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Thanks to a gift from the Berry Family Foundation and the Berry family, the UHP offered 10 rising juniors the opportunity to participate in the 2023 Berry Summer Thesis Institute.

First initiated in the summer of 2012, the Institute introduces students with a proven record of academic success and interest in intensive research, scholarship opportunities and professional development. Students selected for the Institute were competitively selected for participation by the University Honors Program review committee. Each student pursued a summer-long research project under the guidance of a UD faculty mentor.

In coordination with the Fitz Center for Leadership in Community, the students also learned about civic engagement and servant leadership by volunteering with local community partners.

How Porous Materials Affect the Boundary-Layer Transition of Hypersonic Flight Vehicles

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Abstract

A major problem in hypersonic flight is the excessive heating of the vehicle while in flight. Hypersonic vehicles have thermal protection systems (TPS), and a large area of concern is how to design these TPS to not cause any harm to the vehicle's performance while also protecting the vehicle from heating. This undergraduate research project will investigate the most prominent instability that causes turbulence, and consequently, heat, on a flat-plate at Mach numbers of 4 and above: the second-mode boundary-layer instability. Different porous materials have been shown to dampen acoustic waves, which are the cause of second-mode boundary layer instabilities. This project looks to study different porous materials and how they affect the second-mode boundary-layer instability, which is a continuation of the study "Effect of Porosity on the Ability of Silicon-Carbide Foams to Attenuate the Second-Mode Boundary-Layer Instability" (Bemis et al.). This project is using a larger flat plate, a total of 14 PCB pressure sensors, schlieren imaging, and possibly infrared thermography with the hope of locating exactly where the boundary-layer changes from laminar flow to turbulence. The goal of this summer project is to have all the data analysis codes written, to have the flat plate built, and have the experiment put together to test at the end of the summer or early fall.

Introduction

Hypersonic flight is the direction that the current aerospace industry is moving towards. With the prospect of flying from New York to London in under 90 minutes, and its defense and space applications, making hypersonic flight a reality is a huge goal for different companies and the government. Hypersonic speed is recognized as speeds around Mach 5 or faster, meaning five times the speed of sound.

The faster a vehicle goes, the more energy it creates. That energy is then transformed into heat at the surface of the vehicle in an area known as the boundary-layer through shear stresses. This boundary-layer, a pocket of air surrounding the vehicle, has a direct impact on the heating of the vehicle. The boundary layer has three states, each of which has a different heating effect. The boundary-layer can be in a laminar state, a turbulent state, or a transitional state. The turbulent boundary-layer has been shown to have about five times more heating than a laminar boundary-layer [1]. If the boundary-layer is controlled, then the heating of the vehicle is controlled. Thermal protection systems (TPS) are systems placed on air vehicles that protect from temperature extremes. A hypersonic vehicle with a turbulent boundary-layer would then need a more significant, and possibly larger TPS [2]. Therefore, the control of the boundary-layer is a major design criterion when creating TPS for different vehicles. As stated in Bemis et al. [2], there are two different types of techniques that the hypersonic research community is studying for a boundary-layer TPS:

active and passive techniques. An active technique would be a TPS actively working to keep the boundary-layer in a laminar state, such as wall cooling/heating or blowing/suction techniques. A passive technique would be a TPS not actively attempting to change the boundary-layer state, such as porous walls or surface roughness techniques. Bemis et al. [2] and Bemis et al. [4] found that porous materials have the ability to dampen out an instability that causes turbulence and will be explained further in the coming paragraphs. This experiment looks to continue with the work of Bemis et al. [2] and study how porous materials affect the boundary-layer state.

The boundary-layer is acted upon by outside forces to change its state. The second-mode boundary-layer instability is the most prominent instability known for causing transition of a boundary-layer on flat plate models at Mach numbers of four and above [3] and will be the focus of this study. The second-mode instability is caused by acoustic waves trapped between the model surface and the sonic line [3]. To control the state of the boundary-layer, this instability must be controlled as well. Porous materials have the ability to dampen out acoustic waves by adding or subtracting energy to the wave as it hits the material. This experiment will test materials of varying porosity on a large flat plate model in the AFRL's hypersonic wind tunnel to see if that second-mode instability can be damped out.

Work Done

Bemis et al. [2] and Bemis et al. [4] tested silicon-carbide foams of varying porosities on a flat plate model in a hypersonic wind tunnel at Mach number 6.1. The silicon-carbide foams were chosen because their material is highly porous, has a rigid skeletal structure, and is customizable [4]. This current experiment will expand on those previous experiments and will test silicon-carbide foams. This current experiment will also test carbon-carbon foams because that material has more real-life applications. Existing TPS are often made of carbon-fiber materials which have some irregular surface roughness. Therefore, carbon-carbon foams of random porosities are possibly more applicable than silicon-carbide foams would be. The previous experiments [2, 4] showed successful damping of the second-mode instability. This experiment will be building off that and will be testing materials on a much larger flat plate model. It will be 15" wide and 20" long, almost twice as long and three times as wide as previous models [2, 4]. This model will be made from impermeable steel and have a top made from standard polyether ether ketone (PEEK). PEEK was used in both Bemis et al. [2] and Bemis et al. [4] as the impermeable testing material to take a baseline, non-porous data set. The top of the model will have an opening 10" long and 2" wide for the foams to be placed in during testing. This is another difference from the previous experiments, allowing data to be taken from both a porous and non-porous material simultaneously to limit error. This model is currently being made by the University of Dayton Research Institute's machine shop, so no testing has been completed this summer.

The testing will be completed in the Wright Patterson Air Force Base hypersonic wind tunnel. It is a Ludwig tube type wind tunnel. Ludwig tubes are characterized by their simpler design and require minimal infrastructure to support them [7]. It operates at Mach 6 [7], which means that the air flowing through the tunnel flows at six times the speed of sound. The Ludwig tube has two different sides: a high-pressure end and a low-pressure end. The low-pressure end is where the testing section is. An actuation device called a fast valve separates the two sides [7]. When the tunnel is turned on, an expansion wave travels from the high-pressure area to the low-pressure area. This provides a period of "steady stagnation conditions" [7] allowing measurements to be taken in a uniform airflow. The model will sit in the test section with its leading edge facing upstream, towards the fast valve, and secured to the wind tunnel itself on a stand.

The experimental techniques used will be similar to ones used in Bemis et al. [2] and Bemis et al. [4]. PCB pressure sensors and high-speed schlieren imaging will be used. PCB pressure sensors are sensors that measure the exact pressure at the spot in which they are located at any time. However, where the previous experiments used 4 PCB sensors, this experiment will use 14. High-speed schlieren imaging is a technique that captures density gradients of a flow [8]. A self-aligned focusing schlieren setup will be used. The self-aligned focusing schlieren setup was first implemented by Hill et al. [8]. It was found that this setup is accurate in depths of focus on the order of 1-10 mm [8]

and achieves framerates from 100 kHz to 1 MHz [8]. The self-focusing setup also circumvents the limitations of traditional schlieren imaging, which are mainly noise related. Noise is anything other than the airflow that is affecting the measurements, an example could be air conditioning.

Another experimental technique used will be infrared thermography. Infrared thermography is a technique that obtains surface temperatures from a model using thermal radiation [6]. Thermal radiation is energy radiating from a model with a nonzero temperature, essentially heat. According to Running [6], it is a non-invasive and global measurement with “much higher spatial resolution.” This means that this technique gets a more accurate reading of the complete surface temperature of a model than other sensors, such as thermocouples, would. This method of measurement was not used in Bemis et al. [2] and Bemis et al. [4] and therefore will be a relatively new experience for this lab.

When the raw data is collected from the different measurement techniques, it needs to be changed into a usable form to examine. This is usually done through MATLAB codes. Work was done this summer to revise old codes used for the post-processing of PCB data and schlieren data. Since infrared thermography is an unfamiliar measurement technique, work was done this summer to learn how that post-processing code would work. Boyd et al. [5] highlights the heat-flux calculations used and how they are applied in the MATLAB code to change the raw electrical signals into surface temperatures. Heat flux is the rate of heat transfer from the model surface to the camera lens. All of this usable data is then examined with the focus of looking at the second-mode boundary-layer instability and how it develops over time.

This summer ended with lots of preparation for future experiments. The hope is that we are fully prepared for the model to be built and tested in the fall.

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References

1. Reed, H. L., Kimmel, R., Schneider, S., Arnal, D., and Saric, W., “Drag prediction and transition in hypersonic flow,” AGARD Conference Proceedings, Vol. 3, AGARD, 1997, pp. C15–C15.
2. Running, C. L., Bemis, B. L., Sieve, M. C., Hill, J. L., Borg, M. P., Redmond, R., Ruggeri, M., J. J., Jantze, K., and Scalo, C., “Effect of Porosity on the Ability of Silicon-Carbide Foams to Attenuate the Second-Mode Boundary-Layer Instability,” AIAA Paper 2023-2194, May 2023
3. Mack, L. M., “Boundary-Layer Linear Stability Theory,” Tech. rep., DTIC Document, 1984
4. Running, C. L., Bemis, B. L., Hill, J. L., Borg, M. P., Redmond, J. J., Jantze, K., and Scalo, C., “Attenuation of Hypersonic Second-Mode Boundary-Layer Instability with an Ultrasonically Absorptive Silicon-Carbide Foam,” AIAA Paper 2022-5315, November 2022
5. Boyd, C. F., and Howell, A., “Numerical Investigation of One-Dimensional Heat-Flux Calculations,” October 1994
6. Running, C. L. (2020). Global Measurements of Axisymmetric Hypersonic Shock-Wave/ Boundary-Layer Interactions. [Doctoral dissertation, University of Notre Dame].
7. Kimmel, R. L., Borg, M., Jewell, J. S., Lam, K. Y., Bowersox, R., Srinivasan, R., Fuchs, S., and Mooney, T., “AFRL Ludwig Tube Initial Performance,” AIAA Paper 2017-0102, January 2017
8. Hill, J. L., Reeder, M. F., Borg, M. P., Benitez, E. K., and Running, C. L., “Implementation of Self-Aligned Focusing Schlieren for Hypersonic Boundary Layer Measurements,” AIAA Paper 2022-5405, November 2022

Ultra-Stretchable, Self-Healing, DLP 3D-Printed Elastomers for Damage-Resistant Soft Robots: A Review

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Abstract

Inspired by nature, *soft robots* composed of compliant (“soft”) materials are well-suited for uncertain, dynamic tasks requiring safe interaction between a robot and its environment. Vat photopolymerization (VP) additive manufacturing (AM) processes such as digital light processing (DLP) have disrupted traditional manufacturing of soft devices, enabling the fabrication of soft robotic components with unprecedented speed, resolution, and complexity. Concurrently, the rapid development of novel *self-healing photo-curable soft materials* for VP-based AM has paved the way for soft robots with embedded healing of damage (e.g., perforations, tears) induced, for instance, by an unintended interaction with a sharp object in their operating environment. This literature review explores past studies of self-healing materials and their underlying mechanisms. It also defines these materials in the context of 3D-printing, especially that of “continuous” DLP.

Applications Of Self-Healing Materials

Through the leveraging of self-healing elastomers in combination with DLP 3D-printing, increasingly complex, modular robotic systems can be created through the “self-healing” of multiple components together. One of the common examples of these robotic systems being that of a “soft robotic gripper”, in which multiple pneumatic actuator modules are combined into one gripping system.¹

Self-healing materials also have the potential for multiple biomedical applications. Recent studies have investigated the viability for implementation into vascular repair, and therapy practices for aortic aneurysms, nerve coaptations, and bone immobilization in animal models.^{2,3}

Literature Review

I. MECHANISMS OF SELF-HEALING MATERIALS

Self-healing materials employ 2 separate types of mechanisms for self-repair: intrinsic and extrinsic. Extrinsic self-healing does not rely on properties inherent to the material itself. Rather, it employs the use of micro-capsules imbedded within a catalyst composite matrix. When cracks occur in the matrix, the micro-capsules rupture. Upon breaking, they release a healing agent that

fills in cracks and tears. As this is happening, the healing agent reacts with the catalyst and polymerizes, sealing the gaps. A drawback of this method of self-healing is that once the material has self-healed in an area, if damaged again in the same spot, it won't be able to consistently repair due to a decreasing amount of healing agent present.⁴

Intrinsic self-healing materials on the other hand, do not rely on external methods for repair. Rather, intrinsic self-healing materials employ either inherent dynamic covalent bonds or dynamic non-covalent bonds, resulting in reversible chemical bond formations or physical cross-linking to occur. These bonding processes are capable of healing macroscopic damage to the material.⁵

One of the common types of dynamic covalent bonding is that of Diels-Alder bonds. With this type of bonding, a chemical or thermal stimulus is required for self-healing activation to occur. When this occurs, the Diels-Alder bonds are broken, increasing intermolecular mobility, and allowing cracks and cuts to fill. Once the material is brought back down to a resting temperature, the bonds reassemble and polymerize to seal the cracks and damage.⁶

Hydrogen bonding, on the other hand, represents a common form of physical cross-linking in intrinsic self-healing materials. In hydrogen bonding, a donor atom essentially shares electrons with an acceptor atom, allowing reversible bond formation.⁷ By employing these bonds at the ends of polymer chains, large, reversible cross-linking networks can be formed.⁵ In some instances, both dynamic covalent bonds and physical cross-linking can be combined for increased healing effect.⁸

II. INTRINSIC SELF-HEALING ELASTOMERS

In 2017, Terryn et al. were able to demonstrate the intrinsic self-healing property of soft Diels-Alder materials. They designed 3 prototype self-healing soft pneumatic actuators: a soft gripper, a soft hand (Fig. 1), and artificial muscles. In order to create these prototypes, a technique known as “shaping through folding and self-healing” was employed. This process entails the folding of multiple Diels-Alder sheets into parts that are then “self-healed together”.⁶ Some of the problems with this technique though is the extensive manual labor required and the time-consuming nature of folding multiple sheets by hand. In addition, this method of forming soft robots does not allow for parts with complex geometry.⁹

After being subjected to damage through either over-pressurization or cutting with a sharp object, these actuator devices were heated up to 80 C. After undergoing this thermal treatment for 8 hours and returning to room temperature, the actuators had recovered 93.4% of their mechanical properties (storage modulus) and were able to successfully function. Terryn et al. showed that where these damages occurred, after self-healing, there were no “weak spots” and that it was possible to achieve nearly completely recovered actuator performance. In addition, through mechanical testing, it was shown that the Diels-Alder material (DPBM-FGE-J4000) used in creating the soft actuator prototypes had a Young's Modulus of 5.0 MPa, a storage modulus of 13.0 MPa, and a strain at fracture of 360%.⁶

III. VAT PHOTOPOLYMERIZATION 3D PRINTING

3D Printing, also known as additive manufacturing, is a process originating in the 1980s in which three dimensional parts and objects are created through “layer by layer” printing. In general, the process consists of three main tasks: first, designing a 3D model to be printed using 3D modeling

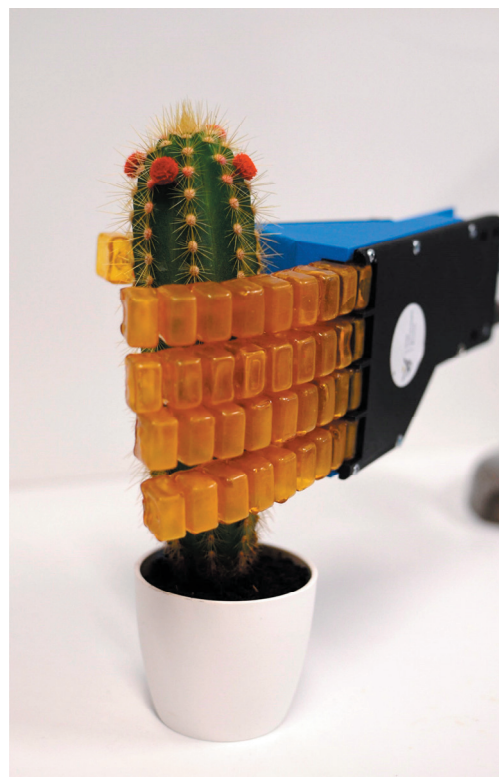


Figure 1: Prototype soft pneumatic hand made with DPBM-FGE-J4000. Figure courtesy of Bram Vanderborght.

software; second, the digital model is then “cut” into many slices by a printing software; and third, the file is sent to the printer to be constructed layer by layer, as dictated by the slices. One of the first types of 3D printing developed was that of photo-curing through photopolymerization techniques. This is done through a vat of photo-sensitive liquid resin being exposed to light radiation (generally UV) in specific patterns to “print” the object. This is a highly precise and relatively quick process that allows the rapid production of models and prototypes.¹⁰

IV. DLP 3D-PRINTING OF SOFT MATERIALS

Digital Light Processing (DLP) is a type of vat photopolymerization in which an image of the objects cross-section is projected, layer by layer, upon a vat of photo-curable resin. This results in a highly precise print, but one that is limited to a relatively small print size. In the schematic below (Fig. 2), a bottom-up projection system is shown in which the cured section adheres to the platform and the bottom of the tank. The platform is then raised, separating the cured section from the tank. The platform then lowers back down, leaving a small gap between the cured sections and the tank for resin to fill to cure a new layer. This repeats until the entire part is finished printing.¹¹

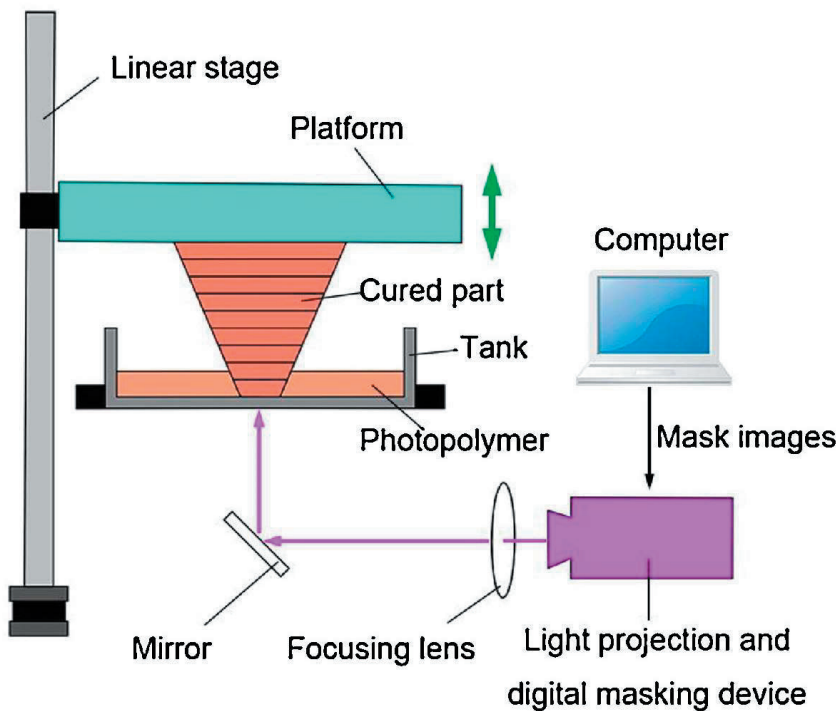


Figure 2: DLP 3D Printing Schematic. Reprinted from *Sensors and Actuators A: Physical*. Lisen Ge, Longteng Dong, Dong Wang, Qi Ge, Guoying Gu. “A digital light processing 3D printer for fast and high-precision fabrication of soft pneumatic actuators. Pages 285-292. Copyright 2018. With permission from Elsevier.

In 2017, Magdassi et al. presented a series of highly stretchable, UV curable elastomers, suitable for DLP 3D-Printing. Through a combination of epoxy aliphatic acrylate (EAA) and aliphatic urethane diacrylate (AUD) they were able to develop a DLP printable elastomer, that when undergoing mechanical testing, presented a Young’s Modulus of 4.21 MPa and an elongation at break of 1100%. This far surpassed (by about 5x) similar reported elastomers at the time. The main drawback though is that Magdassi et al. had to employ a custom-made “heat resin bath” in order to minimize the effect of the resin’s high viscosity.¹² This meant that there was no commercial option for printing and the results could not be reproduced.

Following this, Thrasher et al. (Ref. [13]) presented a series of photo-curable resins to be used for 3D printing of parts using commercial DLP-AM 3D printers. Their motivation was to try to create photo-curable resins for DLP 3D printing of elastomers with tunable properties that worked with commercial and widely available equipment. Through testing of multiple 3D printable resins, including silicones and hydrogels, they were able to show elongations up to 472%, tunable swelling behavior, and a range of hardness values, all without the need for specialized equipment nor excessive

processing steps. In addition, these resins were shown to have stability at ambient conditions, short cure times, and low viscosities. In demonstrating the functionality of these elastomers, they created a functional “multi-material three-armed pneumatic gripper” that was printed as one single part (Fig. 3). By incorporating a highly flexible layer and a higher modulus “strain limiting” layer, Thrasher et al. were able to demonstrate enhanced actuator efficiency of an pneumatic gripper. With this device, they were able to demonstrate the lifting of a plastic ball with mass 2.6 g and a diameter for 38 mm.¹³

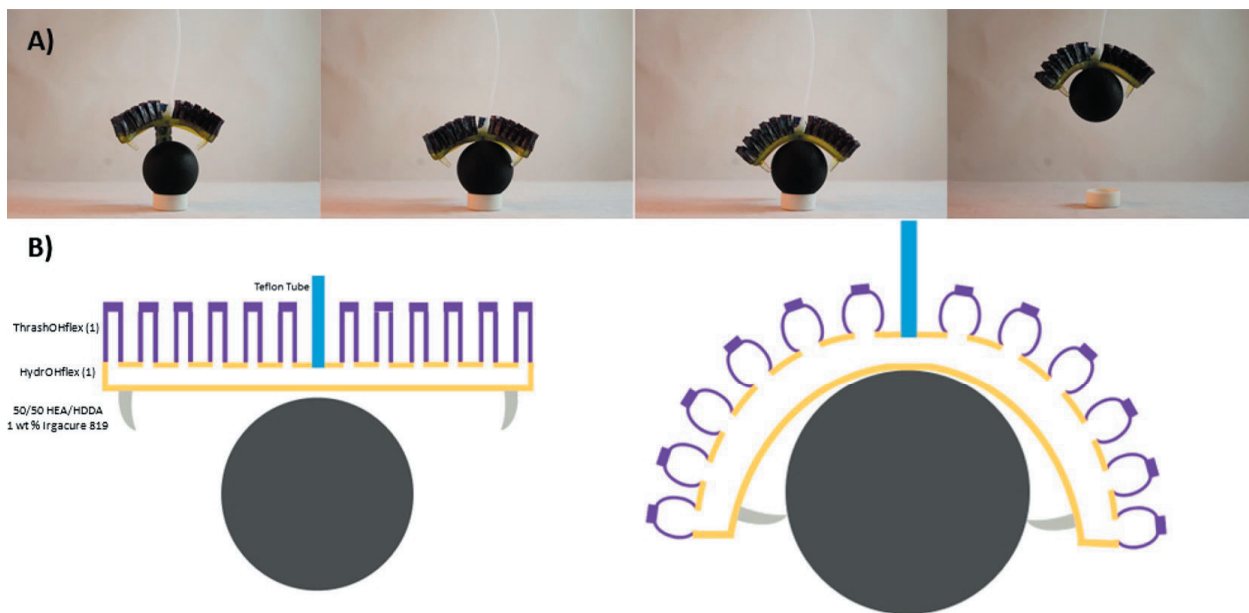


Figure 3: “Multi-material three-armed pneumatic gripper”.

