occurring.

Innovation

This project is unique in many ways. One of the biggest ones is the use of technology. Current mask models do not use nanofibrous material to filter the more significant pollutants, such as PM 2.5 and lower. This study strives to use a filter that was made from electrospinning. Another innovative aspect of this study is that it will test the mask's filtration efficiencies through a controlled environment test. Additionally, this mask will implement exhalation valves for proper distribution of inhaled and exhaled air, an aspect that is uncommon in the mask industry. This study will demonstrate these unique aspects to create a nanofibrous-based mask.

Methodology

The methodology of this study consists of multiple procedures and tests that will accurately gather data. The first method is using an electro-spun filter.

Electrospinning

Electro-spinning is a high-tech procedure that will create a mesh capable of high-filtration mechanisms. It is a technique widely used to develop highly efficient nanofibers to filter out most atmospheric pollutants (Chen et al., 2022). It starts with a polymer dissolving in a solvent and then loaded into a syringe, and then an electric current is run through the syringe to produce nanofibers.

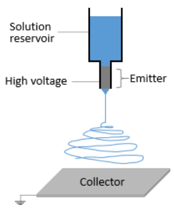


Figure 3: Visual representation of the process of electrospinning. The solution in the syringe is emitted into a high voltage, and then it is spun onto the collector to create the nanofiber mesh (Chen et al., 2022).

With this high-tech procedure, this study has a unique scope that will bring innovative results and discoveries. Electro-spinning will produce a nanofibrous mesh that efficiently filters out the most petite sizes of PM 2.5 while maintaining maximum breathability and comfort. This study intends to find a filter in the market that was made from these methods. After finding one, a light transmittance test will be implemented to test the newly spun filter's filtration efficiency.

Light Transmittance Test

This test appropriately displays the amount of light that passes through a particular area. This test will be conducted by having the filter in a controlled area. This controlled area will contain samples of PM 2.5 in the atmosphere. These samples will come from collecting aroma smoke and chalk dust. Airflow will then be implemented, and the pollutants will be directed toward the filter to test whether they have been filtered out. On the other side of the mask, there will be a stationary laser constantly emitting light and a light sensor. The sensor will be placed parallel to the laser. As the pollutants travel through the filter and reach the other side, they will be met with the laser's light. However, if this test contains skewed data, it will not determine the filtration efficiency of the mask. This was seen in the graph in Appendix A. There was little light detection difference between the two-time periods when applying the chalk dust in the controlled environment. Since chalk dust is significantly larger than PM 2.5, the light sensor would not be able to pick up smaller particles, thus being an inefficient testing method. Another test that could be implemented uses a specified PM 2.5 detector.

Particulate Matter Detection Test

This test will have a similar setup to the previous Light Transmittance test. The filter will be placed in a controlled environment with an airflow directing the particulate pollutants into the filter. However, a different type of sensor will be used instead of a laser and a light sensor. This sensor is called the Davis Instruments AirLink Air Quality Monitor. This sensor can detect low and high amounts of PM 2.5 in the atmosphere (Vernier, 2024). So, the sensor will be able to pick up if the filter was able to block out air pollutants by quantifying the number of pollutants present after the filter. With these tests, we can certify the effectiveness of the filter.

Specific Aim #1: Finding a mask filter that uses electrospinning technology

This specific aim was to determine a way to efficiently filter out pollutants in the atmosphere. The primary objective was to find a filter that would prevent small and larger–sized pollutant particles from entering the runner’s respiratory system. Our approach was to research filters that were made from electrospinning methods. Our rationale was that electro-spinning creates a nanofibrous material, which would make it filter out the smallest particles.

Justification and Feasibility

Electro-spinning is crucial in developing a high-tech filter because of its filtration capabilities toward smaller particles. After researching, it was found that the Airinum air filter was the most proficient and cost-effective mask on the market, with the cost being $20 (Airinum, 2024). It inhibits electro-spun techniques and can filter up to PM 0.3 but can also maintain optimal oxygen intake levels (Airinum, 2024). It also contains exhalation valve holders that can use my own designed valves.

Summary of Preliminary Data

With this data, this mask is known to be capable of filtering out PM 0.3 while also maintaining breathability. Additionally, with its built-in exhalation valve holders, it can now provide optimal oxygen intake and carbon dioxide outtake without trapping it in the mask.

Expected Outcomes

The expected outcome of this specific aim is to use the nanofibrous material that will serve as a filter for the designed mask.

Potential Pitfalls and Alternative Strategies

Some potential issues accompany this specific aim. One could be the amount of time it takes for the mask to come in. If the mask takes a prolonged time, then the process of measuring the mask will also be delayed. The strategy that will solve this is to order the filter as soon as possible so that future methodology will not be delayed.

