THE TOWER

Undergraduate Research Journal at Georgia Institute of Technology

SPRING '25

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Provision of Photos

Letter from the Editors

Dear Reader,

The Spring 2025 Issue of The Tower, Georgia Tech's undergraduate research journal, is a reflection of research among our student body. From a study of posets in combinatorial mathematics to investigations of campaigns on campus and in Palestine, these manuscripts are deeply intertwined with the academic and social culture at this university. Georgia Tech is an established R1 university, where much of the ongoing work of the students and faculty on campus is heavily driven by research. As a student, I have been reminded that research is no easy task. As an editor, I am perpetually enthralled by the writing put forth by my undergraduate peers on this campus. The writing in these pages represents the culmination of months, and sometimes years, of late night after late night of dedication, advocacy, and hard work.

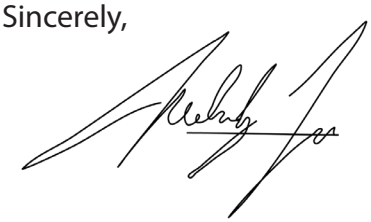
As you, dear reader, flip through the pages of this journal, I urge you to see more than just the words on the page. I urge you to consider the motivations of these students, to consider the questions that drove their curiosity, and to consider your role in the wider realm of research at this institution. You hold in your hands the opportunity to acknowledge the voice of these authors, who have taken yet another step forwards in their research careers.

For many, the publication of these papers would not have been possible without the support of their research advisors and mentors. Thus, we extend a heartfelt thank you to both the authors and their advisors. Furthermore, on behalf of The Tower's editor team, we are immensely grateful to the mentorship provided by the Director of Undergraduate Research, Dr. Laura Williams, and advisor for undergraduate research writing, Dr. Courtney Hoffman, as our team has sought to reignite the presence of this journal on campus. We are also thankful for the Director of Student Media, Mac Pitts, for his advice on handling our logistics and maintenance of the space that our editor team has come to call home. And to all of the supporting organizations in making this journal possible – from Alexandra McGee with the Georgia Tech Archives, to the Society of Women Engineers, to Shirley Shabnam with the Undergraduate Research Ambassadors – we deeply appreciate your partnership and hope to continue this connection well into the future.

With that, I conclude this letter with one last message to you, reader. Thank you for taking the time to read this journal. I sincerely hope that you find within it not only an artifact of the interests of our students, but moreover a reflection of your own curiosity, which brought you to pick up this publication.

I wish you the best.

Sincerely,



Melody Lee
The Tower Editor-in-Chief

What is *The Tower*?

The Tower is the only publication of the Georgia Institute of Technology that publishes peer-reviewed undergraduate research from all academic disciplines. A biannual publication, The Tower provides a comprehensive forum for discourse on cutting-edge research. In order to ensure only high quality research is published, all submissions undergo stringent blind, peer-review.

Papers are reviewed based upon methodology, originality, and relevance of results. Statistical analysis should be used and reported where appropriate. Depth of analysis should be comprehensive. The most important consideration is to ensure that the paper is written for a general, educated audience. If the final set of accepted articles is not balanced to the satisfaction of the Editorial Board, accepted articles may be "held over" until the next year's issue. Additionally, The Tower's editorial staff maintains the right to revise articles for clarity and modifications for layout adherence.

Who Is Eligible?

To submit, students must:

1. Be undergraduate students currently enrolled at the Georgia Institute of Technology.

2. Submit research work done while enrolled as a student at the institute.

3. Not be graduating in the fall semester of the year of submission.

How Do Submissions Work?

Submissions are reviewed by trained graduate and undergraduate students as well as expert faculty in the field of the submission. The peer-review process takes several few months, on average. Often manuscripts will need several cycles of review and revision before they can be accepted for publication. Therefore, it is highly suggested that every effort is made to be early and prompt with submissions to ensure inclusion in the next issue of the journal.

1. Submit your manuscript

Submissions open in late fall until early January—check out the website for more updates.

2. Notification of selection

Authors of selected papers will be notified in the weeks following the submission deadline.