Reprinted (adapted) with permission from Carl J. Thrasher, Johanna J. Schwartz, and Andrew J. Boydston, *ACS Applied Materials & Interfaces* **2017** 9 (45), 39708-39716. Copyright 2017. American Chemical Society.

In 2019, Huang et al. were able to develop tunable silicone elastomers with DLP 3D printing capabilities that through tensile testing were shown to be stretchable up to 1400% with an ultimate tensile strength of 2.59 MPa. This elongation at break far surpassed the majority of other reported UV-cured elastomers and reported thermo-cured elastomers at the time.

With these silicone elastomers they also demonstrated stretchable electrical devices by coating the super-stretchable silicone elastomer (SSSE) in a CNT-doped hydrogel layer and using it to connect a power supply to an LED. Even when compressed and elongated, the device was capable of conducting electricity, showcasing its potential for use in wearable technology and electricity conduction for soft robotics. Huang et al. concluded from this that “super-stretchable 3D printed silicone elastomers have wide potential applications in areas such as soft robotics, flexible actuators, and medical implants”.¹⁴

V. “CONTINUOUS” DLP 3D PRINTING

Traditional DLP 3D-printing is a layer-by-layer process which results in anisotropic mechanical properties dependent on which direction the part is printed. This is due to a “stair-casing” effect that occurs during the repositioning of the build plate after separating the cured layer from the bottom of the vat, which in addition creates an uneven finish on the part.¹⁵

In 2016, Januszewicz et al. were able to utilize continuous liquid interface production (CLIP) by creating an oxygen permeable window resulting in oxygen inhibition during printing (Fig. 4). This modified version of DLP 3D-printing allowed the creation of layer-less parts with isotropic properties, smooth finishes, and with relatively fast print times. This method was able to circumvent

the “stair-casing” effect that normally occurs with DLP 3D-printing by removing the need for the build platform to separate the polymerized part from the bottom of the vat, removing the need for repositioning, and allowing “continuous” printing. This ensures isotropic mechanical properties of the printed parts, something Januszewicz et al. believe represents a key step in bringing AM 3D printing from that of rapid prototyping to the field of manufacturing.

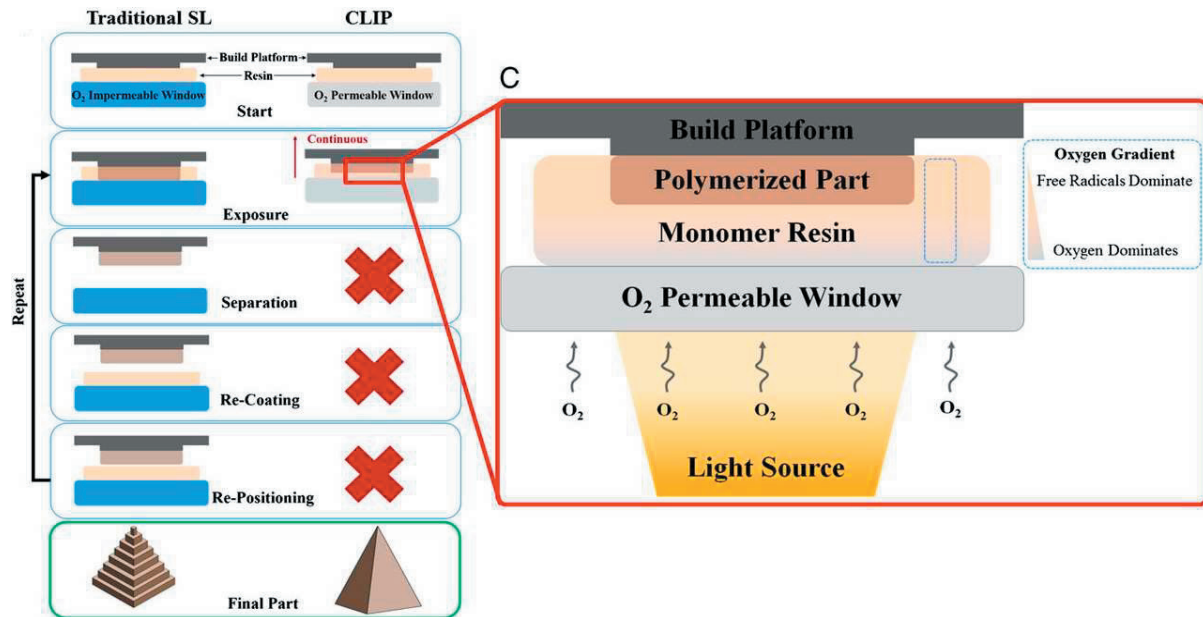


Figure 4: Schematic of the “continuous” DLP additive manufacturing process. An oxygen permeable window holds the photo-curable resin while allowing oxygen and light to pass through, creating a dead zone where polymerization is inhibited, preventing the resin from curing to the window. Figure courtesy of Ref. [15].

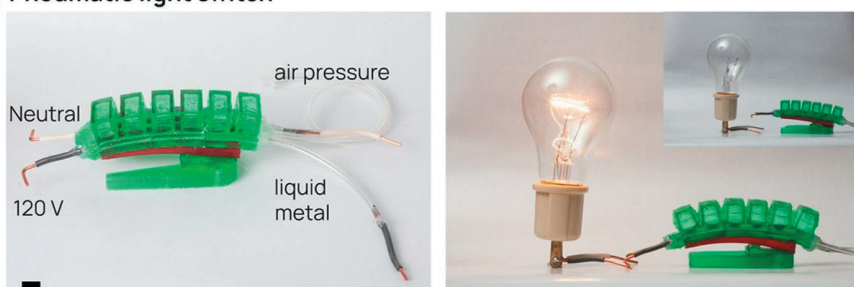
VI. DLP 3D-PRINTED, SELF-HEALING ELASTOMERS

Combining the practice of “continuous” DLP 3D-printing with that of intrinsic self-healing elastomers allows the printing of parts with complex geometry for highly functional, self-repairing soft robots.¹

Going with this in mind, Thrasher et al. (Ref. 1) developed a tunable, self-healing, thiol-acrylate elastomer with VP-3D-printing capabilities. Through the use of a modular systems approach, they were able to combine multiple 3D-printed parts through self-healing processes into one system to create complex and functional robotic units. To demonstrate this, they developed a “large soft robotic gripper”, consisting of 3 pneumatic actuator modules that were “self-healed” together and capable of lifting a ball with a mass of 142 g (Fig. 5). They also explored the process of creating liquid metal channels within the modular system for added mechanical and electrical functionality. Through this process, Thrasher et al. were able to create a pneumatic light switch using the modular robotic system. This further demonstrates the wide range of applications in robotics and electrical devices that these elastomers have. In addition, they were able to demonstrate comparable mechanical properties between 3D-printed samples and those that had been cured in a mold.

As a whole, this work was a large advancement in the field due to the successful integration of intrinsic self-healing elastomers with DLP 3D-printing in order to create large, modular soft robots with complex geometries and self-healing abilities.

(d) Pneumatic light switch



(e) Large soft robotic gripper



Figure 5: Top: Pneumatic light switch made using 3D printed self-healing actuator. Bottom: Three armed “large soft robotic gripper” lifting a 142 g ball. Reprinted (adapted) with permission from E.F. Gomez, S.V. Wanasinghe, A.E. Flynn, O.J. Dodo, J.L. Sparks, L.A. Baldwin, C.E. Tabor, M.F. Durstock, D. Konkolewicz, and C.J. Thrasher. “3D-printed self-healing elastomers for modular soft robotics.” *ACS Applied Materials & Interfaces* 13, 24, 28870-28877. Copyright 2021. American Chemical Society.

Acknowledgments

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References

1. E.F. Gomez, S.V. Wanasinghe, A.E. Flynn, O.J. Dodo, J.L. Sparks, L.A. Baldwin, C.E. Tabor, M.F. Durstock, D. Konkolewicz, and C.J. Thrasher. “3D-printed self-healing elastomers for modular soft robotics.” *ACS Applied Materials & Interfaces* 13, 24, 28870-28877.
2. Jiang, C., Zhang, L., Yang, Q. et al. “Self-healing polyurethane-elastomer with mechanical tunability for multiple biomedical applications in vivo.” *Nat Commun* 12, 4395 (2021).
3. Xiao Kuang, Kaijuan Chen, Conner K. Dunn, Jiangtao Wu, Vincent C. F. Li, and H. Jerry Qi. *ACS Applied Materials & Interfaces* 2018 10 (8), 7381-7388.
4. White, S., Sottos, N., Geubelle, P. et al. “Autonomic healing of polymer composites.” *Nature* 409, 794–797 (2001).
5. So Young An, Dhamodaran Arunbabu, Seung Man Noh, Young Kyu Song, and Jung Kwon Oh. “Recent strategies to develop self-healable crosslinked polymeric networks.” *Chem. Commun.*, 2015, 51, 13058-13070
6. S. Terryn, J. Brancart, D. Lefeber, G. Van Assche, and B. Vanderborcht. “Self-healing soft pneumatic robots.” *Science Robotics* 2(9), 1-12, 2017.

7. Gadwal I. A Brief Overview on Preparation of Self-Healing Polymers and Coatings via Hydrogen Bonding Interactions. *Macromol.* 2021; 1(1):18-36.
8. Sandra Schäfer and Guido Kickelbick. *Macromolecules* 2018 51 (15), 6099-6110.
9. Ellen Roels, Seppe Terryn, Joost Brancart, Robrecht Verhelle, Guy Van Assche, and Bram Vanderborght. "Additive Manufacturing for Self-Healing Soft Robots." *Soft Robotics*. Dec 2020. 711-723
10. Haoyuan Quan, Ting Zhang, Hang Xu, Shen Luo, Jun Nie, Xiaoqun Zhu. "Photo-curing 3D printing technique and its challenges", *Bioactive Materials*, Volume 5, Issue 1, 2020, 110-115
11. Lisen Ge, Longteng Dong, Dong Wang, Qi Ge, Guoying Gu. "A digital light processing 3D printer for fast and high-precision fabrication of soft pneumatic actuators". *Sensors and Actuators A: Physical*. Volume 273. 2018. 285-292
12. Patel, D. K., Sakhaei, A. H., Layani, M., Zhang, B., Ge, Q., Magdassi, S., *Adv. Mater.* 2017. 29, 1606000.
13. Carl J. Thrasher, Johanna J. Schwartz, and Andrew J. Boydston. *ACS Applied Materials & Interfaces*. 2017. 9 (45), 39708-39716
14. Tingting Zhao, Ran Yu, Shan Li, Xinpan Li, Ying Zhang, Xin Yang, Xiaojuan Zhao, Chen Wang, Zhichao Liu, Rui Dou, and Wei Huang. *ACS Applied Materials & Interfaces*. 2019. 11 (15), 14391-14398
15. R. Januszewicz, J.R. Tumbleston, A.L. Quintanilla, S.J. Mecham, and J.M. DeSimone. "Layerless fabrication with continuous liquid interface production." *PNAS* 113 (42), 11703-11708, 2016.

Extrapolation of Scalar Measurements in a Helium Jet Using Rainbow Schlieren Deflectometry

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1. Introduction

Experimental measurements are integral to examining physical and mathematical laws. Experimental measurements are necessary to validate physical models and physical models can be used to represent these measurements. Accurate models that are based on the empirical measurements of real-world phenomena serve the engineer in designing new systems and optimizing old ones. These measurements generally fall under two categories: intrusive and non-intrusive. Intrusive measurement techniques are typically probes that collect data at a single point such as thermocouples and pressure probes. This measurement category does not perform properly under sensitive flow fields, fast time scales, or harsh environments. Non-intrusive measurements on the other hand are optically based techniques and are able to perform effectively under these difficult conditions.

There are nominally three different types of non-intrusive measurement techniques: point, planar, and line of sight measurements. Point measurements are accurate in their measurement, but they only examine one point of the flow field restricting the data being collected. Planar measurements use a laser to create a plane image of the flow field which allows for an accurate measurement of the full field. The downsides to this technique are that it requires expensive custom-made optical equipment, no dust can be in the field, and liquid-gas mixture flow fields cannot be properly measured. The line-of-sight technique is the final non-intrusive method that will be discussed. The line-of-sight method is similar to the planar technique being able to capture an accurate measurement of the full flow field of interest, with the added benefit of utilizing commercially available optical equipment and being able to examine fields that contain dust and multiphase flow fields. The only requirement of line-of-sight techniques is that they require geometric symmetry within the flow field that they are examining.

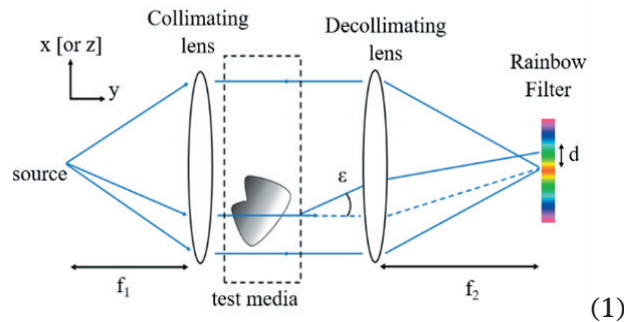
2. Literature Review

One such example of a line-of-sight technique is Rainbow Schlieren Deflectometry. The research article, "Quantitative Concentration Measurements in a Turbulent Helium Jet Using Rainbow Schlieren Deflectometry," (Wanstall et al., 2021) discusses the ability to utilize this method as a means to collect accurate scalar measurements of a laminar to turbulent helium jet. Prior to this point RSD has been used to collect accurate measurements in laminar flow but has not been validated in quantitative mixing measurements in turbulent flow (Wanstall et al., 2021). Wanstall et al. (2021) are able to showcase through several steps that RSD can in fact be used to accurately measure turbulent

flow fields. The article highlights the necessary requirements needed to replicate the experimental setup and the settings needed to capture the raw images. It then goes on to discuss the mathematical background that allows for the measurement to be possible, and the analysis and results of the data that prove that RSD is a viable option to accurately measure the flow of a laminar to turbulent jet. Wanstall et al. (2021) states, “The results show that RSD can provide high-quality quantitative data with low measurement uncertainties, which will be useful to validate computational models, especially in regions where self-similarity may not be satisfied. (p. 12)”

3. Experimental Setup

This paper will discuss the process to recreate the experiment that was discussed above. RSD focuses on the deflection of light which allows for the possibility to extract thermodynamic properties from measured color values of captured images. This is possible due to the deflection of light through density gradients of a turbulent helium jet.

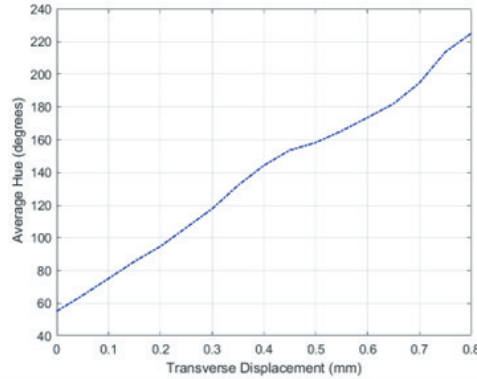


Taken from Wanstall et al. (2021)

The experimental setup shown above begins with a white light source positioned to point through a collimating lens which straightens the dispersed light rays into horizontal parallel light rays. These light rays then pass through a turbulent helium jet which is exiting from a 1/4 in. stainless steel pipe. As the light passes through the helium jet it will encounter density gradients of the helium and air mixture as the helium disperses in the surrounding air. The density gradients in turn cause the light to reflect at various angles depending on the density of the helium-air mixture. The deflected light then passes through a decollimating lens which focuses the light at a point determined by the focal length of the lens. A 1 mm. rainbow filter is then placed at the focal point to relate the deflection of light at various angles to specific colors located on the filter. Finally a highspeed Photron Camera is located at the end of the line to capture the raw RSD images that showcase the density gradients of the turbulent helium jet in color.

4. Theory

Once the raw RSD images have been captured, the first step to process the data is to create a graph called a calibration curve. This graph displays the transverse displacement of the deflected light in millimeters along the x-axis versus the average hue in degrees of where the light was displaced along the filter.



(2)

Kastner (2023)

The calibration curve utilizes the asymmetric rainbow filter shown above in order to create a plot of transverse displacement versus average hue. In doing so a ruler is effectively created in order to convert color values that are displayed on the raw images into their respective deflection distance values, that is the distance the light has been deflected from the center of the filter.

After converting the color values of the images to deflection distance via the calibration the next task is to calculate the deflection angle. This calculation is done with the equation,

$$\epsilon = d/f_2 \quad (3)$$

Taken from Wanstall et al. (2021)

The left side of the equation takes the deflection distance of the light, d , and divides it by the focal length of the decollimating lens, f_2 . This division results in the deflection angle of the light, ϵ . Note that this simple calculation of the deflection angle from deflection distance is only possible if the small angle assumption is applied to the trigonometric properties of angles.

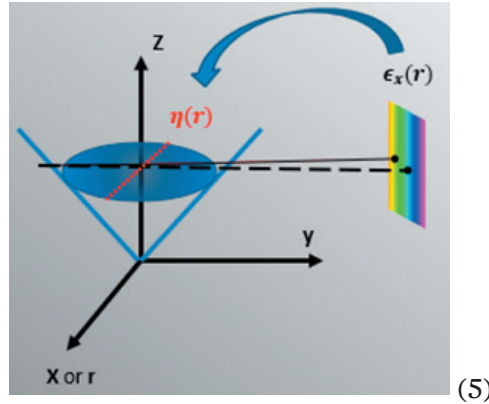
Once the deflection angles of the images has been calculated Abel Inversion is then used in order to obtain the local refractive index of the density gradients. The first equation below represents an integration utilizing local properties of the refractive index that then results in line-of-sight data which corresponds to deflection angle. The second equation is the inverse transform of the first equation which is known as the Abel Inversion. This integral does the opposite, integrating line of sight data to obtain local properties which are needed to reach the desired thermodynamic properties.

$$\epsilon_x(x, z) = \frac{1}{n_0} \int_{-\infty}^{\infty} \frac{\partial n(x, y, z)}{\partial x} dy \quad (4a)$$

$$\eta(r) = -\frac{1}{\pi} \int_r^R \epsilon_x(x) \cdot \frac{dx}{\sqrt{x^2 - r^2}} \quad (4b)$$

Taken from Wanstall et al. (2021)

In order to use the Abel inversion however, an axial symmetric flow field is required. The reason for this is that an axial symmetric flow field, like that of the turbulent helium jet, creates symmetric boundary conditions that are necessary for the Abel inversion to be used which can be seen in the image below.



(5)

The final step of the RSD process is to take the refractive index calculated utilizing the Abel Inversion and extract thermodynamic properties. The refractive index that was collected from the previous step can be applied to the Gladstone-Dale relation,

$$n = 1 + \rho\kappa \quad (6a)$$

Taken from Wanstall et al. (2021)

here κ and ρ are the Gladstone-Dale constant and density respectively and n is the refractive index. The density is then substituted with the Ideal Gas Law resulting in the final Gladstone Dale Equation.

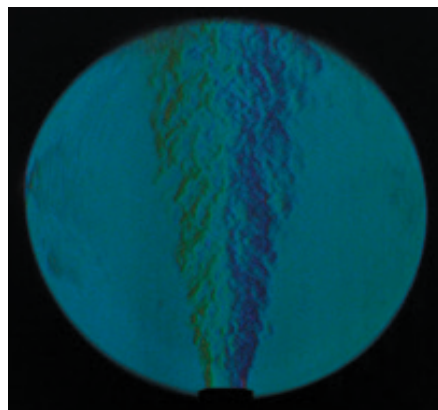
$$n = 1 + \frac{P}{RT} \sum_i M_i \kappa_i x_i \quad (6b)$$

Taken from Wanstall et al. (2021)

In this final equation the P , R , T , M , κ , and x represents pressure, universal gas constant, temperature, molecular weight, Gladstone-Dale constant and the mole fraction of helium and air respectively. This equation completes the data processing as it is now possible to examine the multiple thermodynamic characteristics of the turbulent helium jet.

5. Results

The results of replicating the findings of Wanstall et al. (2021) has been a success with the exception of the final step of the data analysis process due to a time constraint. The image below is one frame from the two-thousand images that were taken of the helium jet during the experiment.

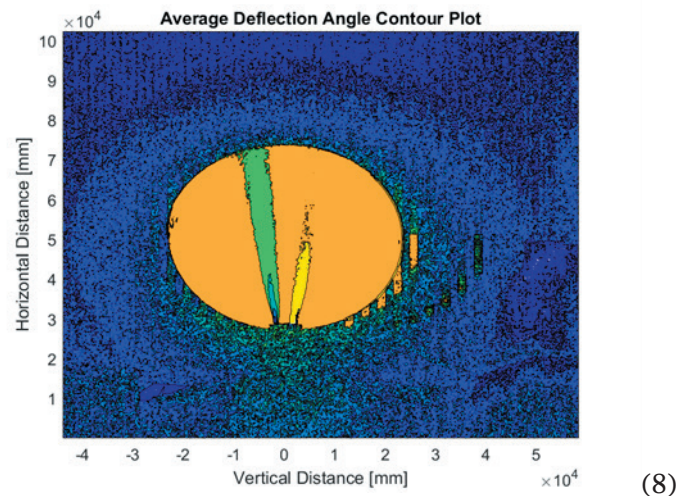


(7)

Kastner (2023)

The raw contour image contains the turbulent helium jet split in two different colors green and blue, while the background of the image contains a lighter blue color. As the light source passes through the test medium, the light that does not pass through any density gradients of the jet will focus directly on the center of the rainbow filter thus producing the light blue color. However, the light rays that do pass through the density gradients found in the turbulent flow field are deflected at certain angles causing the light to bend off its original trajectory and focus on positions of the rainbow filter to the left and right of the light blue center therefore showing up as green and blue.