Specific Aim #2: Particulate Matter Detection Test

This specific aim hopes to determine the filtration efficiency of the filter made by the electro-spinning process. Our approach for this aim is to test the filter through a particulate matter detection test. This will help determine how many pollutants manage to go through the filter.

Justification and Feasibility

This particulate matter detection test quantifies the number of pollutants that were able to bypass the mask. However, the test has a similar set-up to a study conducted by Nakai and Enoki. The test has features that both researchers had in their test. Nakai and Enoki (2019) conducted a light-scattering test using a 0.3-micron particle.

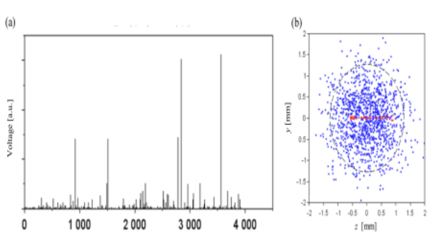


Figure 5: An example of simulation results with regard to the 0.3μm diameter particle. (a)output signal waveform with regard to the 0.3μm diameter particle, (b) spatial particle distribution (Nakai & Enoki, 2019).

The graph above shows the data when light scattered from a 0.3 micron-sized particle. This justifies quantifying the number of light-scatters is possible, so doing the same for particulate matter is plausible.

Summary of Preliminary Data

After testing, the results were recorded and graphed. See Appendix B for the results. Before the airflow directed the pollutants into the mask, there were approximately 431 particles of PM 1.0, 1097 particles of PM 2.5, and 1764 particles of PM 10.0 in the controlled area. Then, when the airflow was created, there was an average of 30.96 particles of PM 1.0, 55.13 particles of PM 2.5, and 67.93 particles of PM 10.0 present through the mask over a span of 30 trials. The mask successfully filtered out approximately 96% of all pollutants.

Expected Outcomes

The expected outcome of this specific aim is to determine the number of pollutants that manage to bypass the filter through a particulate matter detection test. This knowledge will be used to determine the filtration capability.

Potential Pitfalls and Alternative Strategies

Additionally, there are some obstacles that could be in the way of this procedure. One is the problem mentioned above, where the laser's light output exceeds the maximum capacity, the sensor could record. If this does occur, the data will be inaccurate. A solution to this problem would be to use the Davis Instruments AirLink Air Quality Monitor to quantify the amount of particulate matter. This would completely change the procedure from a light-transmittance test to a simple particulate matter detection. However, this would only occur if the problem mentioned above happened.

Specific Aim #3: Computer-Aided Designing Exhalation Valves

The primary objective was to make sure breathability and comfort in the mask is optimal and the carbon dioxide and oxygen would be properly distributed in and out of the mask. Our approach was to CAD exhalation valves for the mask. Our rationale was these valves will not let any air be trapped inside the mask.

Justification and Feasibility

Computer-Aided Design is the most optimal method of designing these valves because it allows for personal customization based on specific measurements and it has great flexibility. These valves will make breathing much easier without the worry of potential suffocation within the mask.

Summary of Preliminary Data

After thorough research and designing, the model of the exhalation valve was created and can be seen in Appendix B. This exhalation valve fits onto the Airinum mask filter. The material that was used to CAD this valve is flexible and will be able to endure outside conditions.

Expected Outcomes

The expected outcomes are that the exhalated valves will be designed using CAD and will be able to provide maximum breathability, while the cotton fabric sewn on will make the mask pleasant.

Potential Pitfalls and Alternative Strategies

One potential problem that could occur is that the valves may be larger or smaller than the holder on the filter. Accurate measurements and careful analysis will be needed when 3D printing them. Another problem could be that the cotton fabric may be sewn on or may tear through the filter. Careful attention and precision are also needed.

Section IV: Resources/Equipment

The equipment I require for this study is as follows:

1. Particulate Matter 2.5 Samples
2. A Davis Instruments AirLink Air Quality Monitor
3. Plastic, Metal, and Fabric for the mask base
4. 3-D Printer

Section V: Ethical Considerations

Along with these tests comes a certain degree of risk that can endanger someone's safety. A laser will be used for the light-transmittance test. This laser could contact someone's eye and cause permanent damage. Additionally, hazardous pollutants will be used, and if they are ingested or exposed to sensitive areas, they can cause internal lung damage or irritation. People will be strongly warned to stay at least 5 feet away from the direction of the laser to counteract these risks. They will also be asked to wear protective gear, such as masks, glasses, gloves, and an apron.