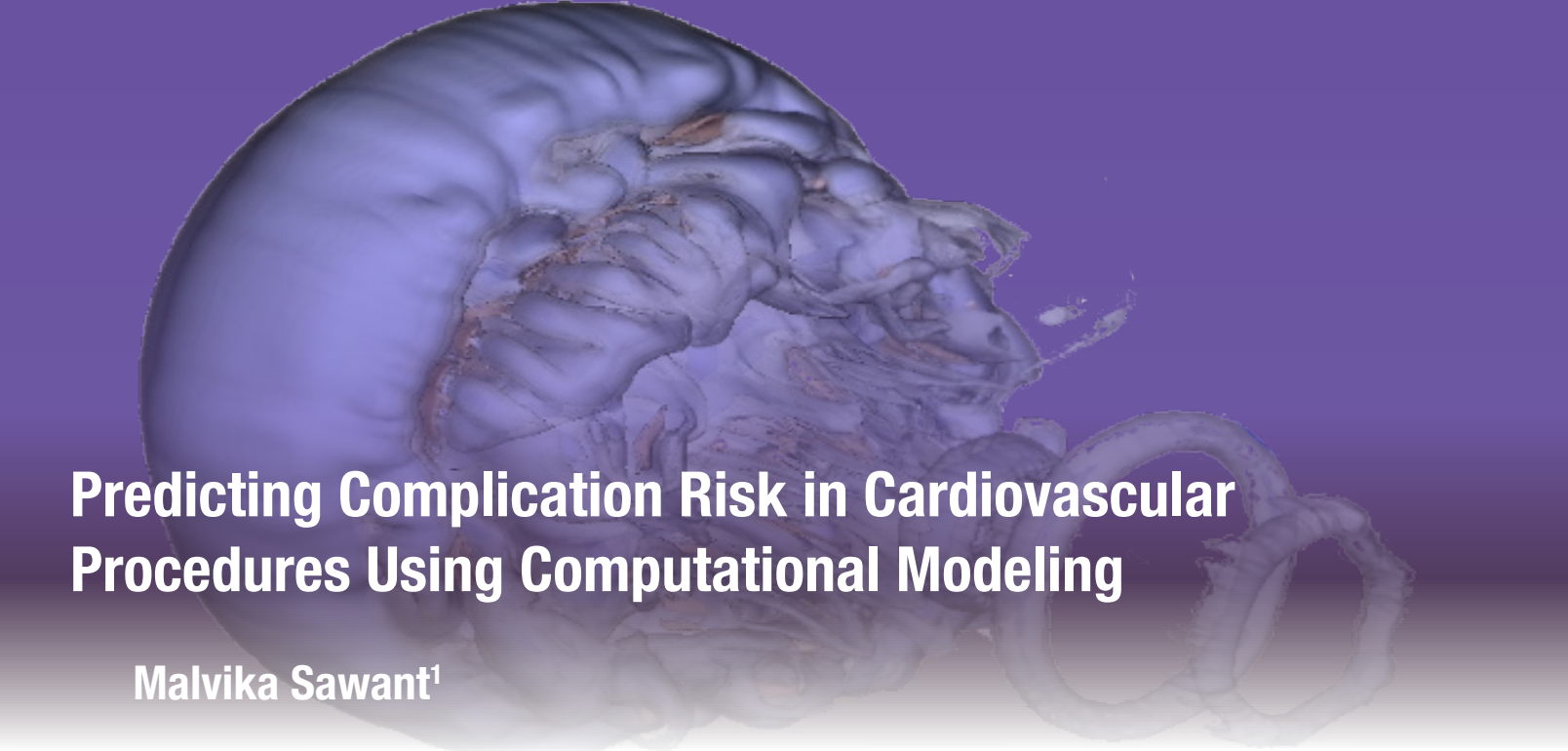
3. Collaboration with editors

Authors will be connected with an editor from *The Tower* and a graduate student or faculty editing advisor to revise and finalize the manuscript. Authors are expected to keep their editors updated every two weeks.

4. Final Publication

The manuscript will be formatted into the final journal. Journals will be printed and distributed by late spring.

Table of Contents



Predicting Complication Risk in Cardiovascular Procedures Using Computational Modeling

Malvika Sawant[1]

Malvika Sawant is a second-year undergraduate student at the Georgia Institute of Technology majoring in Biomedical Engineering. Her interests center on cardiovascular engineering. She plans to pursue an MD/Ph.D. to further explore the intersection of medicine and engineering, particularly in cardiovascular health and disease. In her free time, she enjoys volunteering with community health organizations and exploring the latest advancements in medical technology.