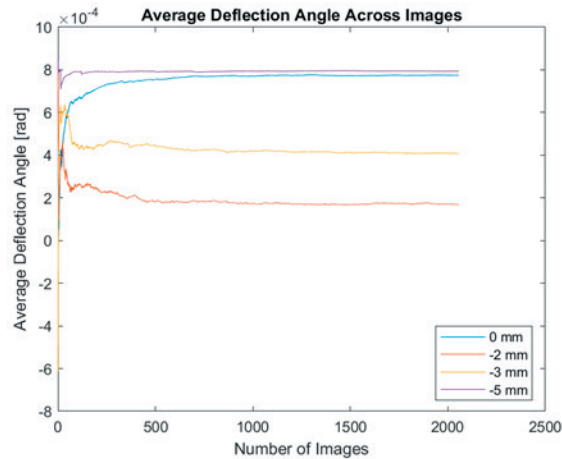
A part of the process to validate the data that was published by Wanstall et al., (2021) was to create average contour plots at various steps along the data analysis process. One such example is the image below which shows the average deflection angle across all of the images captured.



Kastner (2023)

The contour plot graphically represents what the average deflection angle was across all of the images that were captured. The orange section of the plot depicts the background of the images where there is no deflection occurring and the yellow and green/blue sections are representative of locations where there are deflections of light occurring. Similarly the rest of the graph depicts noise from outside the area of interest, possibly receiving chaotic values from the ambient light of the laboratory.

Finally, there is a need to prove that the data being collected is accurate enough to be relied upon. Due to the nature of turbulent flow fields, instantaneous data collected at the beginning of the experiment may not be the same as the last data set so there is a necessity to prove that the data collected with RSD is accurate across all of the images that were taken. To do this time averaging across the images of the average deflection angle is needed. In the graph below four positions were chosen moving from the center of the jet to the left outside of the turbulence. Those positions being found at zero, two, three, and five millimeters.



(9)

Kastner (2023)

It can be seen that towards the beginning the graph the average deflection angle at all positions has a great amount of fluctuation, however as more images are compiled into the average deflection angle the values of each position reaches an equilibrium thus proving that enough data has been collected to be considered accurate and reliable.

6. Conclusion

In conclusion, Rainbow Schlieren Deflectometry provides the ability to examine the thermodynamic characteristics of a laminar to turbulent flow field. The experimental setup of RSD is inexpensive and simple compared to common alternative line-of-sight techniques. Wanstall et al. (2021) have set the foundation for future applications of Rainbow Schlieren Deflectometry which has the potential to be quite effective in quantitatively measuring flow fields of various types. One such application that has been chosen to be the next topic of research in partnership with the Airforce Research Laboratory is utilizing RSD to quantitatively measure a nitrogen shockwave flow field. This shock wave will be pressurized on one end of a shock tube and then released to flow down the rest of the shock tube. The shock wave will be examined with Rainbow Schlieren Deflectometry for the first time to better understand the various thermodynamic properties.

References

1. Wanstall, C. T., Bittle, J. A., & Agrawal, A. K. (2021). Quantitative concentration measurements in a turbulent helium jet using Rainbow Schlieren Deflectometry. *Experiments in Fluids*, 62(3). <https://doi.org/10.1007/s00348-021-03154-2>

Credits

1. Figures 1,3, 4a, 4b, 5, 6a, 6b, - Wanstall, C. T., Bittle, J. A., & Agrawal, A. K. (2021). Quantitative concentration measurements in a turbulent helium jet using Rainbow Schlieren Deflectometry. *Experiments in Fluids*, 62(3). <https://doi.org/10.1007/s00348-021-03154-2>
2. Figures 2, 7, 8, 9 - Joseph R. Kastner 2023

Characterizing the Frequency Response of Pressure-Sensitive Paint

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Abstract

Pressure-Sensitive Paint (PSP) is an incredible application that is used for optically collected, global pressure data. It possesses luminescent qualities that are related directly to oxygen content and therefore, air pressure. When paint is subjected to different pressures, the intensity of light it gives off changes, allowing for pressure data to be collected without the use of pressure sensors. One drawback of using PSP is its response time. It has been demonstrated in previous works that the accuracy of PSP has a steep drop off the higher the frequency of pressure change becomes (Kasai, 2021). In order for PSP to be reliably viable in high-speed environments, further testing must be conducted, and new PSP formulations must be created.

A resonance tube was designed and constructed with the purpose of characterizing novel PSP formulations on a broadband set of frequencies. Collecting response time data up to 45 kHz will allow PSP to reach new heights when it comes to high-speed applications. The design, based on previous similar works (McCullen, 2013), is able to reach past the standard 10 kHz barrier due to a new high-frequency speaker designed for stereo systems. Due to hiccups in the pressure sensor data collection system, the tube has not been run yet.

Introduction

One of the most important quantitative values to measure when researching the aerodynamics of flight vehicles is pressure. Data points typically are collected using standard pressure transducers that are built into a model prior to testing. Pressure transducers are limited to singular points and require immense time, effort, and funds in order to gather enough data to construct a pressure field for a model. Despite the relatively small size of the sensors, they can still cause issues if the point of interest on a model is not thick enough to house a sensor (Liu, 2021). Such issues have led researchers to employ another form of pressure data collection.

Pressure Sensitive Paint (PSP) is an application used for optically collected, global pressure data. Whereas pressure transducers can only provide data limited by the number of sensors, PSP is limited by the resolution of the camera. Because every pixel is a data point, it becomes far easier to construct and understand the pressure field for the model in question. Spatial resolution is the main benefit of PSP, but there is more to be said about the comparison between transducers and paint. PSP allows for a no-contact approach which ensures the model is unaffected by the data collection. The upper hand that transducers still possess is that of response time. The delay for data collection through PSP was found to be 20 μ s in a study (Sealy, 2017). The more quickly a pressure field changes, the less reliable PSP becomes due to this short delay. The end goal of my own research is to shorten this

time as much as possible so that PSP can be used reliably in rapidly changing pressure conditions. The development of a fast-responding and reliable PSP is a crucial step to widen the applicable range for the method of data collection.

Pressure-Sensitive Paint

The component of a PSP recipe that allows the paint to provide pressure data is the luminophore. The luminophore atom has a unique characteristic in that in its excited state, it will radiate away the excess energy in the form of luminescence (Liu, 2021). A necessary part of the setup for PSP testing is a powerful excitation light with a wavelength corresponding to the luminophore atom of choice. This light, generally in the form of a powerful laser, excites the atoms throughout the entire test, providing them with the energy needed to luminesce. In previous works, as well as active use in the University of Dayton Research Institute, a blue laser of wavelength 445 nm is used in correlation with a RuDPP-based PSP (Running, 2021). The luminescent intensity of the paint, courtesy of radiating luminophore atoms, is the quantity of interest for these tests. In static conditions, the luminescent intensity will remain constant. When subjected to the forces of a wind tunnel or else, the luminescent intensity begins to change.

The phenomenon that is exploited to make the paint pressure sensitive is called oxygen quenching. While the luminophore atoms are in the excited state, there is the opportunity for them to react with oxygen molecules that they come into contact with. If an excited luminophore atom reacts with oxygen, it becomes deactivated and no longer radiates. This “quenching” of the luminophore demonstrates the inverse relationship of luminescent intensity to oxygen density. In other words, the more oxygen is present, the less bright the paint will shine. The amount of oxygen present is relative to the amount of air (pressure) present. The points on a model expected to be at high pressures will display lesser luminescent intensity relative to the points expected to experience low pressures. Because this testing method is limited by pixels and the luminophore is homogenous throughout the paint, this allows for reliable global pressure data that varies from point to point based on luminescent intensity. The data collected in full is a pressure field rather than pressure points.

The luminescent intensity data collected (I) is relativistic and can be described using the Stern-Volmer equation to find pressure (p):

$$\frac{I_{ref}}{I} = A + B \frac{p}{p_{ref}}$$

I_{ref} and p_{ref} represent the luminescent intensity and pressure at known reference conditions. The coefficients A and B are determined experimentally via calibration. The relation equation is used to get pressure data because it aids in eliminating any inconsistencies in testing such as “...nonuniform illumination, uneven coating, and nonhomogeneous luminophore concentration in PSP” (Liu, 2021). Though this alleviates some problems, others still can arise. The main error source tends to be how the temperature affects the paint. This can be sorted out using in-situ testing with transducers or using temperature-compensating measures in the data processing stages.

Setup

The experimental setup for PSP, from testing to usable data, requires several steps. The paint itself must first be mixed or purchased. At UDRI we create PSP on our own which allows us to make experimental changes to the formula in an effort to increase efficiency and speed. Four main ingredients are used in making fast PSP: dichloromethane as a solvent, RTV rubber as a binder, tris-bathophenanthroline ruthenium II as the luminophore, and silica gel as a surface area enhancer. The “surface area enhancer” allows more pathways for the oxygen to reach the luminophore. PSP has a

delay in readings because it takes time for oxygen molecules to work their way through the binder. By roughing up the surface on a microscopic level, quenching of the luminophore atoms occurs at a faster pace. The paint is immediately applied to the model's surface either by spraying or dipping and then set aside to cure. While the paint is being mixed and the model cures, the paint is kept in complete darkness so as to not damage the luminescent qualities of the paint.

Once the model is ready and in place, all lights are turned off and the diffused excitation laser beam is turned on. The energy from the beam sends the luminophore atoms into an excited state and begins their luminescence. In order to capture the intensity data, a high-speed camera with the appropriate lens is employed. This lens is necessary to distinguish the excitation light from the luminescence. Typically, a short recording is done so that frames can be averaged giving the most accurate intensity results possible. Once the images have been obtained and conditioned appropriately, the Stern-Volmer equation in conjunction with reference images can be applied to gather images of pressure data. A relative color gradient can then be applied to the results to ensure visual clarity of the data.

Frequency Response

The limiting factor for Pressure-Sensitive Paint when it comes to usability in high Mach speed situations is its response time. Response time, although a function of several variables, is mainly decided by the formula of the paint and by the surface the paint is applied. Different surfaces provide conditions more or less suitable to high-speed environments, with anodized aluminum showing the highest performance (Yomo, 2022). In order to determine what the response time of PSP is, various methods have been employed such as shock tubes (McCullen, 2013), resonance tubes (Kasai, 2021), and fluidic oscillators (Gregory, 2006). The former examines a one-step jump in pressure while the latter two experiments measure frequency response time.

A resonance tube was designed and constructed for the purpose of characterizing PSP formulations on a broadband set of frequencies. The design consists of a speaker section, tube, and endcap. The speaker section was designed such that it could hold two different speakers both in alignment with the front of the tube. A low-frequency speaker (Edifier R2000DB) was used to cover the 20-20,000 Hz range. The majority of previous works (Sugimoto, 2017) (Kasai, 2021) also operate in this range due to the fact that the human auditory spectrum ends at 20 kHz. These works collected data up to 10 kHz due to the Nyquist theorem stating that accurate data can only be obtained at half of the sampling frequency. A high-frequency speaker (Townshend maximum super-tweeter) was used to produce frequencies up to 90 kHz. Though experimental due to its lower dB output, its capabilities allow PSP data to be gathered at up to 45 kHz. The speakers are run by a function generator (B&K precision sweep function gen) and a signal amplifier (Aim-TTi WA301 RF Amplifier).

At a variable distance from the front of the speaker(s) sits a clear, five-foot-one-inch long, three-inch inner diameter acrylic tube. The tube is supported by 80/20 aluminum framing. This size tube was chosen due to its ability for our 445 nm wavelength laser to pass through, as well as the ability to house a two-by-two-inch square plate for PSP. Being clear ensures the camera can view the paint sample without issue. The length of the tube corresponds with a fundamental frequency of 55.46 Hz. This can be calculated using the following equation from acoustic physics:

$$f = \frac{v}{\lambda}$$

f represents the frequency in Hz while v and λ are the speed of sound and wavelength respectively. The wavelength is known to be four times the length of the tube for the fundamental frequency inside a closed tube (New York University, 2017). Playing tones at the fundamental frequency and its corresponding harmonics ensures that a clean standing wave forms inside the tube. This standing pressure wave creates a pressure antinode at the closed end of the tube. The exploitation of these

physics is what allows for a high enough pressure difference to occur and PSP data to be gathered at various frequencies.

The endcap was designed, and 3D printed to sit at the closed end of the tube. It houses a two-inch by two-inch aluminum plate as well as a Kulite pressure transducer. The square is inset at a depth of one mm such that the inner surface of the endcap is completely flush. This is done to aid in forming a clean standing wave. Utilizing a through hole for a pressure transducer allows for in-situ calibration by comparing sensor data with paint data. Once a paint square is prepared, it is adhered to the endcap with double-sided tape, and the sensor is applied using nail polish or putty. Both the laser and the high-speed camera will be pointed at the PSP sample in the endcap for data collection. The signals from the sensor run through a conditioning box before being sent to a computer.

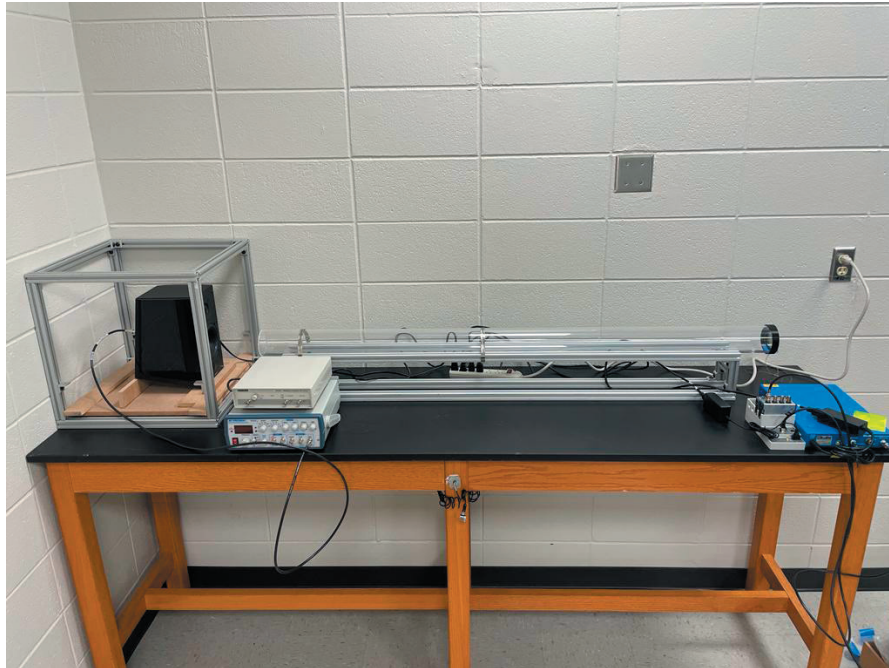


Figure 1. Resonance tube experimental setup (2023)

The findings of the tests run with this resonance tube are expected to match those of previous tests when not testing fast PSP. This would mean the paint should keep pace with the pressure fluctuations and the accuracy will fall gradually until around 2500 Hz. At this point, the gain and phase shift begin to show steep declines (Kasai, 2021). This same graph is likely to be found with fast PSP, only shifted to higher frequencies. The resonance tube will be able to test either fast or regular PSP at a range of 20 Hz all the way up to 90 kHz. This broadband set allows us to see what the typical PSP graph will look like after the standard 10 kHz cutoff.

Closing remarks

Although construction has been finished and preparations have been made, the tube has yet to be run due to noise issues with collecting pressure transducer data. Despite the setup being in a low-decibel environment, the sensor currently sits at a resting noise level of about ± 1 kPa. Due to the fact that the tube will only produce on the order of Pascals as shown by the sound level equation, the data from the sound waves will get lost in the noise (McGraw, 2003). Issues such as this do have workarounds and solutions are already being put forward and tested so that the resonance tube can be up and running as soon as possible. This will allow for the testing of novel PSP formulations in an effort to speed up response time so that it will be viable at higher speeds.

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References

1. Gregory, J.W., Sullivan, J.P. (2006). Effect of Quenching Kinetics on Unsteady Response of Pressure-Sensitive Paint. *AIAA Journal* 44(3), 634-645. <https://doi.org/10.2514/1.15124>
2. Kasai, M., Sasaki, D., Nagata, T., Nonomura, T., & Asai, K. (2021). Frequency Response of Pressure-Sensitive Paints under Low-Pressure Conditions. *SENSORS*, 21(9), 3187. <https://doi.org/10.3390/s21093187>
3. Liu, T., Sullivan, J., Asai, K., Klein, C., Egami, Y. (2021). Pressure and Temperature Sensitive Paints. *Springer*. <https://doi.org/10.1007/978-3-030-68056-5>
4. McCullen, R.M., Huynh, D.P., Gregory, J., Crafton, J.W. (2013). Dynamic Calibrations for Fast-Response Porous Polymer/Ceramic Pressure-Sensitive Paint. *AIAA Ground Testing Conference*, 2013-3123. <https://doi.org/10.2514/6.2013-3123>
5. McGraw, C., Shroff, H., Khalil, G., Callis, J. (2003). The phosphorescence microphone: A device for testing oxygen sensors and films. *Rev Sci Instrum* 74, 5260-5266. <https://doi.org/10.1063/1.1626009>
6. New York University. (2017). https://physics.nyu.edu/~physlab/GenPhysII_PhysIII/Intermediate_Physics_I_writeups/Resonance_tube_physics_majors-08-25-2017.pdf
7. Peng, D., Jensen, C.D., Juliano, T.J., Gregory, J.W., Crafton, J., Palluconi, S., Liu, T. (2013). Temperature-Compensated Fast Pressure-Sensitive Paint. *AIAA Journal* 51(10), 2420-2431. <https://doi.org/10.2514/1.J052318>
8. Running, C., Juliano, T. (2021). Global Skewness and Coherence for Hypersonic Shock-Wave/Boundary-Layer Interactions with Pressure-Sensitive Paint. *Aerospace* 8(5) 123. <https://doi.org/10.3390/aerospace8050123>
9. Sealy, W., Casper, K.M. (2017). Dynamic Calibration of High Frequency Pressure Sensitive Paint. SAND2017-2852C. <https://www.osti.gov/servlets/purl/1429170>
10. Sugimoto, T., Sugioka, Y., Numata, D., Nagai, H., Asai, K. (2017). Characterization of Frequency Response of Pressure-Sensitive Paints. *AIAA Journal* 55(4), 1460-1464. <https://doi.org/10.2514/1.J054985>
11. Yomo, K., Ikami, T., Fujita, K., Nagai, H. (2022). Investigation of Formulations on Pyrene-Based Anodized-Aluminum Pressure-Sensitive Paints for Supersonic Phenomena. *Sensors*, 22(4430), 4430. <https://doi.org/10.3390/s22124430>

Understanding Calcium Signaling in Invasive Glioblastoma Cells in a Microfluidic Model: A Review

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Abstract

Glioblastoma Multiforme (GBM) is one of the most malignant types of brain cancer and, therefore, highly fatal. Current lines of treatment include surgical resection, radiation, and chemotherapy, all of which GBM resists due to the complexity of GBM tumors, cells, and their microenvironment. Numerous research studies have been conducted to understand the oncogenesis, invasion mechanisms, and cellular characteristics of GBM. It has been found that GBM cells disseminate out of the primary tumor through white matter tracts and perivascular regions of the brain, where they can migrate toward any brain tissue. As GBM cells migrate and interact with brain tissue, their extracellular matrix (ECM) overexpress brain ECM components, such as fibronectin, collagens, proteoglycans, integrin proteins, and lamins, that promote motility and invasion through signaling cascades and altering cell morphology. One specific mechanism that has caught the attention of researchers is calcium signaling, which plays a significant role in cell-to-cell communication and is implicated in GBM proliferation, resistance to treatment, and metastatic-related processes. The calcium signaling pathway allows for an increase in cytosolic Ca^{2+} concentration through activating transmembrane channels and signaling Ca^{2+} release from the endoplasmic reticulum (ER), creating hypoosmotic environments with the exchange of K^{+} and Cl^{-} ions, serving as checkpoints in the cell cycle and therefore controlling migration and proliferation. Our research works to understand the calcium signaling pathway further, as we have been visualizing Ca^{2+} levels using Fluo-8AM dye. Future trials hope to explore emerging targets for calcium signaling, including transient receptor potential channels (TRP), a family of channels that mediate Ca^{2+} signaling and play a role in GBM development and invasion.

1. Introduction to Glioblastoma multiforme (GBM)

GBM is one of the most common, aggressive, and deadly types of brain cancer (Alpetkin et al. 2015). Its high malignancy is attributed to its surrounding environment, consisting of a great amount of blood vessels, allowing them to reproduce quickly (Alpetkin et al. 2015). Upon diagnosis, GBM patients have a median survival time of 12-15 months, even with available treatment modalities such as surgery, chemotherapy, and radiotherapy (So et al. 2021). Surgical resection of GBM, the highest standard of treatment, is deemed nearly impossible to cure the disease due to the cancers' high level of invasiveness and infiltration as GBM cells interact with various cells, including astrocytes, neurons, and the ECM, and can make their cell body shrink and infiltrate narrow spaces of the brain and escape from surgery (So et al. 2021). Oftentimes, these surgical attempts lead to the formation of secondary and tertiary tumors and leave the patients with deficits due to the delicacy of the brain tissue (Nizamutdinov et al. 2018). Chemotherapy and radiation are likewise ineffective due to the heterogeneity of GBM tumors, cells, and their microenvironment, often leading to cancer recurrence and causing more issues due to toxicity.

Researchers have been examining and trying to understand the oncogenesis, invasion, and migration mechanisms and the unique cellular characteristics of GBM that make it invasive and, therefore, resistant to treatment. It has been found that GBM cancer cells disseminate out of the primary tumor and into brain tissue (So et al. 2021). Other high-grade solid cancers commonly invade blood and lymphatic vessels, whereas GBM is unique because it rarely intravasates into any vessels (Hatoum et al. 2019). Instead, GBM glioma cells disseminate and migrate along blood vessels in the perivascular space (Hatoum et al. 2019). Invasive growth of GBM occurs along numerous regions, including perivascular growth, perineural growth, surface growth, intrafascicular growth, interfascicular growth, white and gray matter growth (Hatoum et al. 2019; Wang et al. 2021). Glioma cells mostly follow the brain's white matter tracts and can reach brain tissue 3-5 cm from the glioma and enter brain tissue on the contraside of the brain through the corpus callosum, gaining access to the entire brain. The overall prognosis and survival of the patient depend on the locations the tumor cells migrate to, with the lowest survival with invasion into the right anterior thalamic radiation, right inferior fronto-occipital fasciculus, right/left corticospinal tract, and corpus callosum (Wang et al. 2021).