Section VI: Timeline

Name: Ayaan Hegde
Title of Project: Air Pollution - Resistant Running Mask

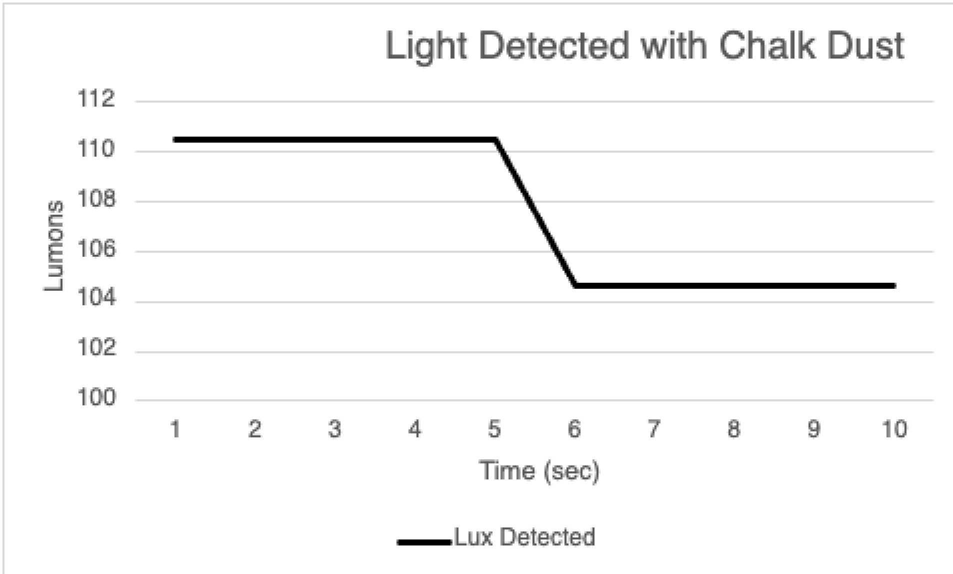
Phase 1: **Initial Research (Aug - Oct)**
- Develop 3 PIE Diagrams (8/31)
  - (Biology, Sports, Computers)
- Contact 5 professors for potential mentorship (9/15)
  - Lab use and Expertise
- STEM Update Meeting #2 (10/2)
- Research 10 Articles + 2 Patents (10/11)
- Create a Project Management Table(10/30)

Phase 2: **Prototype Development (Nov - Dec)**
- Draw up initial sketches for prototype (11/04)
  - 3 designs minimum
- Grant Proposal #1 (11/08)
- Gather necessary materials (11/10)
- Hopefully meet up with contacted professors / start building prototype (11/24)
- Grant Proposal #2 (11/29)
- Start data collection with prototype (12/15)
- December Fair (12/09)

Phase 3: **Data Collection / Finalization (Dec)**
- Grant Proposal Draft (12/02)
- Figure out malfunctions within the prototype (12/17)
- 20 Articles + 2 Patents (12/20)
- Start the final product process (12/25)

Phase 4: **Final STEM Product (Jan - Feb)**
- Grant Proposal Final Draft (01/02)
- Create the final product (01/15)
- Test final product and analyze data (01/20)
- Create STEM Thesis
- February Fair (02/15)

Section VII: Appendix



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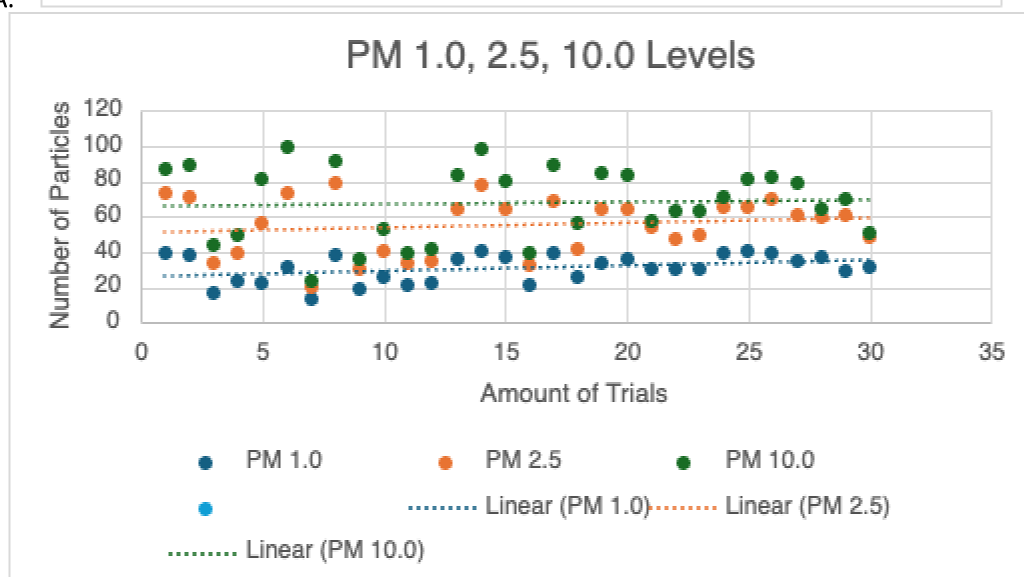

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C.

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