Acknowledgements

I sincerely thank Dr. Lakshmi Dasi, principal investigator of the Cardiovascular Fluid Mechanics Lab, and Aniket Venkatesh, Ph.D. student and graduate researcher, for their invaluable guidance and support. I also acknowledge Dasi Simulations for providing essential resources that contributed to the success of this

Abstract

Hypo-attenuated leaflet thickening (HALT) and leaflet thrombosis (LT) are common complications following transcatheter aortic valve replacement (TAVR), increasing stroke risk and valve deterioration. A comprehensive computational pipeline was developed to evaluate the geometric and hemodynamic risk factors associated with leaflet thrombosis using pre-procedural computed tomography (CT) imaging, finite element analysis (FEA), and reduced order modeling (ROM), along with additional computational methods. The semi-automated segmentation of the left ventricle (LV) from CT images is used to extract hemodynamic features that inform the risk assessment, but it is not solely relied upon to predict HALT. The pipeline integrates these features with various other computational techniques, including advanced modeling and simulations, to provide a more accurate and holistic prediction of risk factors. The model estimates hemodynamic metrics, such as stroke volume and ejection fraction, enhancing post-procedural complication assessment in TAVR patients. Future incorporation of more advanced machine learning algorithms will further refine predictive accuracy and broaden clinical applications.

[1]School of Biomedical Engineering, College of Science, Georgia Institute of Technology
Background photo courtesy of the Computational Physics Group at Georgia Tech

Introduction

Despite the benefits of transcatheter aortic valve replacement (TAVR), complications such as hypo-attenuated leaflet thickening (HALT) and leaflet thrombosis (LT) remain prevalent, leading to increased stroke risk and valve deterioration (Pujari and Agasthi, 2023). Current clinical strategies for managing HALT are hindered by the lack of reliable pre-procedural predictive tools, as existing models are primarily based on post-procedural imaging rather than pre-procedural hemodynamic assessments. Furthermore, contemporary tools fail to account for patient-specific flow dynamics, variations in valve anatomy, and biochemical risk factors for thrombus formation. They also do not integrate machine learning and computational simulations that could enhance prediction accuracy. Therefore, there is a critical need for new computational approaches (Ranasinghe, et al., 2019; Fukui, et al., 2022). This work addresses that gap by proposing a computational pipeline that predicts geometric and hemodynamic risk factors for LT. By utilizing pre-procedural computed tomography (CT) imaging, finite element analysis (FEA), and reduced order modeling (ROM), the pipeline enables fast, patient-specific predictions. This approach not only improves the performance of TAVR but also exemplifies how computational modeling can bridge the gap between engineering and clinical medicine, ultimately enhancing personalized treatment planning (Hatoum, et al., 2021; Shah, et al., 2024).

Methods

I first gathered pre-procedural 45 CT scans of patients who underwent transcatheter aortic valve replacement to develop a computational pipeline for the risk prediction of HALT. Preprocessing the CT images included enhancing clarity by noise reduction filters and standardizing the resolution across these datasets. Specifically, left ventricle (LV) segmentation is challenging yet highly important in this pipeline; I did it using semi-automated tools coupled with manual refinement to ensure precision, especially at regions of anatomical complexity.

Peak systolic flow rate (Q_{sys}) and ejection time (t_{ej}) were considered in evaluating hemodynamic performance, as they provide insights into post-TAVR flow dynamics.

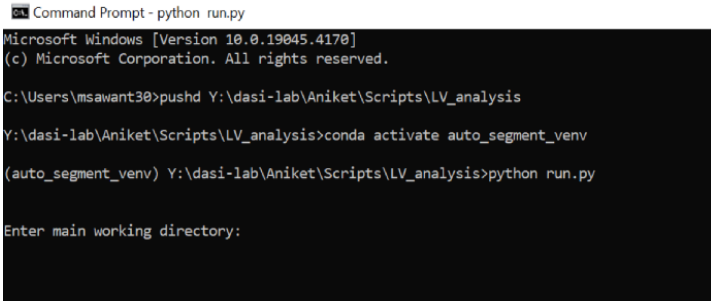


Figure 1. Process of segmentation code.

I obtained pre-procedural CT scans from TAVR patients and procedural CT scans from TAVR patients and segregated the LV region manually and semi-automatically (Figure 1). Accurate segmentation was crucial to extract geometric features that dictate hemodynamics (Denis de Senneville, et al., 2016). The existing process demands outlining complicated anatomic structures while maintaining consistency segregated the LV region manually and semi-automatically (Figure 1). Accurate segmentation was crucial to extract geometric features that dictate hemodynamics (Denis de Senneville, et al., 2016). The existing process demands outlining complicated anatomic structures while maintaining consistency across datasets, as shown in Table 1.

Table 1. Overview of processing steps.