2. GBM Extracellular Matrix (ECM) and Invasion

The migration of GBM cells out of the primary tumor and through various brain tissues enables numerous tumor cell-ECM interactions, which determine the specific nature of the invasion. Glioblastoma cells continuously interact with their extracellular matrix (ECM) through signaling (So et al. 2021). Components of the brain ECM, including integrin proteins, fibronectin, collagens, proteoglycans, and lamins, influence the behavior of GBM cells by contributing to a pro-migratory environment for them (Hatoum et al. 2019; Mohiuddin et al. 2021; So et al. 2021). GBM cells can overexpress most of these adhesive and migratory ECM components with specific receptors enhancing migration via increasing interactions between GBM cells and the ECM (Mohiuddin et al. 2021). Integrins can bind to extracellular ligands, such as fibronectin, which triggers intracellular signaling cascades that activate the motility mechanism (Hatoum et al. 2019). Additionally, the tumors synthesize altered proteins that promote the degradation of the tumor ECM and increased synthesis of specific ECM components by normal tissues in the vicinity (Mohiuddin et al. 2021). Specifically, the degradation of ECM components such as hyaluronic acid and proteoglycans is crucial to promoting invasion along perivascular spaces. Glioma cells can also secrete various proteins such as tenascins, matrix metalloproteinases, and metalloproteinase domains (ADAMs) that can modify their ECM and thus promote their invasion (Wang et al. 2021). These modifications can alter the morphology of the environment of white matter tracts, which are significantly damaged and interrupted by higher-grade glioma cells. Additionally, the overexpression of ECM components makes tumor ECMs more condensed and rigid, creating barriers around the tumor that limit the diffusion of chemotherapy drugs and other therapeutic components (Mohiuddin et al. 2021). These components also diminish the supply of nutrients and oxygen to the tumor, leading to metabolic stress that contributes to resistance to radiotherapy and chemotherapy (Mohiuddin et al. 2021).

3. Ca²⁺ Signaling in GBM Cells

As GBM's tumors alter their ECM to promote invasion, numerous intracellular cascades are triggered, and the calcium signaling pathway has caught the attention of numerous researchers. Calcium signaling pathways are a key step in signal transduction, a series of molecular events linking external stimuli into cellular response, controlling numerous cellular processes, including cell-to-cell communication where calcium acts as a messenger. The activation and dysregulation of calcium signaling pathways have been implicated in GBM's proliferation and invasion. Calcium signaling pathways control the calcium ion concentrations of the cell, and it has been found that the intracellular accumulation of Ca²⁺ is critical for tumorigenesis in GBM and is linked to motility and invasion (So et al. 2021). GBM cells express receptor tyrosine kinase and G protein-coupled receptors (GPCRs) on their ECM, which contribute to Ca²⁺ release from the endoplasmic reticulum by activating inositol 1,4,5-trisphosphate receptors. Additionally, Ca²⁺ entry into the cells from extracellular regions into the cytosol is associated with several channels and receptors such as Store-operated channels, transient receptor potential (TRP) channels, voltage-gated Ca²⁺ channels,

P2 × 7 receptors, ionotropic glutamate receptors and leads to a variety of intracellular signaling (So et al. 2021).

The Store Operated Calcium Entry (SOCE) into glioma cells is a Calcium influx pathway that refills the endoplasmic reticulum after its depletion (Maklad et al. 2021). Low Ca²⁺ levels are sensed by STIM1, and upon interaction with Orai1 Ca²⁺ channels on the membrane, the membrane opens enabling Ca²⁺ influx (Maklad et al. 2021). Higher levels of SOCE and expression of STIM1 and Orai1 are observed more in malignant GBM cells and are crucial to cell proliferation (Leclerc et al. 2016; Maklad et al. 2021).

Upon activation of voltage Gated Calcium Channels (VGCCs), a high influx of Ca²⁺ enters the cell, signaling for processes such as neurotransmitter release, neuron growth, and gene expression. A subgroup of the VGCCs, T-type channels control cell proliferation and differentiation by regulating Ca²⁺ levels with low voltage by creating a resting inward calcium current. When a t-type Ca²⁺ channel blocker was tested, GBM proliferation induced apoptosis and sensitized cells to ionizing radiation (Maklad et al. 2021).

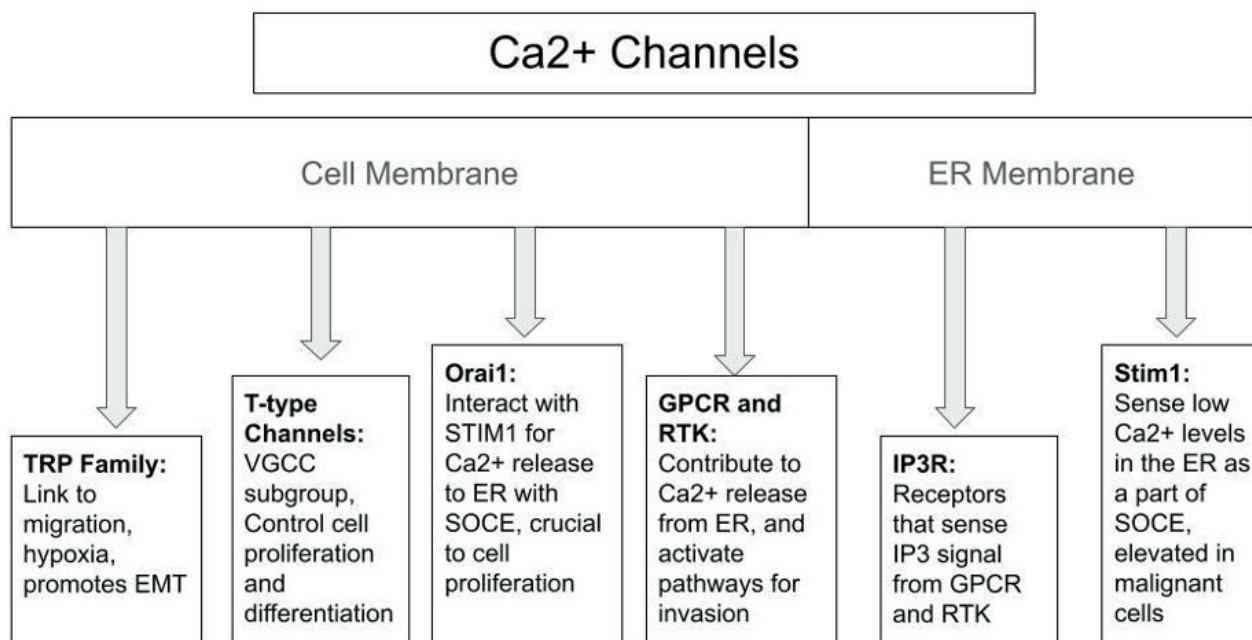


Figure 1: Ca²⁺ channels and their functions in GBM

4. TRP Channels in GBM

Transient receptor potential (TRP) channels belong to the cation-selective channel superfamily. TRP channels, including TRPC1, TRPC6, TRPM2, TRPM3, TRPM7, TRPM8, TRPV1, and TRPV2, are overexpressed in GBM patients, revealing a connection between TRP channels and the progression of GBM (So et al. 2021). Previous studies found a significant relationship between the overexpression of TRP genes and the poor survival of patients (Alpetkin et al. 2015). TRP channels play an essential role in maintaining cellular calcium homeostasis by enabling calcium release from various organelles and changing cytosolic calcium concentration (Chinigo et al. 2021). As mentioned, this calcium influx alters gene expression, leading to increased cell proliferation and migration of cancer cells. TRPC (TRP canonical) channels are linked to migration in GBM, as they are localized on the leading side of migrating cells. They have been shown to control glioma chemotaxis in response to stimuli such as EGF, and their inhibition revealed a decrease in chemotaxis towards such stimuli (Leclerc et al. 2016). TRPC1 specifically is implicated in cell proliferation and tumor size through regulating Cl⁻ ion channels and changing the volume of the glioma cells to assist in migration, as we will further discuss later.

TRP channels have also been found to play a crucial role in tumor angiogenesis as they respond to hypoxia and low tumor oxygenation by increasing their expression or activity (Alpetkin et al. 2015). Hypoxia is a marker of GBM tumor pathogenesis that contributes to capillary formation and initiates tumor angiogenesis by secretion of growth factors such as vascular endothelial-derived growth factor (VEGF) (Bai et al. 2023). Specific TRP channels such as TRPC3 and TRPC6 are associated with hypoxia and would be located in excess in GBM, and suppressing these channels would inhibit cell migration in GBM in response to hypoxia (Alpetkin et al. 2015). The activation of TRPC6, specifically under hypoxic conditions, plays a role in stabilizing the hypoxia-inducible factor-1 (HIF-1), a family of proteins that form transcriptional complexes that are involved in regulating tumor formation, progression, angiogenesis, the epithelial and mesenchymal transition (EMT) and enhance cancer cells capacity to self-renew (Leclerc et al. 2016; So et al. 2021).

TRP-mediated calcium signaling also plays a crucial role in Epithelial-Mesenchymal Transition (EMT) and ECM degradation, which contributes to cancer invasion and metastasis (Bai et al., 2023). During EMT, cells lose their epithelial traits and gain mesenchymal characteristics, which lead to the loss of basement anchoring and cell-cell junctions, enhancing migration and invasion capabilities (Bai et al., 2023). Studies reveal that TRP channels have been shown to have different expression profiles between epithelial and mesenchymal phenotypes, assuming a role in promoting EMT (Bai et al., 2023).

5. Mechanisms of GBM Invasion and Proliferation with Ca²⁺ Signaling

One specific molecule that can control GBM migration by attracting cells to the blood vessel is Bradykinin. The activation of type 2 bradykinin receptors (B2R) on the ECM induces cyclic changes in intracellular Ca²⁺ in GBM, which has a downstream effect, activating KCa3.1 and ClC3 channels and affecting the invasiveness of the cells (Hatoum et al. 2019). In order to navigate the tortuous extracellular spaces that cells disseminate along white matter tracts, cells must be able to reduce their volume and appear “elongated and slender wedge-shaped”(Hatoum et al. 2019). When the “chemoattractant” bradykinin binds to the GPCR B2R, the IP3R is activated and triggers the release of Ca²⁺ from the endoplasmic reticulum. Ca²⁺ entry into the cell leads to depolarization that activated voltage-gated ClC3 channels create a hypoosmotic intracellular environment where the Cl⁻ and K⁺ flow out of the cell forces water out through aquaporins, reducing the cell volume (Hatoum et al. 2019).

Researchers also have hypothesized that the main checkpoints that control a cell's fate are also dependent on the Ca²⁺ signaling pathways. Ion channels are thought to facilitate the progression through the cell cycle and are, therefore, required for cell proliferation (Leclerc et al. 2016). In cytokinesis, inhibiting the TRPC1 channels triggers incomplete cell division, and therefore, they are suggested to play a role in Ca²⁺ entry during the late M-phase of the cell cycle. TRPC6 similarly plays a role in cell growth and clonogenic ability, the ability of the cell to proliferate into cell colonies, and G2/M phase cell cycle transition (Maklad et al. 2021). During proliferation, invasion, migration, and prior to each cell division, the volume and shape of GBM cells change, and these morphological changes can be attributed to the movement of ions (Cl⁻ and K⁺) and water associated with the increase in Ca²⁺ discussed previously (Leclerc et al. 2016).

Although the majority of pathways and interactions that arise due to Ca⁺ influx have been shown to promote GBM proliferation, migration, and invasion, the relationship between them is far more complex. A study conducted to examine the mechanism of the drug NNC-55-0396, a T-type calcium channel blocker, could trigger cell death (Visa et al. 2022). Unexpectedly, it was found to increase calcium while leading to apoptosis. The study focused on the unfolding protein response (UPR), which responds to ER stress, and its overactivation in GBM is a contributing factor to therapeutic resistance and tumorigenesis. A branch of UPR, Alpha Inositol Requiring Enzyme 1 (IRE1 Alpha) was activated upon administration of NNC, activates IP3R, and triggers calcium release from the ER, leading to cell death (Visa et al. 2022). These findings are significant because they reorient researchers on their understanding of the relationship between calcium influx and GBM proliferation.

6. Research Approaches and Therapeutic Targets

During summer research, we have significantly learned about Ca²⁺ signaling pathways and the complicated role they play in the ECM, and the cell life cycle. We then started experiments to visualize intracellular calcium expressed by GBM cells within the artificial 3D tumors called spheroids. The Ca²⁺ signal is being studied through the use of Fluo-8 AM dyes and fluorescent microscope. These dyes have a high affinity for calcium ions and become fluorescent upon binding with Ca²⁺ intracellularly. As we identify Ca²⁺ channels implicated in growth and proliferation, we can use drugs and inhibitors to test therapeutic opportunities. The most promising therapeutic targets are the ion channels themselves, with TRP and T-type channels being candidates that we would like to explore in the lab through inhibition trials.

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References

- Alptekin, M., et al. "Gene Expressions of TRP Channels in Glioblastoma Multiforme and Relation with Survival." *Tumor Biology*, vol. 36, no. 12, 2015, pp. 9209–9213., <https://doi.org/10.1007/s13277-015-3577-x>.
- Bai, Suwen, et al. "The role of transient receptor potential channels in metastasis", *Biomedicine & Pharmacotherapy*, Volume 158, 2023, <https://doi.org/10.1016/j.biopha.2022.114074>.
- Chinigò, Giorgia, et al. "TRP Channels in Brain Tumors." *Frontiers in Cell and Developmental Biology*, vol. 9, 2021, <https://doi.org/10.3389/fcell.2021.617801>.
- Ding, Xia, et al. "Essential Role of TRPC6 Channels in G2/M Phase Transition and Development of Human Glioma", *JNCI: Journal of the National Cancer Institute*, Volume 102, Issue 14, 21 July 2010, Pages 1052–1068, <https://doi.org/10.1093/jnci/djq217>
- Hatoum, A., Mohammed, R., & Zakieh, O. . The unique invasiveness of glioblastoma and possible drug targets on extracellular matrix. *Cancer management and research*, 11, 2019. Pages 1843–1855. <https://doi.org/10.2147/CMAR.S186142>
- Leclerc, Catherine, et al. "Calcium signaling orchestrates glioblastoma development: Facts and conjunctures," *Biochimica et Biophysica Acta (BBA) - Molecular Cell Research*, Volume 1863, Issue 6, Part B, 2016, Pages 1447-1459, ISSN 0167-4889, <https://doi.org/10.1016/j.bbamcr.2016.01.018>.
- Kai F, Drain AP, Weaver VM. The Extracellular Matrix Modulates the Metastatic Journey. *Dev Cell*. 2019 May 6;49(3):332-346. doi: 10.1016/j.devcel.2019.03.026. PMID: 31063753; PMCID: PMC6527347.
- Maklad A, Sharma A, Azimi I. "Calcium Signaling in Brain Cancers: Roles and Therapeutic Targeting. *Cancers (Basel)*. 2019 Jan 26;11(2):145. doi: 10.3390/cancers11020145. PMID: 30691160; PMCID: PMC6406375.
- Mohiuddin, E., & Wakimoto, H. (2021). Extracellular matrix in glioblastoma: opportunities for emerging therapeutic approaches. *American journal of cancer research*, 11(8), 3742–3754.
- Ndyabawe, Kennet, et al. "Spheroid Trapping and Calcium Spike Estimation Techniques toward Automation of 3D Culture" *SLAS Technology*, Volume 26, Issue 3, 2021, Pages 265-273, <https://doi.org/10.1177/2472630320938319>.
- Nizamutdinov, D, et al. "Prognostication of Survival Outcomes in Patients Diagnosed with Glioblastoma", *World Neurosurgery*, Volume 109, 2018, Pages e67-e74, ISSN 1878-8750, <https://doi.org/10.1016/j.wneu.2017.09.104>. (<https://www.sciencedirect.com/science/article/pii/S187887501731611X>)
- So, Jae-Seon, et al. "Mechanisms of Invasion in Glioblastoma: Extracellular Matrix, ca²⁺ Signaling, and Glutamate." *Frontiers in Cellular Neuroscience*, vol. 15, 2021, <https://doi.org/10.3389/fncel.2021.663092>.
- Visa, Ana, et al. "Tetralol derivative NNC-55-0396 induces glioblastoma cell death by activating IRE1 α , JNK1 and calcium signaling", *Biomedicine & Pharmacotherapy*, Volume 149, 2022, 112881, 0753-3322, <https://doi.org/10.1016/j.biopha.2022.112881>.
- Wang, Jun, et al. "Glioma invasion along white matter tracts: A dilemma for neurosurgeons," *Cancer Letters*, Volume 526, 2022, Pages 103-111, ISSN 0304-3835, <https://doi.org/10.1016/j.canlet.2021.11.020>.

A Brief Review on the TGF- β Pathway During Epithelial to Mesenchymal Transition of Glioblastoma Multiforme

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Abstract

Glioblastoma Multiforme (GBM) is one of the most aggressive and fatal forms of brain cancer. Despite the multiple advances in treatment, median survival is only about 14 months upon diagnosis. Hence, multiple studies have been conducted to further our understanding of GBM tumor biology and the mechanisms underlying its malignancy. Recent research has presented that GBM can initiate highly tumorigenic pathways that lead to changes in the surrounding normal tissue, increasing metastasis, invasiveness, and resistance to treatment. The most prominent being the Epithelial to Mesenchymal Transition (EMT) in GBM, particularly its induction via Transforming Growth Factor- β (TGF- β). EMT is the process in which epithelial cells undergo biochemical changes and alter their morphology from cells with tight adhesion to mesenchymal cells which are characterized by their loose organization. In GBM, cancer cells undergoing EMT-like processes typically have weak adhesion, enhanced migration, and resistance to chemotherapy. One of the major driving factors of EMT is TGF- β , a multifunctional cytokine known to be capable of regulating cell proliferation, differentiation, and homeostasis. TGF- β is highly researched because of its dual role in the progression of GBM. In early stages of cancer, the induction of the SMAD dependent and independent pathways allows it to act as a tumor suppressor, but during the later stages of GBM progression, alterations in these pathways mediate a tumor promoting role. Research on the therapeutic treatments against TGF- β induced EMT pathway usually focus on the incorporation of antisense oligonucleotides, blocking ligands with soluble receptors, and suppressing TGF- β receptor kinase activity.

Glioblastoma Multiforme (GBM)

Glioma refers to any primary tumor occurring in the Central Nervous System (CNS) (Hanif et al. 2017). Glioma includes four major subtypes classified by their cell of origin: astrocytic, oligodendrogliomas, ependymomas, and mixed gliomas (Hanif et al. 2017). Glioblastoma multiforme (GBM), designated as a Grade IV tumor by WHO, is an astrocytic glioma and is the most common, aggressive, and invasive tumor found in the central nervous system (Hanif et al. 2017, Taylor et al. 2019, Oronsky et al. 2021). Based on its clinical features, GBM can be divided into two subtypes: primary and secondary. While secondary tumors arise from the dissemination of a previously existing low grade astrocytoma, primary tumors arise without any evidence of a precursor lesion (Hanif et al. 2017). GBM can also be classified based on the status of its IDH1/2 (isocitrate dehydrogenase) mutation: IDH mutant, IDH wildtype, or not otherwise specified. These mutations block the normal process of cellular differentiation and hence promote tumorigenesis.

GBM prognosis is extremely poor with median survival about 14 months after diagnosis and the cause of 2.5% of cancer related deaths (Hanif et al. 2017). Recent research has shown that GBM cells can initiate highly tumorigenic pathways that lead to changes in the surrounding normal tissue,

increasing metastasis, invasiveness, and resistance to treatment (Gürsoy et al. 2022, Taylor et al. 2019, Hanif et al. 2017). For example, GBM can promote neovascularization by secreting angiogenic factors. Additionally, the Go-or-Grow hypothesis specifies that cells can either migrate or proliferate, but not both. The cells that don't migrate undergo cell death, eventually leading to an area of central necrosis. The repeated cycle of angiogenesis, vascular necrosis, and migration all compound and contribute to the invasiveness of GBM. Additionally, its high molecular heterogeneity accounts for its aggressiveness and high recurrence rate (Gürsoy et al. 2022).

Despite the heterogeneity of GBM and its resistance to therapies, due to the lack of successful targeted therapies treatment is often identical, including surgical resection, followed by radiotherapy and chemotherapy to kill any remaining tumor cells (Taylor et al. 2019, Oronsky et al. 2021). Another challenge is the presence of the Blood Brain Barrier, a selectively semipermeable membrane that separates blood from the brain. It prevents about 98% of small molecule drugs from entering the central nervous system, reducing the efficacy of drug based strategies (Taylor et al. 2019). However, surgery only is not sufficient either as about 80% of cases result in recurrence after surgical resection (Hanif et al. 2017), Oronsky et al. 2021). Due to the complexity of GBM biology and its interaction with targeted therapies, a combination of therapies is the best path of treatment. Research has shown that this strategy can improve life expectancy of patients with relapsed GBM, but not so much in newly diagnosed patients (Hanif et al. 2017).

Epithelial to Mesenchymal Transition (EMT)

EMT is defined as the process in which epithelial cells, characterized by their tight adhesion and organization, lose polarity and separate from each other by altering their morphology and undergo biochemical transformation into the mesenchymal phenotype, characterized by high motility and loose adhesion. (Iwadate et al. 2016, Iser et al. 2016, Hao et al. 2019). While EMT occurs during normal development and physiological processes such as embryo formation, wound healing, tissue regeneration, EMT found in malignant cells has become an important event of cancer progression as it induces migratory and invasive abilities without losing viability. In GBM, cancer cells undergoing EMT-like processes typically have weak adhesion, enhanced migration, and resistance to chemotherapy (Hao et al. 2019).

EMT is not a swift transformation, rather it is a multistep process in which cells can be found in intermediate hybrid states called partial EMT states (P-EMT). Whereas the complete transition from epithelial cells to mesenchymal cells is often not reversible, transforming into the P-EMT state is and this process can occur back and forth multiple times throughout the progression of the cancer (Hao et al. 2019, Iser et al. 2016). While the acquisition of mesenchymal characteristics is necessary for the metastasis of GBM, Mesenchymal to Epithelial Transition is also crucial as it allows for the tumor cells to conclude migration and continue growing, as per the Go-or-Grow Hypothesis (Iser et al. 2016, Oronsky et al. 2021).

Transforming Growth Factor- β (TGF- β) Induced EMT

One of the major driving components of EMT is *Transforming Growth Factor- β* (TGF- β), a multifunctional cytokine known to be capable of regulating cell proliferation, differentiation, and homeostasis (Hao et al. 2019). TGF- β is known to have an interesting dual effect on the progression of GBM. In normal epithelial cells and the early stages of cancer, it plays a suppressor role by inhibiting proliferation and inducing apoptosis (Baba et al. 2022). But in later stages of oncogenesis, mutations to TGF- β receptors can lead to tumor cells becoming resistant to the growth and migration inhibitory properties.

There are two main pathways that TGF- β play an EMT related role in: SMAD dependent and SMAD independent. As a tumor suppressor in the SMAD dependent pathway, TGF- β activates the cyclin dependent kinase inhibitor to mediate cell cycle arrest in the G1 phase, or mediate the pSmad3C (C-terminally phosphorylated Smad3) signaling that plays a role in the resistance to mitotic proliferative responses (Han et al. 2015). The SMAD independent pathway involves the activation of PI3K-Akt-mTOR1 or MAPK signaling to mediate caspase-8-dependent apoptosis (Iser et al. 2016, Baba et al. 2022).

As a tumor promoter in the later stages, the SMAD dependent pathway involves TGF- β binding to TGF- β I/II receptors to activate the Smad2 and 3 proteins. This complex then combines with Smad4 in the cytoplasm and moves to the nucleus where it acts as a transcription regulator, repressing important target genes like E-cadherin and activating the factors for Snail, Zeb, Twist, Fibronectin, and Vimentin (Iser et al. 2016). This collaboration represses the epithelial phenotype and increases the activity and effect on the expression of EMT-related genes (Iser et al. 2016, Iwadate et al. 2016). In the SMAD independent pathway, TGF- β promotes the secretion of matrix metalloproteases (MMP)-2 and -9, endopeptidases that facilitate tumor cells to disseminate and invade, leading to EMT and metastasis to distant sites (Baba et al. 2022, Han et al. 2015, Hao et al. 2019).

Intervention related to TGF- β pathways

Research on TGF- β pathway intervention has become prominent in the development of glioma therapy. Most clinical studies on TGF- β inhibition involve the use of antisense oligonucleotides, blocking ligands with soluble receptors, and suppressing TGF- β receptor kinase activity (Han et al. 2015, Taylor et al. 2019).

Antisense oligonucleotides are single stranded synthetic RNA sequences that selectively bind to mRNA. They can be incorporated into cells to block translation or even degrade the TGF- β mRNA. Studies of two novel antisense oligonucleotides, STH1047 and ISTH0047, which specifically inhibit TGF- β I and TGF- β II, have shown a downregulation effect on both TGF- β I/II mRNA. As a result, it led to a reduction of intracellular Smad2 phosphorylation, and therefore a reduction in migratory and invasive capabilities among glioma spheroid models (Papachristodoulou et al. 2019).

Soluble receptors can be used to bind TGF- β and prevent it from binding to its cell surface receptors. However, targeting a single ligand is often only partially effective since gliomas, and GBM in particular, usually secrete multiple ligands. Therefore, targeting TGF- β RI and II offers many advantages (Hjelmeland et al. 2004, Franzen et al. 1993). LY2109761, an inhibitor for both TGF- β RI and TGF- β RII has been shown to have anti-migratory and anti-angiogenesis effects in *in vitro* trials (Han et al. 2015).

Another therapeutic method to inhibit signaling of TGF- β is by blocking TGF- β RI/II kinase activity. This prevents the phosphorylation of Smad proteins downstream, hence blocking the movement of the complex into the nucleus. One inhibitor of TGF- β RI, SD208, inhibits the matrigel invasion and expression of TGF- β target genes such as PTHrP, IL-11, CTGF, and RUNX2, etc. This resulted in a decrease in progression of osteolytic lesions in glioma models (Hao et al. 2019). Phase 1 clinical trials of Galunisertib (LY2157299), a small-molecule inhibitor that binds to TGF- β RI, has also revealed promising anti-cancer activity in patients with glioma (Baba et al. 2022).

One of the most prominently studied inhibitors of TGF- β is SB-431542. Studies have shown that it inhibits the expression of two important effectors of TGF- β : plasminogen activator inhibitor-1 (PAI-1) and vascular endothelial growth factor (VEGF). Glioma cultures that have been treated with this inhibitor displayed inhibited proliferation, EMT-like morphological changes, and cellular motility (Hjelmeland et al. 2004). PAI-1 typically regulates the extracellular matrix around mesenchymal tissue and is often overexpressed in malignant gliomas. PAI-1 also regulates invasion and angiogenesis, and is a target for TGF- β and SMAD DNA transcription. SB-431542 treatment has been able to inhibit both basal expression and levels of PAI-1 that are the inductive response of exogenous TGF- β . This means that it could reduce the autocrine responses (Hjelmeland et al. 2004). Similarly, VEGF, which is related to malignant glioma progression and is regulated by TGF- β has been shown to have blocked expression as well, leading to inhibition of invasion and angiogenesis (Hjelmeland et al. 2004, Yancopoulos et al. 2000).

Research Methods

In my summer research, I investigated the specific effect of the TGF- β inhibitor, SB-431542, on the sprouting responses of GBM cells. Using the non-adherent method and microfluidic technology, I generated a three-dimensional GBM model to mimic an *in vivo* tumor microenvironment. I then introduced the TGF- β inhibitor and quantified the resulting sprouting and behaviors of the invasive

cells. I hypothesized a detectable decrease in the level of invasion among the treated spheroids compared to the control. After completing two trials, I was able to see a significant decrease in sprouting among the treated groups in comparison to the control groups. After completing a few more trials with a more refined procedure, I plan to isolate the cells for transcriptomic analysis, particularly on the mRNA expression of EMT-related genes. The findings of this proposed study will broaden our knowledge of the complexity of EMT and its role in GBM cancer development and metastasis. Moreover, I hope my work will provide the means to improve therapies that can inhibit cancer cell dissemination in GBM patients.

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References

1. Baba, Abdul Basit, et al. "Transforming growth factor-beta (TGF- β) signaling in cancer-a betrayal within." *Frontiers in Pharmacology*, vol. 13, 2022, <https://doi.org/10.3389/fphar.2022.791272>.
2. Franzen, P. "Cloning of a tgfbeta; type I receptor that forms a heteromeric complex with the tgfbeta; type II receptor." *Cell*, vol. 75, no. 4, 19 Nov. 1993, pp. 681–692, [https://doi.org/10.1016/0092-8674\(93\)90489-d](https://doi.org/10.1016/0092-8674(93)90489-d).
3. Gürsoy, Güven, et al. "The role of transforming growth factor beta and SMAD receptors in determining prognosis in high-grade primary brain tumors: Glioblastoma multiforme." *Arquivos Brasileiros de Neurocirurgia: Brazilian Neurosurgery*, vol. 42, no. 02, 2022, <https://doi.org/10.1055/s-0042-1743555>.
4. Han, Jianfeng et al. "TGF- β signaling and its targeting for glioma treatment." *American journal of cancer research* vol. 5,3 945-55. 15 Feb. 2015
5. Hanif, Farina et al. "Glioblastoma Multiforme: A Review of its Epidemiology and Pathogenesis through Clinical Presentation and Treatment." *Asian Pacific journal of cancer prevention : APJCP* vol. 18,1 3-9. 1 Jan. 2017, doi:10.22034/APJCP.2017.18.1.3
6. Hao, Yang, et al. "TGF- β -mediated epithelial-mesenchymal transition and cancer metastasis." *International Journal of Molecular Sciences*, vol. 20, no. 11, 2019, p. 2767, <https://doi.org/10.3390/ijms20112767>.
7. Hjelmeland, Mark D., et al. "SB-431542, a small molecule transforming growth factor- β -receptor antagonist, inhibits human glioma cell line proliferation and motility." *Molecular Cancer Therapeutics*, vol. 3, no. 6, 2004, pp. 737–745, <https://doi.org/10.1158/1535-7163.737.3.6>.
8. Iser, Isabele C., et al. "The epithelial-to-mesenchymal transition-like process in glioblastoma: An updated systematic review and in silico investigation." *Medicinal Research Reviews*, vol. 37, no. 2, 2016, pp. 271–313, <https://doi.org/10.1002/med.21408>.
9. Iwadata, Yasuo. "Epithelial-mesenchymal transition in glioblastoma progression." *Oncology letters* vol. 11,3 (2016): 1615-1620. doi:10.3892/ol.2016.4113
10. Oronsky, Bryan, et al. "A review of newly diagnosed glioblastoma." *Frontiers in Oncology*, vol. 10, 5 Feb. 2021, <https://doi.org/10.3389/fonc.2020.574012>.
11. Papachristodoulou, Alexandros, et al. "Therapeutic targeting of TGF β ligands in glioblastoma using novel antisense oligonucleotides reduces the growth of experimental gliomas." *Clinical Cancer Research*, vol. 25, no. 23, 2019, pp. 7189–7201, <https://doi.org/10.1158/1078-0432.ccr-17-3024>.
12. Taylor, Olivia G et al. "Glioblastoma Multiforme: An Overview of Emerging Therapeutic Targets." *Frontiers in oncology* vol. 9 963. 26 Sep. 2019, doi:10.3389/fonc.2019.00963
13. Yancopoulos, George D., et al. "Vascular-specific growth factors and Blood Vessel Formation." *Nature*, vol. 407, no. 6801, 14 Sept. 2000, pp. 242–248, <https://doi.org/10.1038/35025215>.

The Effects of Environmental Factors on *Listeria monocytogenes* Fitness and Pathogenesis

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Abstract

Listeria monocytogenes is a foodborne pathogen that causes the disease listeriosis with mild to severe symptoms depending on strain variations and host factors. *L. monocytogenes* infections have a high mortality rate and require millions of dollars annually to treat infected patients. As a result, *L. monocytogenes* has been under intensive research to identify effective preventative and treatment strategies. In our lab, we have focused on the role of propionate and anaerobic environments as two relevant factors in modulating the growth and pathogenesis of *L. monocytogenes*. For this proposed BSTI research, I have been looking at the role of propionate and anaerobic environments on *L. monocytogenes* interactions with mucin and antimicrobial peptides. To determine how the fitness of *L. monocytogenes*, grown with or without propionate or oxygen, was affected by mucin and antimicrobial peptides, I performed survival assay and found that mucin could provide protective effects for *L. monocytogenes* against antimicrobial peptides. Further investigations into the production of the toxin listeriolysin O (LLO) and infections of mammalian cells in response to the mucin and antimicrobial peptide exposure are underway. With findings from these experiments, we hope to gain a better understanding of *L. monocytogenes* and contribute to the ultimate goal of protecting vulnerable populations from *L. monocytogenes* infections.

A Personal Introduction

As an Environmental Biology student, I did not picture myself doing medical biology research in a microbiology lab, but over the summer of 2023 I conducted research in Dr. Sun's microbiology lab that focuses on studying a human pathogen. This research began in December of 2022 when I approached Dr. Sun about the Berry Summer Thesis Institute and asked her if I would be able to work in her lab as a Berry Summer Thesis student. We also discussed the research topic I would be focusing on over the summer and began to formulate a research plan. In the spring semester of 2023, I studied abroad and met Dr. Sun over zoom to work on and write my Berry Summer Thesis Institute proposal. My thesis research focuses on how different environmental factors affect *L. monocytogenes* its subsequent infections. The environmental factors I experimented with this summer were propionate, anaerobicity, mucin, and antimicrobial peptides. Over the summer I learned about and performed a few different procedures all of which tested *L. monocytogenes* against the environmental factors. This proceeding is a summary of what I have learned over the past few months.

Mucin and the Mucosal Barrier

To begin I had to research and learn more about mucin and the role it plays in the human body. After reading different articles about mucin, I have learned that mucin plays an integral part in the human body's immune defense system by acting as a barrier used to keep fatal pathogens and bacteria from entering the gastrointestinal tract, which resides in the intestines¹. Mucin is often the first molecule invading pathogens interact with when they enter the human body and because of this mucus secretion increases when pathogens invade the body to provide a defense mechanism to help fight off the invading pathogens². The mucin barrier is a physicochemical surface that allows nutrients to pass but blocks pathogens and toxins from getting through. Specifically, cell surface mucins control the mucosal layer by averting pathogens away from the mucosal surface³. Mucin plays an integral part in the health of the human body and varies in thickness based on where the mucus resides in the body. For example, the mouth houses a thin layer of mucus which is often mixed with saliva, while the colon has two layers of mucus. In the colon the top layer of mucus can be easily removed, but the bottom mucus layer stays attached to the colon for protection⁴. However, many enteric pathogens, such as *L. monocytogenes*, can adapt and bypass the mucin barrier protecting the GI tract and disseminate to cause serious infections outside the GI tract. This is why my research focuses heavily on the interactions between *L. monocytogenes* and mucin¹.

While mucin has many beneficial roles in the human body it also can greatly benefit other animals. Priscia Hoorens and others are studying bovine mucin in cattle. In one study, 9 bovine membrane-associated mucins and 6 secreted mucins were found in cows⁵. Along with cattle, the mucin in amphibians is often studied because oviducal mucin covers the outside of amphibian eggs and contribute to fertilization. The oviducal mucin makes up a "jelly coat" that covers the egg and protects the embryo from outside harm while it grows⁶. The reason the jelly coat contributes to fertilization is because the sperm must pass through the jelly coat in order to reach the egg which then triggers the fertilization process⁷. One interesting article I found focused on jellyfish mucin and how it could possibly be used to help treat osteoarthritis. Osteoarthritis is a joint disease often found in older people and slowly degrades the cartilage in knee and hip joints. Scientists have been unable to produce mucin sufficient enough to help stop the degeneration of the cartilage. The purpose of the study was to inject jellyfish mucin into a rabbit with osteoarthritis to see if the mucin would help keep the cartilage from degrading⁸.

Antimicrobial Peptides

Another integral part of my research this summer was working with antimicrobial peptides. Antimicrobial peptides are a huge part of our immune defense mechanisms, fighting against bacteria, viruses, and other Eukaryotic pathogens⁹. When the body has become infected by a pathogen, or a virus the human body's response is to send the antimicrobial peptides to the infection to kill the invading pathogens or bacteria. These peptides are composed of amino acids and specifically target and destroy pathogens while sparing the body's host cells¹⁰. Antimicrobial peptides are small molecular peptides responsible for many functions, including immune regulation, angiogenesis, and wound healing. They are made up of around 12 to 50 amino acids and are usually produced by epithelial cells¹¹. Antimicrobial peptides have a hydrophobic side chain, meaning it repels water, and a hydrophilic side chain, meaning it attracts water. Since antimicrobial peptides have both a hydrophobic and hydrophilic side, they are soluble in water¹².

I reviewed five literature pieces about antimicrobial peptides, and I learned about the different uses antimicrobial peptides can have in the human body. In 1939 antimicrobial peptides were first discovered from a soil sample that yielded an antimicrobial agent. It has been further discovered that antimicrobial peptides have four different structures which consist of β -sheet, α -helix, extended, and loop¹³. The article titled *The Antimicrobial Peptides and Their Potential Clinical Applications* relates the study of antimicrobial peptides to the progression of antibiotics. As antibiotics have become increasingly popular there have been many different bacteria that have become resistant to popular antibiotics. This has fueled a new section of research dedicated to finding new ways for the human body to fight off infections that does not involve antibiotics. One solution to this problem are antimicrobial peptides because they act as natural antibiotics when facing an infection in the body¹⁴.

While antimicrobial peptides are essential to our immune systems, they could also cause significant damage. In the article *Diversity of Antimicrobial Peptides and Their Mechanisms of Action* scientists work to increase the strength and potency of antimicrobial peptides to increase the rate at which they can kill bacteria, while also making sure they do not harm human cells¹⁵. If antimicrobial peptides become overly potent, they could potentially end up harming human cells along with the invading cells.

Listeria monocytogenes

The bulk of my research revolves around *L. monocytogenes*, a food borne pathogen that has an alarmingly high mortality rate. *L. monocytogenes* causes the disease listeriosis with mild to severe symptoms and requires millions of dollars annually to treat the infected patients. The CDC estimates that approximately 1,600 people contract listeriosis each year and out of those roughly 260 people die¹⁶. *L. monocytogenes* is such a heavily studied pathogen because listeriosis can be fatal to anyone with a compromised immune system. A reoccurring pattern has been found with listeriosis meaning people who are subject to being infected by *L. monocytogenes* are ones whose T-cell-mediated immunity is suppressed¹⁷. One common way people contract *L. monocytogenes* is through different foods because *L. monocytogenes* is a food borne pathogen. Scientists studying *L. monocytogenes* have discovered that the food borne pathogen can easily grow in food processing equipment because there may be hidden or leftover soil and water on the equipment that might be hard to wash off¹⁸. These leftover patches of soil and water make the perfect environment for *L. monocytogenes* to grow and thrive. As mentioned earlier some bacteria including *L. monocytogenes* can modify its surface components to resist antimicrobial peptides in the body. For example, one way *L. monocytogenes* resists positively charged antimicrobial peptides is by increasing teichoic acid glycosylation to decrease the surface negative charge¹⁹.

L. monocytogenes interacts with both mucins and antimicrobial peptides in the human body and because of this the survival assay I performed over the summer tested *L. monocytogenes* with both mucin and antimicrobial peptides. It has been discovered that *L. monocytogenes* binds to intestinal mucins, but not to the cells surface mucin²⁰. PFG, a common method used to study *L. monocytogenes*, is used by many scientists, and has become the common method when studying the food borne pathogen. However, it has been discovered that PFG is not an accurate method to study the evolution of *L. monocytogenes*. Instead, scientists have begun using MLST which provides a new way for scientists to get a better understanding of *L. monocytogenes* and to study how it has adapted to become a pathogen²¹.

Propionate

In Dr. Sun's lab, we are interested to find out how propionate, a fermentation acid found in the intestinal lumen, alters *L. monocytogenes* interactions with mucin and antimicrobial peptides. Propionate is known as the "microbial metabolite" and helps by aiding in digestion and metabolism²². This fermentation acid is most well-known for its role in the human digestive system and it may also be able to help control appetite²³. Since propionate plays an important role in human digestion many scientists have concluded that there are three different pathways in which bacteria travels in the human body to produce propionate²⁴. Our lab has reported that anaerobic propionate exposure can significantly alter *L. monocytogenes* fitness and pathogenesis, including adherent growth and LLO production. Most notably, anaerobic propionate treatment resulted in an increase LLO production while aerobic propionate treatment resulted in a decrease in LLO production. These results showed that oxygen can affect how *L. monocytogenes* responds to propionate²⁵. Our lab has also discovered that the pretreatment of propionate to anaerobic, but not aerobic, *L. monocytogenes* increases intracellular infections, which justifies that propionate is a vital signaling molecule and can modify outcomes of *L. monocytogenes* infections²⁶. Specifically, for anaerobicity, our lab has discovered that when *L. monocytogenes* is exposed to an anaerobic environment, growth is decreased and there are changes in the surface morphology. Compared to aerobically grown bacteria, *L. monocytogenes* grown anaerobically has an increased level of invasion but a decreased level of intracellular growth²⁷.

Since *L. monocytogenes* is a food borne pathogen in order to study this pathogen scientists must

replicate the cells of the human intestines. To achieve this Caco-2 cells are often used for experimentation with *L. monocytogenes* because they can imitate the cells found in the intestines. Over the summer I worked on growing and maintaining a flask of Caco-2 cells which were then used to perform three transwell experiments. Caco-2 cells are unique because they form a tight junction that is often tested with TER, or Trans-epithelial resistance, which measures the flow of ions from one side of the membrane to the other²⁸. The use of Caco-2 cells began when scientists started using the cells to study gastrointestinal tumors. Even though Caco-2 cells can imitate human intestinal cells there are still a few significant differences between these cells and real human intestinal cells. One main difference is that human intestines contain more than one type of cell. The second difference is that Caco-2 cells do not contain mucus and they can form a water layer on their surface²⁹. Caco-2 cells are not only used to study food borne pathogens but are also commonly used for the study of drug absorption. Using Caco-2 cells for drug testing is often recommended because it has proven to be more consistent to test on than actual human cells, which can vary based on the existing medical conditions of the hosts²⁸.

Post BSTI Reflection

I began the summer as student who was completely unexperienced in research, but I ended the summer with a plethora of knowledge regarding microbiology and *L. monocytogenes*. I learned how to perform a transwell experiment and I ended up performing three transwell experiments over the course of the summer. However, the bulk of my summer was spent performing a survival assay where I would test *L. monocytogenes* against mucin and antimicrobial peptides. This led me to eventually answer my initial research question of whether environmental factors have a significant effect on *L. monocytogenes*'s susceptibility. It was clear in my experiments that antimicrobial peptides affected anaerobic *L. monocytogenes* significantly more than aerobic *L. monocytogenes*. I was also able to learn how to perform a fibroblast plaque assay which again tested if exposure could change *L. monocytogenes*'s cell to cell spread. Although this plaque assay did not yield successful results, I now know how to perform one when the time comes in the fall. While I performed many experiments this summer, I also spent a significant amount of time performing lab chores including making plates, restocking pipet tips, and cleaning glassware. Even though I was not working on research when doing lab chores, I was still learning about how to work and function in a research lab. Along with all my learning successes this summer there were a few mistakes made along the way. For example, one mistake I made ended in my cells being lysed, or killed, which turned into a beneficial learning experience. Along with mistakes also came inconclusive experiment results like the fibroblast plaque assay I mentioned above.