Step	Description	Tools Used
CT Preprocessing	Importing DICOM files and denoising images	MATLAB, ITK SNAP
LV Segmentation	Manual and automated segmentation techniques	Python (CNN, convolutional neural network)
Data validation	Comparison with clinical measurements	Excel, SPSS

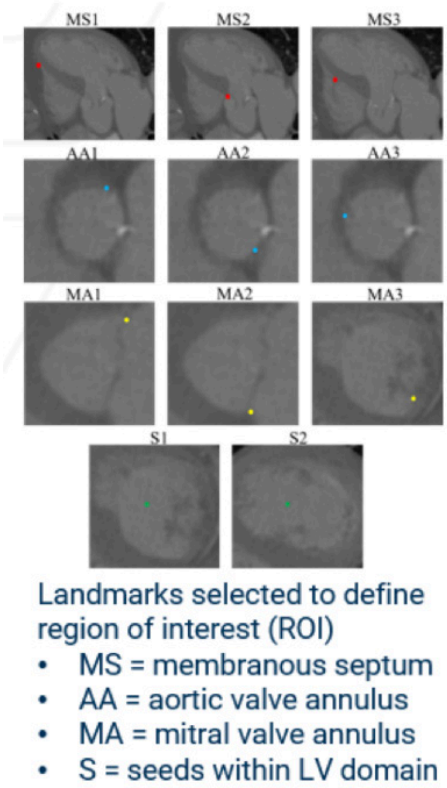


Figure 2. Semi-Automatic LV Segmentation Pipeline (Part 1)

I applied ROM and FEA techniques to structural and hemodynamic simulations. Through the use of ROM, computation time is greatly reduced without sacrificing solution accuracy (Denis de Senneville, et al., 2016); the analysis of post-TAVR dynamics can be performed much faster (Figure 3).

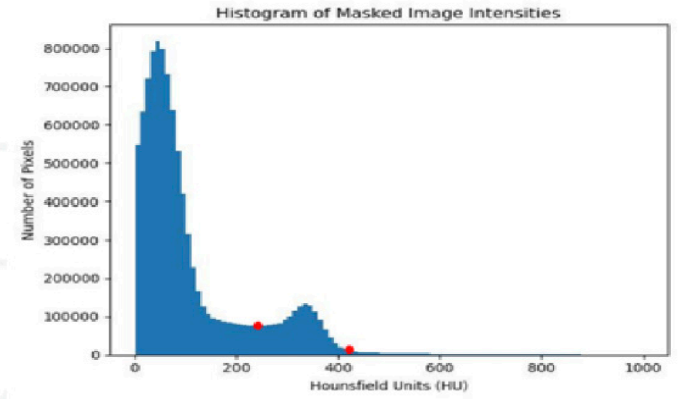


Figure 3. Automatic Detection of Blood Pixel Intensity Threshold

A key challenge was variability among the anatomy of patients, which can introduce inconsistency in segmentation. I have used automation techniques based on convolutional neural networks (CNN) for resolving it, namely landmark detection, and quality enhancement. The CNN model was trained on pre-procedural CT scans from TAVR patients on hand and semi-automatically segmented labels. To ensure accuracy, model outputs were checked using expert annotation and clinical measurement.

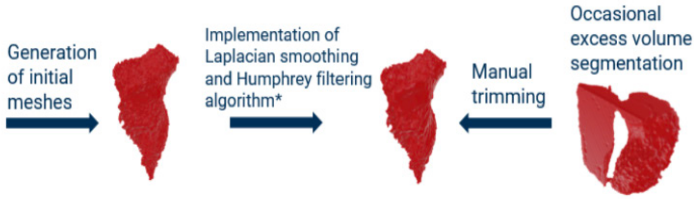


Figure 4. Automatic Detection of Blood Pixel Intensity Threshold (Part 2)

Ejection volume (V_{ej}) was determined by using end diastolic volume (EDV) and end-systolic volume (ESV), calculated as

$$V_{ej} = EDV - ESV$$

Furthermore, ejection fraction (EF) was derived as

$$EF = V_{ej} / EDV$$

providing a key metric in assessing cardiac function post-TAVR. Additionally, the relationship between systolic velocity and stent geometry was analyzed using

$$v_{sys} = Q_{sys}/A_{stent,\ waist}$$

which helped quantify flow characteristics across the valve replacement.

Preprocessing procedures standardized imaging data variability to make robust LV segmentation and credible HALT risk prediction possible. Another confounding factor was heterogeneity in the imaging protocols across datasets. These were mitigated by standardization of pre-processing methods and normalizing the imaging inputs. The approach was multifaceted in which various advanced computational tools along with machine learning techniques build a strong pipeline for efficient and effective prediction of risk in HALT.