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References

1. McGuckin, M. A., Lindén, S. K., Sutton, P. & Florin, T. H. Mucin dynamics and enteric pathogens. *Nat. Rev. Microbiol.* **9**, 265–278 (2011).
2. Kim, J. J. & Khan, W. I. Goblet Cells and Mucins: Role in Innate Defense in Enteric Infections. *Pathogens* **2**, 55–70 (2013).
3. Sheng, Y. H. & Hasnain, S. Z. Mucus and Mucins: The Underappreciated Host Defence System. *Front. Cell. Infect. Microbiol.* **12**, (2022).
4. Derrien, M. *et al.* Mucin-bacterial interactions in the human oral cavity and digestive tract. *Gut Microbes* **1**, 254–268 (2010).
5. Hoorens, P. R. *et al.* Genome wide analysis of the bovine mucin genes and their gastrointestinal transcription profile. *BMC Genomics* **12**, 140 (2011).
6. Delplace, F., Maes, E., Lemoine, J. & Strecker, G. Species specificity of O-linked carbohydrate chains of the oviducal

- mucins in amphibians: structural analysis of neutral oligosaccharide alditols released by reductive beta-elimination from the egg-jelly coats of *Rana clamitans*. *Biochem. J.* **363**, 457–471 (2002).
7. Mourad, R., Morelle, W., Neveu, A. & Strecker, G. Diversity of O-linked glycosylation patterns between species. *Eur. J. Biochem.* **268**, 1990–2003 (2001).
 8. Ohta, N. *et al.* Jellyfish mucin may have potential disease-modifying effects on osteoarthritis. *BMC Biotechnol.* **9**, 98 (2009).
 9. Huan, Y., Kong, Q., Mou, H. & Yi, H. Antimicrobial Peptides: Classification, Design, Application and Research Progress in Multiple Fields. *Front. Microbiol.* **11**, (2020).
 10. Zhang, Q.-Y. *et al.* Antimicrobial peptides: mechanism of action, activity and clinical potential. *Mil. Med. Res.* **8**, 48 (2021).
 11. Rima, M. *et al.* Antimicrobial Peptides: A Potent Alternative to Antibiotics. *Antibiotics* **10**, 1095 (2021).
 12. Boparai, J. K. & Sharma, P. K. Mini Review on Antimicrobial Peptides, Sources, Mechanism and Recent Applications. *Protein Pept. Lett.* **27**, 4–16 (2020).
 13. Bahar, A. A. & Ren, D. Antimicrobial Peptides. *Pharmaceuticals* **6**, 1543–1575 (2013).
 14. Lei, J. *et al.* The antimicrobial peptides and their potential clinical applications. *Am. J. Transl. Res.* **11**, 3919–3931 (2019).
 15. Epand, R. M. & Vogel, H. J. Diversity of antimicrobial peptides and their mechanisms of action. *Biochim. Biophys. Acta BBA - Biomembr.* **1462**, 11–28 (1999).
 16. Listeria (Listeriosis) | Listeria | CDC. <https://www.cdc.gov/listeria/index.html>.
 17. Farber, J. M. & Peterkin, P. I. Listeria monocytogenes, a food-borne pathogen. *Microbiol. Rev.* **55**, 476–511 (1991).
 18. Carpentier, B. & Cerf, O. Review — Persistence of Listeria monocytogenes in food industry equipment and premises. *Int. J. Food Microbiol.* **145**, 1–8 (2011).
 19. Carvalho, F. *et al.* L-Rhamnosylation of Listeria monocytogenes Wall Teichoic Acids Promotes Resistance to Antimicrobial Peptides by Delaying Interaction with the Membrane. *PLoS Pathog.* **11**, e1004919 (2015).
 20. Lindén, S. K. *et al.* Listeria monocytogenes internalins bind to the human intestinal mucin MUC2. *Arch. Microbiol.* **190**, 101–104 (2008).
 21. Ragon, M. *et al.* A New Perspective on Listeria monocytogenes Evolution. *PLoS Pathog.* **4**, e1000146 (2008).
 22. Hosseini, E., Grootaert, C., Verstraete, W. & Van de Wiele, T. Propionate as a health-promoting microbial metabolite in the human gut. *Nutr. Rev.* **69**, 245–258 (2011).
 23. Collins, S. M. *et al.* Development of a prebiotic blend to influence *in vitro* fermentation effects, with a focus on propionate, in the gut. *FEMS Microbiol. Ecol.* **97**, fiab101 (2021).
 24. Reichardt, N. *et al.* Phylogenetic distribution of three pathways for propionate production within the human gut microbiota. *ISME J.* **8**, 1323–1335 (2014).
 25. Rinehart, E. *et al.* Listeria monocytogenes Response to Propionate Is Differentially Modulated by Anaerobicity. *Pathogens* **7**, 60 (2018).
 26. Hobbs, L. *et al.* The Opposing Role of Propionate in Modulating Listeria monocytogenes Intracellular Infections. *Front. Microbiol.* **12**, (2021).
 27. Wallace, N., Newton, E., Abrams, E., Zani, A. & Sun, Y. Metabolic determinants in Listeria monocytogenes anaerobic listeriolysin O production. *Arch. Microbiol.* **199**, 827–837 (2017).
 28. Sun, H., Chow, E., Liu, S., Du, Y. & Sandy, K.-C. The Caco-2 cell monolayer: Usefulness and limitations. *Expert Opin. Drug Metab. Toxicol.* **4**, 395–411 (2008).
 29. Caco-2 [Caco2] - HTB-37 | ATCC. <https://www.atcc.org/products/htb-37>.

How We Free Ourselves: Contemporary Feminism and Freedom

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Abstract

This project will further seek to understand the connections between feminism and other sociophilosophical traditions that explore liberation, such as colonialism, neoliberalism, patriarchy, and misogyny. De Beauvoir in *The Second Sex* provides that the existential situation of women is different than that of men. I would add that the material situation of women can contribute to forming the fabric of freedom. Either by nurture or nature, we have a social situation wherein the oppression of people – the control and domination over people of many identities - is necessary for the world to function properly. What alternative story of history, or society, could be told when the structure of our world is no longer patriarchal? Competitive? Dominating? Or rigidly individualistic? The traditions of Marxism, radical feminism, anti-racism, anti-colonialism, and care ethic may hold a few of the answers to this question. My project seeks to draw upon the liberatory traditions of Marxism, anarchism, and feminism to reconsider our contemporary class context through the eyes of women. This project is to understand more deeply how a traditionally masculine project of control and domination perpetuates systemic disconnection, exploitation, and eventually the backwards movement of civilization. In doing so, I seek out the difference between men and women in how we free ourselves, and the pieces of freedom that man's existential and ethical story has overlooked.

Capitalism

Not only is Male Freedom based on female silence, but a man's life depends on the death of a woman. *Money, Sex, and Power*,

Hartsock, 1984

What is feminism when women have the right to work? To vote? To have credit cards? And has this led to our freedom? Has it led to the full development of all the desires of our mind, body, and spirit, as many feminists have hoped? Ask black women with children who are at the highest risk for eviction, when women are paid 83% of men's salaries on average (Gould, 2017), even while working an average of 10 additional hours in domestic labor (Chavda, 2023). Women gaining the right to supposed economic self-determination has counterintuitively resulted in quickly compounding alienation and the space for men to practice misogyny from the top-down. We must ask the question, is the free economy really as free it declares itself to be, or is it a tool for the white, the masculine, the oppressor to further compound his power at his own convenience. In any case, women's uncomfortable conditions in life have not been entirely alleviated by their right to participate in the economic world. My project seeks to draw upon the liberatory traditions of Marxism, anarchism, and feminism to reconsider our contemporary class context through the eyes of women.

When people work as we do, when people divide labor into bite-sized pieces, perfect for cold capitalist efficiency, when people work to make money for their superior and come home themselves empty, when they remain out of touch, estranged, and alienated from the thing they work for, from their fellow workers (as they are competition) and from their own independent desires, things get weird. Marx established in his philosophic and economical manuscripts a three-tiered conception of estranged labor, alienation from the product of labor, from fellow laborers, and from the self.

Self denial, the denial of life, and of all human needs, is its Cardinal doctrine. the less you eat, drink and read books; the less you go to the theater, the dancehall, the public house; the less you think, love, theorize, sing, paint, fence, etc., the more you save - the greater your treasure which neither mods nor dust will devour - your capital. the less you are, the more you have; the less you express your own life the greater is your alienated life - the greater is the store of your estranged being. (Marx, 1844)

People under capitalism are not made to be human people, but objects for the generation of wealth. The product of labor is taken and sold at exploit, consolidating the product of labor from the laborer and leaving him with barely enough to subsist simultaneously creating a compulsion within him to consume. The laborer is alienated from other people because he must understand them first as competition as labor is deskilled in escalation. The laborer is alienated from the self as all his energy is directed into putting money in his master's pocket. So the person is no longer a person, but an object of capitalism. I would argue the condition for women under patriarchy mirrors this alienation in her relationship to her keeper, her masculine counterpart, and is instantiated with a telos from birth, to be mothers and caretakers, people for other people; whereas men are encouraged to be independent, to make their mark on the world and continue to put money in the pockets of the capitalist.

Whereas the working-class man is alienated from the object of his labor because it is taken and sold, woman is isolated from the object of her labor because it can never be her own, for her, but rather must be for man. Woman is isolated from the object of her labor, she is tasked primarily with domestic labor which is conflated both with her personal morality and self-worth; the good woman in America is compelled towards endless service of people, primarily men. The object of her labor then is the social good, the well-being of her family. Often this translates to maintenance, to keeping house and children just as they look in every picture and magazine. She is maintaining the domestic expectation only so that she and her family will not experience shame, of wearing the same clothes to school, or having dirty clothes or unkempt hair. Inherent in this expectation is an unseen expectation for all people to maintain the same kind of house, appearance, etc. which has racial, class, and sexual implications in and of itself. But her labor is made invisible not only because it is primarily isolated to the home, and therefore, the eyes of only her husband, but also because it is not supposed to be exceptional work, only maintenance work. Not only is her work not entirely *for* her, but it is made invisible. If she is a member of the workforce, similar biases are carried into the place of work, for her to do more work with less visibility. Her work is entirely necessary, but entirely frustrated never to be seen. Her value is made to be only in the eyes of her husband, and he cannot see it.

Whereas men under capitalism are alienated from other working-class men because they are competing with one another, women become a private class (Mackinnon, 1989), a people confined to their household, or their social role in service of men. Although in recent history women have found avenues of female solidarity and companionship, for example women's guilds, leagues of female voters, sororities, the connections made under these circumstances are limited by her designated domestic purpose, which is always made to come first. Connections made under these circumstances will always be undermined by the disproportionate amount of labor assigned to women in the household, and the social pressure to care for others first. This is not for some biologically predetermined reason, but because men actively, if unknowingly? seek to practice sovereignty over women. This isolates women from each other and alienates them in service of him, first. Men understand their own freedom as the ability to institute their specific control and sovereignty over the woman symbolically and physically, as they maintain sovereignty over the world. Men limit woman's social circumstances to coerce her into his service. This coercion takes many forms that are worth

attention and which I will attend to later; without the social, physical, and economic protection of a man, woman is out in the cold, more vulnerable to eviction and homelessness, rape and sexual assault, impoverished circumstances of all kinds. This is freedom to man. In doing so, he created women as a private class, as individuals separated into households, overworked in service of the reckless independence of men. And so, women are confined to and by men. Men practice but ironically cannot see this.

Men seek to take away her individuality by confining her to a specific role in the world. Historically, much of this manifested in the relative imprisonment of women as domestic slaves, disallowing her from any serious participation in public life, from bank accounts and credit cards, to leaving the house on one's own; these were privileges women were excluded from. While in contemporary times, women work, and are not confined to the home and if so, this is a manifestation of privilege; nowadays, women are limited not by the prison of the home, but of being overworked. Most U.S. homes today require two incomes in order to make ends meet. The abuse of capitalism has dire consequences for women first and foremost. When she comes home from work there is laundry, dishes, lawn-mowing, and caretaking of all kinds waiting for her. Her male counterpart, although may contribute at her request, does not spend the time to maintain the same consciousness of social and domestic obligation that she feels compelled to, and so her mind and energy are directed towards holding the pieces of his life together, as well as her own, and that of her children. If she does not do them, or ask for them to be done, they do not get done at all. And so, her identity is lost, women are invisible in their labor, in their contribution to society, she is a person for other people only, and never for herself. She has no time to pursue a life outside of her contribution to her family, and so that is all that she is. Patriarchal capitalism effectively made men central and everyone else in service of that end, at too dire a cost. This is the condition of life for the woman. Men cannot see it.

In addition to physical and economic disenfranchisement, she is robbed of self-perception. She must translate her life in the terms of those that are central to the turning of the world, men. The stories of the world are created in man's image, in his terms, he is the victor that writes not only our history, but our advertisements, textbooks, revelatory novels, ethical guidelines, and our commonly held concepts of almost anything. The story of the world is made in man's image, the rest of us have to stretch to see ourselves outside of his eye. Women must always be seen but never by themselves, never with love or admiration or even indifference, always in the context of masculine capitalism. His eye has many names, Margaret Atwood called it the male gaze, Frye called it the arrogant eye, Foucault's Discipline and Punish elaborated what it means to always be seen by an enforcing other (Foucault, 1975), I call him the little white man in the back of my mind. Not only does her condition as a woman determine her life as more confined physically, in identity, but the reach of man is so great that she must always hold him in her mind as well. Men cannot see this.

Men under capitalism are unfortunately compelled to participate in the role of oppressor as people under capitalism. All people are isolated from the object of their labor under capitalism, nothing is ever owned unless we are actively eating, drinking, wearing, or otherwise consuming it. Private property is a fleeting thing for the working class, and so woman must always be at the disposal of man just in case he needs to feel as though he owns her once again. "Private property has made us so stupid and one-sided that an object is only ours when we have it - when it exists for us as capital, or when it is directly possessed, eaten, drunk, worn, inhabited, etc., - in short when it is used by us." Woman must always be practicing her submission, her tireless social labor, so as to always signal her submission.

If my own activity does not belong to me, if it is an alien, a coerced activity, to whom, then, does it belong? To a being other than me. The gods? (Marx, 1844). So what is a woman under patriarchal capitalism then? She is private property, she is the unseen, unheard, unacknowledged caregiver of the man and his things, but mostly she is always giving of herself. She is a glorified Roomba. Woman's activity is coerced for man, she is the sinner, he is the angry god, her cop, her most dangerous predator and lover. So they are stuck in a co-dependent dance where women are made to be selfless and men are made to be selfish. Then is created the woman's ascetic ideal, "But unless she completely renounces herself, swallowed up like a Natasha in a passionate and tyrannical Devotion to her family, she suffers from being reduced to Pure generality. 570" SDB. Unless a woman gives

her entire self for others, for her family, and denies her own desires and development completely she is no one. In either case, she is no one.

All of the world is organized to appeal to the masculine eye. The patriarchal organization of the world is something I will call *patriarchal anthropocentrism*. While women do social labor, men are making a mess of things. “The work of civilization has become increasingly the work of men” (Freud, 1930). Men are creating problems for the sake of creating a solution for which they are indispensable. Consider the charge of masculinity to protect and provide for the family. Let’s assume the family, in this case, means women and children of close proximity to any man. Who does he protect these women and children from? Bears? Sharks? Of course not, he protects them from other men, who make up 98% (Violence Policy Center, 2022) of homicide worldwide. This social obligation has nothing to do with contributing to the family and everything to do with asserting competitive dominance over other men. Providing, again, consolidates man’s obligation not to his family, but to maintain his competitive edge on other men in the workforce. For working class men this is alienating. Even so, the world is organized to create problems only he can solve. Men create social institutions from which women rely on him to protect her.

Men have since created social institutions to coerce women into becoming their private domestic servicers. Men codified in law social institutions to maintain women’s dependence on men. These social institutions continue to control and dominate with a tenet of fear, created to force women into the service of men. Without the acceptance of a husband, or another male counterpart, mothers seemingly have a painful and shameful walk-through life. Single mothers are isolated from the support women in a heterosexual marriage get, socially from peers, and financially from a second income, and often must seek insufficient welfare aid from the government in order to survive.

Much of what damages children in this case isn’t a maternal failure, rather, a maternal fallibility in a callous world. A mother has little control over her own economic, social, or physical conditions, a concept referred to as social impotence (Ruddick, 1989). Single mothers too often end up in poverty. With a single income and children to take care of, and without a reasonable social safety net, women are often forced to seek the acceptance of a man to ameliorate living conditions for herself and her child. This is yet another example of patriarchal anthropocentrism, a problem men created that only men can solve. To gain the power of social mobility, servicing a man is integral for the woman.

In order to maintain men’s dominance, man creates the rule of the free market, the family unit, and competition not only as rules for the state but rules for the social world, to govern the way we relate to other people. Neoclassical social theorists maintain that social interactions should be governed by the same rules as the free market, to create winners and losers, investments and opportunity’s, instead of fellowship among equals. To a neoclassical social theorist, society is a god to be begrudgingly whined to, to foist upon all of our shortcomings, and a pillar in creating in the limitations of our capitalist economy. The neoclassical propagates that our system of complex interdependence in modernity does not arise from any culture of shared interest, shared conditions, or fellowship; instead, it is a result of following the rules of conduct that emanate from markets and moral traditions. For the neoliberal, life is a competition not a team effort. The role, in this case, of a model citizen is to be free, self-sufficient, essentially “responsibilized”, to keep the burden of their needs off the shoulders of social welfare programs, or society, as neoliberal social theorists portray. Instead, social needs of the individual are to be met by the individual family unit. During the early stages of the neoliberal era in Margaret Thatcher’s UK, many social policies went into place to obligate economic responsibility on the shoulders of the family, and the individual instead of strengthening common social welfare policies. Child support, alimony, debt contribution, were part of a movement towards codifying familial obligations in law as an alternative to social welfare. This served effectively to create animosity among family, alienating the worker from a larger collective and pass off this social responsibility onto the “family”, or more accurately the mother (Cooper, 2020). Apparently, the family unit can and should be relied upon for social support, but not any other kind of social unit. Why is this? Because family is another word for mother which is another word for a woman who will always work tirelessly to create beneficial social circumstances for their family. Not only does this reality place that the mother as the property of the individual man, but also institutes generational poverty as so many families crumple under the weight of increasing debt. All this in the name of

self-sufficiency and the free market. Self-sufficiency only means the self-sufficiency of one man from another man. In a social support system of any size, families can be relied upon to make up the difference because of the labor of women. Women take the brunt of man's supposed self-sufficiency, because he does not need to be independent of her, she is his to take for granted. The idea of self-sufficiency in the first place is an entirely fictitious capitalist myth because no man can stand entirely on their own. "A being only considers himself independent when he stands on his own feet; and he only stands on his own feet when he owes his existence to himself. The man who lives by the grace of another regards himself as a dependent being." (Marx, 1844). This narrative undermines not only the interrelatedness of all humanity, but also the project of pregnancy by women. This is a great example of how women's contribution to life itself has been made invisible, in addition to her social contribution. Man's story of civilization has created an economic situation that destroys the common condition of man and twists it into cold-blooded competition, consolidates wealth among only the few, and both necessitates and incentivizes scarcity, a loser, a hierarchy to ensure the game has stakes. The patriarchal economy, then, is the expansion of the free-market to all spheres of life, competition and social-Darwinism becoming laws for life because they continue to compound and justify the dominance men maintain under capitalism.

So where does this leave women? Squeezed like an empty tube of toothpaste. Tired, working, always giving more for the well-being of their family to maintain social welfare. This is the social responsibility that women maintain, and men are disenfranchised from. This is the stuff of women, to care, to give, to be a part of a real social unit. Women do not divide labor in the way the market does, this is the only reason that capitalism works. Moreso, women are excluded from "consequential" opportunities and overworked, exposing them to economic vulnerabilities that make men necessary to their survival. Their options are limited by patriarchal capitalism to force women back into the service of men. Here, women become an extension of men as their entire social and domestic supporters. If only men were allowed to be what women already are.

This is why all women under capitalism become mothers. Many mothers walk through the world without masculine acceptance or support, they contribute to the common good of their social unit tirelessly, often to their detriment. "Mothering is the most courageous thing because women do it alone," (Dworkin, 1976). Dworkin puts motherhood within a conversation on the way the female existence is made to be fearful, lacking, and inadequate without satiating the eyes and needs of men. This is particularly true of single motherhood, but also for all birthing bodies and mothers. Motherhood, although constantly being isolated, changed, and smashed into the will of men, is a reminder that women have the power to create life. This is real, this is powerful, and Mothering is courageous. This inevitably inspires fear and fury in the hearts of men.

A Paper on Sexual Difference: What Men Cannot See

I've been longing to say this out loud — women are born with pain built in, it's our physical destiny — period pain, sore boobs, childbirth, you know. We carry it with ourselves throughout our lives," Belinda says. "Men don't. They have to invent things like gods and demons... they create wars so they can feel things and touch each other... and we have it all going on in here. Inside, we have pain on a cycle for years.

Waller-Bridge, 2016

How does the condition of women under patriarchal capitalism continue to be so awful, yet so unseen? Women are made to be people for other people. The feminine teleology, to be people for other people, is visible in the condition of woman as object, to be a living doll, a thing in service of man, as opposed to men as the subject of all things real, or consequential (DeBeauvoire, 1949). The woman is taught not to exercise her freedom, not to understand herself as a person with independent desires, to squash her curiosity and energy for herself in the world and instead to be a servant of men, to pick up the pieces of the world left in the wake of their reckless "independence". Women serve to create the conditions domestically within which men can practice their full development, Men cannot see this. The social conditions of women can be understood well through this lens. I do not intend in this essay to explore the biological nuances or existential complications of womanhood; I want to examine the psychoanalytic and socially constructed difference of gender and how people

assigned female at birth respond to the charge of their gendered expectations. I assert that gender difference comes from proximity to procreation, women have an inherent relationship to the product of procreation, and men assert a social right to the product of procreation; this discrepancy creates a vengeful motivation for men to dominate and control women.

Jennifer Allen defines mother as “she who produces for the sake of men”. She universalizes the term mother, as woman under patriarchy, who exists as the womb and wife of man (Allen, 2002). Every woman, in this case, is by definition a mother. Allen is not critiquing motherhood as complicit in patriarchy, rather, that male sexuality appropriates women’s biological possibility for the sake of reproducing other men. Other scholars, including Sara Ruddick, use the term maternal work to universalize the practice of sacrificial child-centered labor to all people, without implicit gender. This may include fathers, adoptive parents, teachers, nurses, and all those who practice motherhood under patriarchy (Ruddick, 1989). Mothers in many indigenous societies are revered, as their sex allows them the power of life (Johnson, 1988). Under any definition, a woman’s body is indubitably where people come from, and this is real, important, and undeniable. For a child, a mother is an audience, a provider, an all-powerful being with the ability to give and take everything necessary for comfort and survival. Even so, women’s work as mothers is invisible.

For a child, a mother is everything. A mother is the only way for an infant to meet basic physical needs, she is the first experience a child will have with giving and receiving love, with understanding love as care, and eventually, she is the primary executor in the child understanding itself. Particularly in the primary stages of infancy, a child cannot tell the difference between self and mother. This is called the *psyche-somatic* period in which a child has no sense of separation of any being, particularly the separation between themselves and their mother (Holloway, 2006). A mother meets any and all of her child’s needs, and a child is entirely dependent. A mother to a child is all-powerful. All children, regardless of gender, learn to identify with their mother and depend on their mother. Even before a child understands self and other, a child understands a negotiation, between mother and self, for needs to be met. A child must cry to gain his mother’s attention, he must communicate his needs for them to be met. The infant learns to play a reciprocal dance with his mother, conforming to a system of norms, values, and expectations he does not set for himself (even before he has a concept of self) (Parson, 1958). These expectations are outside of, or different from his own needs. A child must jump through hoops, so to speak, for his own comfort and survival. There is tension in the dependence of Man on his mother: from birth a mother enforces expectations and symbolizes a denial of self-determination. Mothers, in actuality, are the buffer between their child and the world. Mothers symbolize to their child the limitations and burdens that the world provides. She cannot read his mind, she cannot always provide him food, or exactly the food he wants, the child must *do* things in order for things to *happen*. This is new for the child, and it is represented by the mother. Through early childhood and adolescence, children experience the limitations of life as mothers seek to facilitate a child’s socialization into the world. Even as this can be understood and somewhat corrected in adulthood, I believe the impact of this relationship is important in understanding male resentment, imprisonment, the taken-for granted service of women. This tense relationship is a reason for the retributive spirit men hold for women; even before a child has an understanding of self, a mother is all powerful, and represents the limitations and conditions of life that subvert his own will and desires.

This negotiation, as it progresses, must consistently fail for the child to develop a sense of self. A child must understand their own distinct needs as separate from the will of their mother in order to understand themselves as a separate being. This process is called differentiation, where a child learns to differentiate between itself and other (Holloway, 2006). The psychoanalytic approach to motherhood often creates the mother as an all-powerful other, or as a mirror a child looks in to confirm their own identity without any interference from her. Adult Women, often serve as a looking glass for adult heterosexual men, possessing the adored power of reflecting the figure of man at twice his natural size (Johnson, 2014). Mother and partner are seemingly never recognized as a person in and of themselves. As a child develops a sense of self, Mothers can either be a frame of reference for understanding self in the world, a set of boundaries and expectations to be played with in testing the waters of life, as explored earlier, or a tool for meeting one’s own needs. In either case,

mothers, in their male child's eyes, do not have independent desires, ideas, or wills. Walter Benjamin refers to this as false differentiation, when a child understands his own needs and desires as real, important, and dynamic, but those of his mother only as serving his own (Benjamin, as quoted in Holloway 2006). Male children can develop in a way that does not acknowledge the humanity of others; this perception creates misogyny. When a woman, a mother or otherwise, breaks down this façade, when she has ideas aspirations or needs independent of his, the response is hatred, anger, and apathy -- misogyny. This false differentiation creates the motive for the institution of sexual difference, the forced identity of women as merely an extension of the man. Men are constantly seeking to press women back into the symbiotic identity, this time as their servant not their dictator.

Often these answers serve to blame women's mothering for male misogyny, but I would encourage instead examining male patterns of differentiation and domination.

Misogyny implies psychoanalytic conceptions of gender differentiation and the creation of distinct identities. As gendered expectations are created and enforced, the edifice of male hatred towards women is formed. Men, as they differentiate and grow older, are urged to establish their own identity, apart from that of their mothers. Daughters, on the other hand, are allowed and encouraged to continue identifying with their mother (Kittay, 1988). Perceptions of motherhood and woman can be reflected to the child in the dynamics of the household, and so the male child, in a formative period, is either encouraged towards seeing mother as an equal, role-model, with independent desires or decidedly not. Mother can become something detestable, a tool for meeting needs, more so, an obstacle in meeting needs, or only relevant when she crosses the line of vision. This particular kind of absence can thrive in a young mind if it is what she is perceived and treated as by others in the household, particularly the other men. A child notices touch, voice inflection, the way mother acts differently when father is around; these slight changes in tone indicate gender roles, relations, and expectations to a child. This urges the male child to create a personhood outside of and principally apart from identifying with their mother. This internalized male otherness, independence, is crucial to the formation of identity for men but not for women.

The female child does not feel the need to be identified away from mother. Instead, household shame of maternity and womanhood are conflated with her own identity, and translated as shame and self-hatred as she identifies mother with herself. Toni Morrison wrote "A daughter is a woman that cares about where she came from and takes care of them that took care of her," (Morrison, 1981). Holloway wrote "Women must grow out of their childish narcissism to take care of a selfish thing like a child" (Holloway, 2006). Women and girls grow up constantly adjusting to the idea of pregnancy. It does not begin at marriage, or conception, or when a mother starts to show, or when she feels a baby kick. Women are socialized to become mothers; to take care of younger siblings, to play with dolls, and importantly to practice the unconditional emotional labor and social responsibility for all those around them. Therefore, the daughter begins to take on the role of Mother *from childhood*. She internalizes the shame, the burden, the grief, and joy of carrying social and emotional responsibility. The son has the charge of creating his own identity, in spite of and different from the maternal figure and responsibilities. A male child, as he does not identify with the roles and responsibilities of the mother, instead detests them, as they have served to limit him. To him, that's women stuff. From here, men are doomed to always perceive women as unidimensional creatures existing only for their own providence. Simultaneously, though, as they grow up, they are intimidated by her power over them and seek to take her maternal labor under their control. A mother's power and control becomes the ground for retribution as son becomes father.

Women's ability to create children is the *true* basis of gender difference, not potency (penis power), as Freud suggests (O'Brien, 1983). O'Brien sees women and their offspring as the central phenomenon in reproduction and men's ability to impregnate as secondary, because it is alienated from the process of birth itself. A man's relation to his child is a social right, while a women's relation to their child is a physical necessity. Therefore, men create social institutions to isolate women, to undermine the power that women have by their proximity to life, in retribution for this inequality. Pregnancy and motherhood *must* become handicaps in order for men to have control over their descendants. Womb envy is man's motivation for civilization.

The modern appropriation of pregnancy for male ends began in the medical industry. As our world became more scientific, at least theoretically so, women's health, and particularly pregnancy was appropriated not as an ability, but rather, a handicap (Ehrenreich, 1981). The guiding rationale for women's health was relatively simple: women are sick, and it is the task of every man to heal them. The primary agitator for this sickness is the uterus, widely considered the defect of womankind. From this came the concept of medical female invalidism, positing motherhood and child-bearing capacity generally inhibits a woman's full existence as a person (Ehrenreich, 1981). "If we wish woman to fulfill the task of motherhood fully, she cannot possess a masculine brain. If the feminine abilities were developed to the same degree as those of the male, her material organs would suffer, and we should have before us a repulsive and useless hybrid" (Moebius, 1907). Maternity in this quote, and at this time, is seen as not a strength, but a barrier, a weakness, a sickness that condemns a woman to a life without education, exercise, or equal status. Here, men have diagnosed the capacity to create life as a brokenness. Rather than commanding the respect of their child or husband, a learned, or ambitious woman endangers herself and her family. Women were made to be perverted, misguided, sick, or deluded from their so-called "biological destiny" if they acted outside of their role, or even took pride in it. The social institution of pregnancy care was reorganized to be masculine centered. Not only was this male centered, but it was also for the ease of masculine perception. Men were dismantling a challenge to their supremacy, as pregnancy and child-rearing is a reminder of their lack of ability to create life. Pregnancy must be made to *look* like a disability to their eyes, so as to avoid any kind of potential threat to their control, authority, and status.

The compulsion for men to be selfish, to turn their eyes away from the endless invisible service of their female counterparts, and eventually to enforce this domination on women, is the consequence of a problem of ego, a subconscious masculine shortcoming: womb envy (Horney, 1967). The insatiable appetite of men to rewrite women as their subordinate, to exclude her from the public life, comes from the male envy of pregnancy, nursing, and motherhood- of woman's primary role in creating and sustaining life. Women's capacity to create not only life but breastmilk means all children understand her as the being that satisfies hunger. As men differentiate, understand their identity as distinct from their mother, and later in adolescence as they understand their lack of this capacity, envy and resentment grow. Women then become an object of envy for men, from infancy, as they contain the stuff of life – so to speak. This envy, the subconscious shortcoming, is what leads to the perversion of men towards domination and control of all things, particularly women. Men in adolescence and adulthood seek to privatize women's capacity for life for their own use, to compensate for their own shortcoming, and so create the social role of women as a subordinate supporter of the man and child within the household, as retribution. And so, the desire from men to dominate and control women, in addition to the rest of the world is a manifestation of womb envy. Women as a powerful thing, must be kept, hidden, disempowered, entirely privatized and alienated so that men can maintain their power and ego.

So what are her options then? She can lie down and take it, accept her fate of male subservience in exchange for the life she could have had, or she can reject it and end up vulnerable to the retribution of resentful men. Is she only identifiable or understandable in masculine terms? As a victim, a giver, a person for other people? To filter one's presentation largely through the eyes of men, it is required of women to signal their docility and acceptance of their situation by smiling, being generally good-natured in all situations, and participating in their own erasure. Or, she can be truthful in her frustrated walk through life or even rebellious and risk being labelled as difficult, endangering professional career, or even more dire consequences like rape, assault, arrest, or murder. It's an invisible system of limitations imposed upon women by men. So, I return to the wisdom of Simone De Beauvoir. She says *one is not born, but becomes a woman* (Beauvoir, 1949). Understanding and responding to this set of conditions is the catalyst for sexual difference, and for liberatory wisdom. Men practice oppression of women, and women respond to it. Men cannot see this.

Dworkin in *Right Wing Women* provides an interesting commentary on how the performed acceptance and submission to patriarchy provides avenues for women to liberation and self-determination. If women accept the patriarchal conditions she can pursue her own thoughts, goals, and desires even of her gendered expectations. She asks the questions about what the acceptance of patriarchy can

provide for women in terms of solidarity and mobilization, always perpetuating the somewhat sad irony that anything women can have for themselves is always encumbered by the domination of men, as they are committed to maintaining it (Dworkin, 1983). Even so, it is a compelling conversation on the ways women make themselves free, even while under the thumb of man's domination.

Frye provides a conversation on a concept of separatism (Frye, 1983). The nature of oppression in all cases can be made visible through the oppressor excluding the oppressed, and reversing this limitation is a form of liberation. It means stopping the one-sided flow of goods and services that women provide. Separatism as Frye presents it can take the form of complete denial like divorce, or lesbian communes, but it can also refer to when women stop doing the dishes, or suspending any number of sexual and domestic services that she provides. Denying men access to women not only blocks the benefits men receive from women, but also demonstrates her assumption of power. A slave who disallows her master from entering her hut make herself no longer a slave. For women to separate, to deny men access to them means they can grasp some of the power they truly hold, and make their contribution more visible.

Eroticism for Lorde is one of many things' women are not supposed to take hold of for themselves. The erotic is constructed in patriarchal terms as an act of domination for men and passive even painful submission for women; for women all things sex is a source of shame, and a natural indicator of her inferiority. To look away from one's own feelings of any kind is to deny self-realization and full development, to deny joy and energy. This patriarchal, capitalist, story of sex makes women out only to be passive, if not coerced or forced participants in sexual contact of any kind (Lorde, 1984). To engage with one's own departure from the defeated, neutered place for women in sex is to engage in energy that is distinctly female, anti-rape, and self-affirming.

Anger, for Lorde, is a manifestation of the grievance that we deserve better, of intense empathy, of the return of self-respect after it has been stolen or bullied away. She calls upon an asymmetry of anger, when she refers to the purposeless anger it is often pride, defensiveness, or fear constructing a wall upon which "we all flounder" (Lorde, 1984), but anger as it is seen or reconstructed truthfully, for all the change in solidarity and self-realization it can inspire, is a source of freedom and growth. Women are made to feel as though anger is not of or for them because it has shown an ugly and fearful face in the actions of men, as a tool to maintain their own oppression, but when it is recognized as an integral piece of the response to oppression it can be an important reflection upon the self and solidarity. Female rage is one of the many faces of freedom that can bring us together.

I believe women's wisdom can be integral in making all of us free, particularly because it has been gratingly invisible for so long. A distinctly feminine understanding of freedom is important.

Defining Freedom: Womans Radical Freedom

If it were true that sovereignty and freedom are the same, then indeed no man could be free, because sovereignty, the ideal of uncompromising self-sufficiency and mastership, is contradictory to the very condition of plurality,

Arendt, 1958

Freedom is illusive, it's a shape-shifting face of hope, it's about the inside and the outside, the divine the material and everything in between. Freedom is theoretical when it can be, but when it's gone it becomes inescapably material. Freedom is slippery, while so many people live in search of it, but it can only be conceptualized outside of the realm of hard and fast rules, and experienced for oneself. Sometimes freedom can best be seen in the negative, the shadow of what it's not, freedom is not slavery, it's not exhaustion, it's not frustration, it's not submission. What is freedom? What does freedom do? How does freedom act? Is freedom a riot? Is it the man that patronizes a prostitute or the woman providing the service? It is a free country, after all. There are so few concrete conceptions of freedom, but it is a symbol of progress throughout so much of human history. Because of the social situation of women, freedom for woman has to be different than freedom for man (Zerilli, 2005). My words here are to make a distinction between the freedom of men and the freedom of

women. *Man's freedom is freedom from and to other people insofar as he doesn't have to think about them, woman's freedom is freedom to self and free association.*

This is not all of what man's freedom is, often there is a common acceptance of anti-authoritarian, liberal freedom that most people can see and agree upon, a general consensus of non-intervention or obligation that we cast as the extent of freedom. I would say not only is this incomplete, but a distinctly masculine concept of freedom. Freedom cannot just be the freedom of one person from another, it is not *just* a lack of restraints. Often this freedom is conflated with the idea that liberty ends at the end of your nose, the self-sufficient, self-determined approach to freedom untangled from the tiresome conversation of social obligation. This is a masculine concept of freedom because it is conceptualized in terms of self, and in the vision of the masculine promise. This promise is a promise of independence, the ability to make your mark on the world unencumbered by any participation in the social, or domestic sphere as it is cared for by the wife or mother. Inherent in this concept of freedom is the entitlement to the invisible service of women, to make oneself a free agent in this way is to deny the interconnectedness of all life, to create the free as theoretical and ignored privately.

Implicit, then, in the masculine concept of freedom is the sovereignty over women, children, and all the world outside of the sovereignty of men. Sovereignty is often conflated with freedom especially when only men are in the room. Freedom means the freedom to buy a hooker, to mow your grass and kill rats, to a clean sink and eat a home-cooked meal at the end of the day. Freedom is the ability to ignore the wide swaths of people who are different from you, who contribute to your access to these objects of freedom. Freedom, in short, is freedom *from* a life of social responsibility. This freedom is not freedom at all but sovereignty, it is the practice of control and domination men institute in order to unlimit, or free their own lives. They cannot be troubled to find genuine connection and so there is an industry just for him where women are coerced into providing their sexual services for money, most of which does not go to her. Without her suffering, he is not free. Without the invisible labor of women, men can never be free because his freedom is *to* her. Where the masculine promise of freedom is primarily because it divides us, this concept does not compound our liberty but in fact decimates the access to freedom.

The fight for freedom, for liberation from oppression for women, immigrants, religious minorities, and people of color did not come from this masculine promise of freedom, to be unhindered by the ties of social obligation, rather, it is precisely from the strength of hope for freedom found in the multitudes of people embracing their social responsibility that we find the benevolent face of freedom. People who found their freedom in the task of social responsibility, in the energy of the pluralities of people combining their hopes and wishes for a more free world is when freedom can have consequences for all. This is not the blinded freedom of men. Freedom is a practice, not a property of the subject. Free association is the face of liberation.

Not only is free association important, it is essential if people seek to pursue full development of their purpose, if they are to be free in material but also in existence. Free to pursue their hopes and desires. Social responsibility is integral to the ability to reach these goals.

From the eyes of man, freedom begins where politics ends (where the public ends), in the private life. Women are made to be a piece of the private world exclusively, so how do we get free without the space to imagine ourselves in the public eye? Arendt's space of appearance, the common space for freedom, makes up the stuff of liberation. People can only become free with the strength of the plurality. This is part of why women's liberation is so miraculous in the first place, its unladylike to be strong, or to have independent desires, to seek these things in the public realm is far too indelicate for many women to overcome. So is women's freedom private? Personal? Capitalism splits people up into their theoretical self, their public self which can be projected as a false amalgamation of identities one holds, into the realm of ethics and political philosophy; then there is the personal, the place where man actually lives his life. This alienates the worker from other workers, but also is the only place where woman can really exist as she is isolated from the theoretical public life. But in this denial women found freedom by unity in social position.

Motherhood and Epistemology: The Eternal Other

The symbolic debt towards the mother that is the woman who support us in our desires must be paid in a visible public social manner before the eyes of everyone women and men.

De Beauvoir, 1949

It is difficult to speak precisely about motherhood. Overcome by grateful greeting card sentiment, it is troublesome to speak dispassionately about the significance of maternal work. On top of that, the language of male-centrism is so routine it undercuts any attempt to define the mother without the context of a man. The western philosophical tradition presents a clear contempt, or at least ambivalence toward women, their bodies, and their life-giving abilities (Ruddick, 1989). This contempt for the distinctly female character of birth forsakes the symbolic, emotional, and political significance of the common denominator of human experience. This contempt feeds on a philosophical tradition that honors mind over body, idea over matter, and word over the bloody, humble, mortal flesh. Fear and contempt for female procreative bodies results from this tradition. Why is this?

I will not define mother comprehensively as many of other scholars have, rather, I will make a distinction between maternal and birthing labor. Mothering, or maternal labor, is an ongoing, organized set of activities that require discipline and active attention for the overall goal of preservation, growth, and social acceptability of a child. Birthing labor is everything a woman does to protect and sustain her fetus (Johnson, 1988). In what follows, I will be discussing Maternal labor and its consequences. Importantly, though, these concepts are distinct for the sake of clarity, but are certainly not, in practice, separable. Most women who mother are also women who birthed (Bion, 1961), and the inherency of life to a woman's body is central to my argument. Mothers, and women, are people who recognize the significance of social labor.

Marilyn Frye defines the arrogant eye as men seeing all things in relation to themselves and their interests. The arrogant eye sees everything as a resource for their exploitation. The way one is perceived and the way one acts is in tight interdependence (Frye, 1983). Women, instead of being perceived as relative equals with the capacity to create life, are maimed, coerced, and exploited to serve men and their interests. Motherhood is an inevitability, and a disability for women in the western world. To the eyes of men, women exist to give their husbands children, and to give their children life. Relatively, as mother is perceived to exist only for the child's needs, without their own independent identity, they will grow to perceive not only all women, but all "others" in the world as objects to meet their needs. Without acknowledging their common humanity, mothers and others are not to be learned from but to be identified against, or without. A mother becomes the loving foundation from which a man creates his identity, or, more often, the imperfect career woman, the mom who reads too much, the feminist, the nagger, the woman with interests and needs of her own who a man miraculously creates himself in spite of. A woman can either be a mother for her husband and children, or anything else for herself; never both, at least while maintaining social acceptability. This incomplete, male-centric narrative of women is reflected in the household and the impacts the differentiation and socialization of young men. Men cannot identify relationally, they must be independent, a man of their own, in spite of all circumstances. Women's unidimensional presence, their social and emotional service of men, is another justification for men's social attempt to gain control of women's maternal work and care. If men can limit women to pregnancy and domesticity, they can simultaneously invalidate her from a voice in every other part of life simply because this is not what she chose.

Often in the conversation on sexual difference, and human nature the question comes up, is this what people *do* or is this just what people are *doing*? What of this cage of domination and submission, of capitalist hierarchy is just how people are, and how much of it is what we do because of the false scarcity of capitalism?

John Burrows has stated that experimental study of animals in captivity is absolutely useless. their character, their habits, their appetites, undergo a complete transformation when torn from their soil in field and forest. with human nature caged in a narrow space, whip daily into submission, how can we speak of its potentialities?

Freedom expansion, opportunity, and, above all, peace and repose, alone can teach us the real dominant factors of human nature in all its wonderful possibilities. (Goldman, 1972)

Human nature here is dissociated from the typical context, the “that’s just what people do” perception of human nature. She challenges the idea that what people *do right now* is what people *are and will be forever*. What is human nature without the distinct inhumanity imposed by capitalism and the state? This is part of what I’m trying to answer. How can human nature be even imagined when everyone has to ask to use the bathroom from the age of 5? When we herd children by bells? When there are no tools of community or critical thought to be had, only fear of poverty, and the long arm of the state, creating alienated thoughtless laborers, ripe for working. It should be of no surprise to anyone that so many feel the need to dominate and control, between the state and the market no person has any choice in the trajectory of their lives. Capitalism creates the predicate of human nature in its own image – selfish and distrustful.

The patriarchal capitalist has created a system of domination over women, in response to their lifegiving ability. He has both robbed her of free association, among many other tools of liberation, and also obligated her with the entire task of social responsibility and welfare. The only response is anarchist, and communist. The response is firmly footed within what it means to be “mother.” The mother knows people would give of themselves, if only given the chance. She knows and sees the entire world as a subject, not an object. She encourages the full development of every person. She, single-handedly, creates the social circumstances for capitalism to work, and the proof that anarchism will work. To oppose the domination she has experienced, she sees a world where everyone contributes socially, and this is their primary charge. She no longer sees the need for the systems of man that institutionalize social obligation or lack thereof, but instead sees a future. In the age of automation and alienation, only mothers can create the tools of freedom.

From the initial conception of gender, women begin to carry the roles and expectations of motherhood. As discussed above, women are socially identified and defined by their relationality, and particularly, their status as mothers or mothers in training. If women are primarily identified socially, and specifically limited by their capacity to create life, what does it mean for a woman to *freely* choose pregnancy? Is it possible? It would be hard to dispute the claim that contemporary women are raised to be, and somewhat limited to be mothers. Even though this identity currently holds little social capital, limited benefits, and especially more burdensome home-life for women, for many women, children seem not like a choice but an inevitability. A woman’s social situation is changed from her own birth to train her for motherhood. Frye’s definition of coercion is to change a situation to limit options, so that she, the subject, does what is desired by the coercer (Frye, 1983). Public narratives of motherhood, womanhood, and pregnancy create social conditions which limit women to “choosing” pregnancy. Using this definition under contemporary patriarchy, women are coerced into pregnancy. It seems as if pregnancy under patriarchy is both coercive and exploitative. Frye identifies exploitation as the disintegration and reintegration of a subject’s parts to serve the exploiter (Frye, 1983). The exploited changes their habits, skills, schedules, values, tastes to serve the exploiter as opposed to their own purposes, needs or comforts. If we place instead of the exploiter to an exploited, a husband to their post-partum wife, these definitions fit well. A woman is physically, socially, and mentally rearranged to care for something that does not align with, care for, or acknowledge her own wants and needs, rather sees her utility as a caretaker for his sons. When perceptions of coercion and exploitation of Mother are shared by both father and son, the infant is forced to see his mother not as an entire person that he is related to, rather, as a tool to provide for his needs. For a son, looking up to his father, the coercion and exploitation practiced are idealized as Father has broken the oppressive control of Mother for his own needs and comforts. Father has achieved all the retribution, control, and domination the son could imagine, and sees it playing out before him in the home. So, it becomes the private aspirations of men to coerce, exploit, and control the capacity of women to make and maintain children.

The fear of women and female bodies is all-encompassing. So much so, that western conceptions on what it means to be reasonable are snarled together with a fear and resentment of birthing bodies. The female body is a fearful complement to reason. “I will greatly increase your pangs in childbearing; in pain you shall bring forth children, yet your desire shall be for your husband,

and he shall rule over you” (Genesis 3:16). Men in their wisdom, their theories on creation in this case, create female childbirth alongside the creation of sin, and justification of women’s submission. Bodily beginnings, and some women’s participation in them, stand for all that reason is not. While men have an entire 66 books to understand their ethical framework and obligations in life, women are charged with the simple tasks of painful birth, monogamous desire, and submission. When birth figures in reason’s story only as an absence, the birthing woman is silent. When birth figures in reason’s story as a transgression, the birthing woman is a mother. The body is enforced here, and with divine authority, as a distraction, a disease for the overall purpose of ascetic fulfillment, a scheme much of western wisdom is predicated upon.

I encourage a different process and perspective for the acquisition of knowledge than that based on detesting physical bodies. Knowledge and the acquisition of it is not disembodied access to universal reason, but participation in the game of particular communities and sets of values. The concept of the self is not and cannot be developed as individual in isolation, but a set of experiences made up of interactions with others; what is a student without a teacher, a Sonny without a Cher, a preacher without a choir. These ideas are discussed at length in *Motherhood as Metaphor* (Fletcher, 2013). At the forefront of these is self and the mother. Knowledge and the accumulation of knowledge should not be examined as if it is a detached and socially careless body of facts, but would be better understood as *economies of knowledge*, as different traditions of wisdom created and developed through various methods over time. The word economies indicate the ways knowledge, and its methods can be used to qualify some traditions over others. The production and reproduction of knowledge is an important part of motherhood, as they act not only as physical reproduction but also social reproduction. As it is examined in the interreligious context, women and mothers create a story of the world for their children that is relational. As discussed by Fletcher, Many Islamic women were not allowed to worship in the Mosque as the men did, so instead handed down their theological wisdom informally, through stories, cultural traditions, and rituals in the home. Judith Plaskow, a Jewish poet writes about a home-based liturgy in the Jewish tradition as a method of socializing children to the metaphysical and historical outlook of Judaism. Many traditions of African descent are based on women’s vocal and physical movement, some of which survived the middle-passage (Fletcher, 2013). This form of knowledge is resilient, important, and it is motherhood. Traditionally, women’s knowledge has been passed down informally, and in ways that have been discredited by contemporary western epistemology. Truth, in the western enlightened sense, is an individually isolated journey for a detached, isolated truth. Fletcher encourages us to reconsider the concept of the self and truth under social and matriarchal conditions. We should imagine ourselves as beings who are characterized by our otherness, by our relation to others, and our responsibility to others as mothers do. Truth should not be characterized by shame or a desire to depart from one’s physical presence, rather, all knowledge should take on a character of social awareness by acknowledging their relationship to others.

“When we love children, we acknowledge by our every action that they are not property, that they have rights—that we respect and uphold their rights” (Hooks, 1994). The perception of mothers, of women in control, at childhood creates a resentment towards mother and towards life masculine children try to overcome by forcing women into submission. In Fatherhood, this is reflected as creating social conditions that force women into the service of men, so that their maternal labor is for men, no longer for the purpose of procreation but simply because she had no other choice. Men maintain a vengeful spirit, both from the hegemonic control their mother maintained in infancy, and for her proximity to the creation of life. In reaction, men create social conditions within which it is impossible for women to live without the dependence upon men. Of these scholars I studied, some suggest the solution is to be more aware of our nonrelational and unconscious biases, to unseat the man from the back of our minds and pursue courageous motherhood with or without the promise of submission, and for men to take real social responsibility. But I feel the need to call attention to the fact that mothering doesn’t have to be a promise of submission, of pain or shame, as our story of society has made them out to be. These conditions are not inherent to womanhood either, and it’s important for our daughters to know this. Children are born with empathy, with a feeling of interconnectedness and social responsibility that is trained out of them by a responsibility first to self, individual, and the project of dominance. We as people, young and old, long for a realization of

social context. Often control and domination are put in place of this interconnectedness, but it will not suffice. In the context of patriarchy, I believe the obligation of all people is to tell many stories of mothers and others, and never to sacrifice any part of oneself for the project of dominance. Small feet follow in our footsteps.

References

1. Allen, Jennifer. "Motherhood." 2002.
2. Arendt, Hannah. *A Human Condition*. MIND, 1958.
3. Beauvoir, Simone De. *The Ethics of Ambiguity*. 1947.
4. Bion, Wilfred Ruprecht. *Learning From Experience*. Karnac, 1961.
5. Chavda, Janakee. "In a Growing Share of U.S. Marriages, Husbands and Wives Earn about the Same." *Pew Research Center's Social & Demographic Trends Project*, Pew Research Center, 14 Apr. 2023, www.pewresearch.org/social-trends/2023/04/13/in-a-growing-share-of-u-s-marriages-husbands-and-wives-earn-about-the-same/.
6. Cooper, Plehwe, et al. "Neoliberalism's Family Values: Welfare, Human Capital, and Kinship." *Nine Lives of Neoliberalism*, Verso, Brooklyn, NY, 2020, pp. 95–119.
7. DeBeauvoire, Simone. *The Second Sex*. Librairie Gallimard, 1949.
8. Dworkin, Andrea. *Right - Wing Women*. Coward-McCann, 1983.
9. Dworkin, Andrea. "The Sexual Politics of Fear and Courage." *Our Blood*, Harper & Row, 1982, pp. 51–65.
10. Elinor, Ostrom The Late. *Governing the Commons*. Cambridge Univ Press, 1990.
11. Ehrenreich, Bárbara. *Complaints and Disorders; The Sexual Politics of Sickness*. The Feminist Press, 1973.
12. Fanon, Frantz, et al. *The Wretched of the Earth*. Grove Press, 1961.
13. Fletcher, Jeannine Hill. *Motherhood as Metaphor Engendering Interreligious Dialogue*. Fordham University Press, 2013.
14. Foucault, Michel. *Discipline and Punish: The Birth of the Prison*. Vintage Books, 1975.
15. Freud, Sigmund. *Civilization and Its Discontents*. Warbler Press, 1929.
16. Friedan, Betty. *The Feminine Mystique*. W. W. Norton & Company, 1963.
17. Frye, Marilyn. *The Politics of Reality: Essays in Feminist Theory*. Crossing Press, 1983.
18. G., Zerilli Linda M. *Feminism and the Abyss of Freedom*. University of Chicago Press, 2005.
19. Goldman, Emma, and Alix Kates Shulman. *Red Emma Speaks: An Emma Goldman Reader*. Humanities Publishing, 1972.
20. Gould, Elise, and Adriana Kugler. "Latina Workers Have to Work 10 Months into 2017 to Be Paid the Same as White Non-Hispanic Men in 2016." *Economic Policy Institute*, 1 Nov. 2017.
21. Graeber, David. *Fragments of an Anarchist Anthropology*. Prickly Paradigm Press, 2004.
22. Haraway, Donna Jeanne. *Cyborg Manifesto*. The Socialist Review, 1985.
23. Holloway, Wendy. *The Capacity to Care: Gender and Ethical Subjectivity*. Routledge, 2006.
24. Hooks, Bell. *Feminist Theory: From Margin to Center*. South End Press, 1984.
25. Horney, Karen, and Harold Kelman. *Feminine Psychology*. Norton, 1967.
26. Johnson, Allan G. "Why Patriarchy?" *The Gender Knot: Unraveling Our Patriarchal Legacy*, Temple University Press, Philadelphia, 2014, pp. 49–72.
27. Johnson, Miriam M. *Strong Mothers, Weak Wives: The Search for Gender Equality*. University of California Press, 1988.
28. Kittay, Eva. "Woman as Metaphor." *Hypatia*, 1988.
29. Kropotkin, Peter Alekseevich, and Paul Avrich. *The Conquest of Bread*. New York University Press, 1892.
30. Lorde, Audre. *Sister/Outsider*. Crossing Press, 1984.
31. Hartsock Nancy C. *Money, Sex, and Power: Toward a Feminist Historical Materialism*. Northeastern University Press, 1983.
32. MacKinnon, Catharine A. *Towards a Feminist Theory of the State*. Harvard University Press, 1989.
33. Malatesta, Errico. *The Method of Freedom*. AK Press, 2014.
34. Marx, Karl, and Friedrich Engels. *The Communist Manifesto*. 1848.
35. Marx, Karl, et al. *The German Ideology*. International Publishers, 1932.
36. Marx, Karl. *Economic and Philisophic Manuscripts of 1844*. Progress Publishers, 1932.
37. Morrison, Toni. *Tar Baby*. Vintage, 1981.
38. O'Brien, Mary. "Dialectics of Reproduction." *The Politics of Reproduction*, Routledge & Kegan Paul, London, 1983.
39. Parsons, Talcott. *Social Structure and the Development of Personality: Freud's Contribution to the Integration of*

- Psychology and Sociology. Psychiatry: Journal for the Study of Interpersonal Processes*, 1958.
40. Bookchin, Murray. *Post-Scarcity Anarchism*. AK Press, 1971.
 41. Proudhon, Pierre-Joseph. *What Is Property?: An Inquiry into the Principle of Right and of Government*. Forgotten Books, 1840.
 42. Ruddick, Sara. *Maternal Thinking: Toward a Politics of Peace*. Beacon Press, 1989.
 43. Scott, James C. *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed*. Yale University Press, 1998.
 44. Taylor, Keeanga-Yamahtta. *How We Get Free Black Feminism and the Combahee River Collective*. Haymarket Books, 2017.
 45. *Two Cheers for Anarchism*. Princeton University Press, 2012.
 46. “When Men Murder Women.” *Violence Policy Center*, 20 Sept. 2022, vpc.org/when-men-murder-women-copyright/.
 47. Waller-Bridge, Phoebe, director. *Fleabag*. Series, Amazon Prime, 2016.

Perception of Interpersonal Distance in Reality

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Abstract

The perception of interpersonal distance is impacted by both visual and non-visual information. The proposed experiment will test the hypothesis that the perception of interpersonal distance is influenced by the assumption of threat such that the perceived interpersonal distance between a participant and a target stimulus will be closer when the target is more threatening. This experiment will employ a virtual reality head-mounted display, a virtual simulation of a realistic environment, and virtual target persons. Virtual reality is being used in this research because it allows for an easier, safer, and more ethical way of manipulating the characteristics of a target person to make him/her appear more or less threatening. This is a preliminary study to establish the connection between the perception of threat and interpersonal distance. Future studies will explore how this connection can influence the perception of threat stereotypes related to in-group and out-group members and how an assumed threat posed by an out-group member influences the spatial perception of that person.

Introduction to Visual Perception

Visual perception is frequently assumed to be accurate or closely related to the world as it is in reality. However, visual perception is prone to biases and distortions, with the presence of optical illusions serving as an example. Moreover, it is often assumed that perception of the surrounding environment (spatial layout, objects within the environment) is informed solely by visual factors, but non-visual factors also influence spatial perception. Spatial perception is the combination of visual and non-visual factors and how the information received from these factors is processed in the brain. Balcetis and Dunning (2010) observed that having a greater desire for an object in an environment can cause the desired object to appear closer than less desired objects. A follow-up study by Dunning and Balcetis (2013) looked at the integration of desirability and the perception of distance. This study found that participants would take in visual information, and then this information would be subconsciously modified to fit their desires (Dunning & Balcetis, 2013). Misperceptions of distance and space could lead to additional misperceptions of interpersonal distance. These misperceptions could be even more significant when desirable or adverse feelings toward a person exist.

Threat as a Factor of Spatial Perception

Among the non-visual factors that may influence spatial perception is presumed threat. The perception of threat has been observed to have a significant effect on the perception of distance with stimuli (Cole et al., 2013). Another study demonstrated that when threat is put in terms of “pain-evoking stimuli,” threatening stimuli are perceived as being closer than “pain-relieving stimuli” (Tabor et al., 2015). This study supports the idea that the perception of threat can impact the perception of

distance, but this study only observed the perception of threat regarding the tangible threat of pain (Tabor et al., 2015). The initial research done for this thesis will only attempt to establish a significant connection between threatening individuals and the perception of interpersonal distance. The distinction between the Cole et al. (2013) study and the thesis study is that the Cole study specifically looks at the feelings of threat that are intentionally invoked. The thesis study will examine the perception of threat that is based on preconceived notions with no distinctly threatening manipulations. This study will add to the body of evidence that human perception is affected by biases, even the perception of interpersonal distance.

In-groups, Out-groups, and Stereotypes

Future research that builds upon this thesis will look more closely at the perception of threat based on stereotypes and in-group and out-group relationships. In-groups can be defined as a group of individuals who share some commonality, nationality is an example of this, and this commonality creates a sense of community. An out-group is a group of individuals that do not share the same commonalities with the in-group, hence placing them outside the group. Stereotypes are generalizations that are placed on groups of individuals that diminish the group's potential for individuality. Some stereotypes revolve around members of particular groups being considered naturally aggressive or more threatening than others. Understanding how the perception of threat based upon these forms of stereotypes can potentially impact spatial perception is the end research objective of this thesis. The relationship between perceived threats, stereotypes, and group membership is an expanding area of research (Bonam et al., 2010; Cesario & Navarrete, 2014; Cox et al., 2012; Krosch, 2022; Wilson et al., 2017). Bonam et al. (2010) studied how physical space being racialized, as with redlining, can cause the psychology of individuals to change and affect "person perception and social identity threat" towards members of out-groups and those with stereotypes placed upon them. Similarly, Krosch (2022) proposed that perceived threats due to the environment, in-groups, and out-groups can cause minority individuals to appear more threatening than they are in reality. Cesario and Navarrete (2014) examine how perceptual bias based on in-group and out-group relationships can change threat perception. Cox et al. (2012) investigated the effects of prejudice and stereotypes, with one study reporting that white individuals perceived black men as more imposing and potentially threatening than other participants. Wilson et al. (2017) discuss how racial bias can change the perception of size and formidability and how these perceptions can also affect how threat is perceived. Future research relating to the current thesis will build upon this work to determine whether the perceptions of in-groups, out-groups, and stereotypes affect the perception of interpersonal distance. The information from this future research could increase the understanding of how social bias impacts perception.

Experimental Method

When compared to more overt behaviors and actions, perception is more difficult to measure. Measuring perception is indirect since current technology prevents researchers from observing or recording how a person experiences a target or the environment. Blind walking, walking without visual feedback to a previously viewed target using one's perception of distance between them and the target, will be one of the ways participants will be asked to judge the distance between them and virtual stimuli. Blind walking is an overt and measurable action that relies on a person's perception of distance. The reason blind walking is being used is because it is a relatively common way of judging distance in studies, and it is reasonably accurate (Andre & Rogers, 2006; Philbeck et al., 2010). Additionally, verbal reports of perceived interpersonal distance will be used. Verbal reports, while potentially less accurate than blind walking, still serve as a reasonably accurate measure of distance and presumably reveal one's subjective experience of perceived distance (Andre & Rogers, 2006; Napieralski et al., 2011).

Two forms of measurement are being used to establish potential consistency within data. Neither of these forms of measurement are exact; however, the measurement of perception is an ongoing challenge that has yet to be perfected. These methods allow for information similar to self-reports that participants could provide in surveys. The procedure for this thesis will include using a head-mounted display (HMD), blind walking, and using verbal reports. The general overview of the

procedure is that a participant will put on the HMD, see either a threatening or non-threatening virtual person, and then judge the distance between them and the virtual person through verbal reporting or blind walking. The order of which virtual person will be seen and whether the participant will blind walk or verbally report will be randomized. An HMD is being used to facilitate a more ethical and controlled testing environment. The ethical benefit comes from not having participants in rooms with real individuals they feel threatened by. Furthermore, to create non-threatening and threatening depictions of stimuli, there would need to be individuals dressed in stereotypical outfits, which would place a degrading burden on the individuals who act as stimuli. The increased control of the testing environment comes from the ability to modify stimuli quickly. Instead of essentially having actors who change costumes and move in and out of the room for each trial, virtual stimuli can be changed and modified with a click of a few buttons. Using an HMD to observe a virtual environment may result in underestimated perceptions of space compared to observing the physical environment (Kelly et al., 2017). However, these differences will not impact the study's results because this study will be looking at the difference between estimates, not the accuracy of these estimates.

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References

1. Andre, J., & Rogers, S. (2006). Using verbal and blind-walking distance estimates to investigate the two visual systems hypothesis. *Perception & Psychophysics*, 68(3), 353–361. <https://doi.org/10.3758/BF03193682>
2. Balcetis, E., & Dunning, D. (2010). Wishful seeing: More desired objects are seen as closer. *Psychological Science*, 21(1), 147–152. <https://doi.org/10.1177/0956797609356283>
3. Bonam, C. M., Taylor, V. J., & Yantis, C. (2017). Racialized physical space as cultural product. *Social and Personality Psychology Compass*, 11(9), 1–12. <https://doi.org/10.1111/spc3.12340>
4. Cesario, J., & Navarrete, C. D. (2014). Perceptual bias in threat distance: The critical roles of in-group support and target evaluations in defensive threat regulation. *Social Psychological and Personality Science*, 5(1), 12–17. <https://doi.org/10.1177/1948550613485605>
5. Cole, S., Balcetis, E., & Dunning, D. (2013). Affective signals of threat increase perceived proximity. *Psychological Science*, 24(1), 34–40. <https://doi.org/10.1177/0956797612446953>
6. Cox, W. T. L., Abramson, L. Y., Devine, P. G., & Hollon, S. D. (2012). Stereotypes, prejudice, and depression: An integrated perspective. *Perspectives on Psychological Science*, 7, 427–449.
7. Dunning, D., & Balcetis, E. (2013). Wishful seeing: How preferences shape visual perception. *Current Directions in Psychological Science*, 22(1), 33–37. <https://doi.org/10.1177/0963721412463693>
8. Kelly, J. W., Cherep, L. A., & Siegel, Z. D. (2017). Perceived space in the HTC Vive. *ACM Transactions on Applied Perception*, 15(1). <https://doi.org/10.1145/3106155>
9. Krosch, A. R. (2022). Threat alters race perception to facilitate discrimination. *Trends in Cognitive Sciences*, 26(11), 902–905. <https://doi.org/10.1016/j.tics.2022.08.017>
10. Philbeck, J. W., Woods, A. J., Kontra, C., & Zdenkova, P. (2010). A comparison of blindpulling and blindwalking as measures of perceived absolute distance. *Behavior Research Methods*, 42(1), 148–160. <https://doi.org/10.3758/BRM.42.1.148>
11. Napieralski, P. E., Altenhoff, B. M., Bertrand, J. W., Long, L. O., Babu, S. V., Pagano, C. C., Kern, J., & Davis, T. A. (2011). Near-field distance perception in real and virtual environments using both verbal and action responses. *ACM Transactions on Applied Perception*, 8(3), 1–19. <https://doi.org/10.1145/2010325.2010328>
12. Tabor, A., Catley, M. J., Gandevia, S. C., Thacker, M. A., Spence, C., & Moseley, G. L. (2015). The close proximity of threat: Altered distance perception in the anticipation of pain. *Frontiers in Psychology*, 6. <https://doi.org/10.3389/fpsyg.2015.00626>
13. Wilson, J. P., Hugenberg, K., & Rule, N. O. (2017). Racial bias in judgments of physical size and formidability: From size to threat. *Journal of Personality and Social Psychology*, 113, 59–80.

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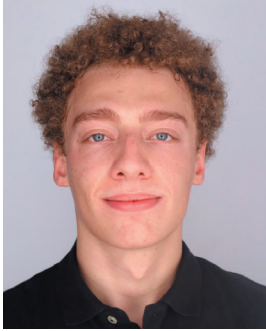
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Joseph Kastner is an Honors Mechanical and Aerospace Engineering student at the University of Dayton. As an undergraduate student Joseph is researching the future applications of Rainbow Schlieren Deflectometry under the guidance of Dr. Taber Wanstall and Dr. Carson Running. Joseph hopes to obtain a Master Degree in Aerospace Engineering through the Bachelors plus Masters Program at the University of Dayton and then enter into the aerospace industry designing rocketry for space exploration companies or for government divisions such as NASA.



Connor Kuntz

Connor Kuntz is a third-year student at the University of Dayton, majoring in psychology, and has been a member of Dr. Ben Kunz's perception psychology lab since the Spring semester of 2023. He has long been fascinated by psychological research and is looking to further this interest by applying to Ph.D. programs for the 2024-2025 school year and beyond. Particular research interests include visual perception, perceptual differences between individuals, and perception in altered mental states.



Megan Sieve

Megan Sieve is studying mechanical engineering with a concentration in aerospace engineering at the University of Dayton. She has been working in Dr. Carson Running's experimental hypersonic aerodynamics lab since July of 2022. She contributed to Benjamin Bemis' paper, "Effect of Porosity on the Ability of Silicon-Carbide Foams to Attenuate the Second-Mode Boundary-Layer Instability," by working on data post-processing. She will be heading the next project, which is a continuation of the above-mentioned, because of her experience working with and learning from Benjamin Bemis and Dr. Running.



Charles J. Strunc

Charles J. Strunc is a dedicated honor student working toward a bachelor's degree in mechanical engineering, a concentration in aerospace engineering, and pursuing graduate school in the near future. He is a member of an undergraduate research team in the Mechanical and Aerospace Research Labs and has been contributing for over a year now. The research, conducted in conjunction with numerous different projects and labs, focuses on Pressure-Sensitive Paint and its various applications, characterization needs, and formulations.



Nicolina Valore

Nicolina Valore is an Environmental Biology major at the University of Dayton. She is currently working on her honors thesis in Dr. Sun's lab which focuses on *Listeria monocytogenes*. Nicolina is a member of Tri-Beta, a collegiate honors society for students majoring in biology and she also participates in Habitat for Humanity and 4 Paws for Ability.