Results

The left ventricle (LV) segmentation semi-automatic pipeline provided a robust foundation for predicting complications in cardiovascular intervention patients, more precisely, patients that underwent transcatheter aortic valve replacement (TAVR). By accurately extracting key geometric parameters, such as end-diastolic volume (EDV), stroke volume (SV), and ejection fraction (EF), the pipeline provided valuable information on heart function (Figure 4). For instance, in Batch 01 Pre032, the LV segmentation possessed an EDV of 184.53 mL, stroke volume of 90.95 mL, and EF of 49.29%, which are essential to determine cardiac function and potential risk. These were obtained from 45 pre-procedural CT scans of TAVR patients, and that the pipeline can replicate these measurements consistently across different datasets proves its utility in large patient assessments.

Pipeline application to hemodynamic simulations allowed for close inspection of the blood flow dynamics in the LV. Regional variations in blood flow and in flow distribution were modeled, and sections of abnormal flow patterns or areas where ischemia or valve dysfunction are most likely to be seen were determined. For example, in Batch 01 Pre056, while the peak systolic flow rate was 362.77 mL/s, the mean flow rate was 256.92 mL/s. These flow dynamics highlighted areas of the heart that were more poorly perfused and more at risk for complications after the procedure. This predictive capability is very useful to help guide individualized treatment strategies and patient outcomes by preempting areas of higher risk before and after procedures such as stenting or valve replacement.

Besides, the pipeline was highly reproducible when used throughout various imaging modalities, demonstrating its potential for use in varying clinical settings. The average difference in LV volume measurements between varying types of imaging was less than 5%, testifying to the pipeline's ability to maintain consistency and reliability amidst heterogeneous imaging protocols. Reproducibility enhances the model's predictive power, ensuring the tool can be used extensively in patient populations without compromising accuracy.

From a clinical utility perspective, the pipeline demonstrated its potential to predict complications in post-TAVR patients by integrating LV geometry and flow dynamics. The cases with anomalous flow patterns or very low ejection fractions were found to be higher-risk, which agreed with traditional clinical markers for complications such as ischemia or valve dysfunction. These findings demonstrate the potential of the semi-automatic LV segmentation pipeline to not only save time and drudgery of the segmentation process, but also release valuable insights from patient risk profiles with significant implications for more informed, personalized treatment planning.

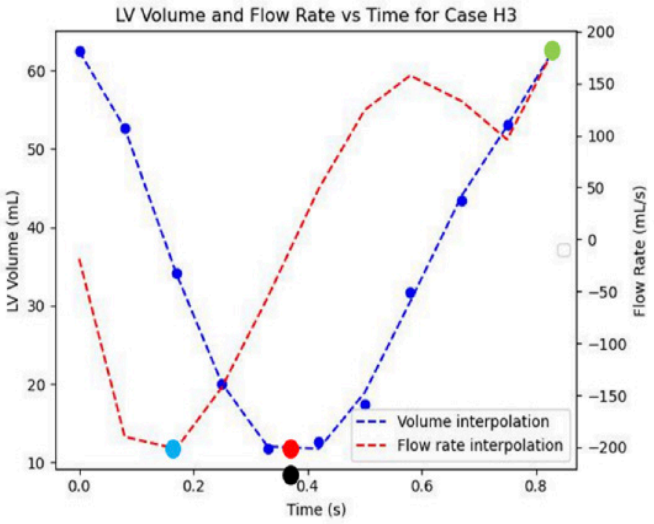


Figure 5. Hemodynamic Measurements and Calculations

Conclusion

This work introduces a computational pipeline intended to assess the risk of hypo-attenuated leaflet thickening (HALT) and leaflet thrombosis (LT) in TAVR patients via the incorporation of semi-automatic left ventricular (LV) segmentation with hemodynamic modeling. The pipeline can obtain significant hemodynamic parameters, such as stroke volume, ejection fraction, and end-diastolic volume, from pre-procedure CT images and enable prediction of post-procedure complications. The model was highly reproducible across modalities, with less than 5% variation in measurements of LV volume, and effectively mapped regions of diseased blood flow more prone to complications like ischemia or valve malformation. Predictions by this model outperformed traditional strategies in delineation of risky areas, improving individualized risk calculations. Innovative integration of machine learning techniques will continue to enhance the accuracy of these predictions, increasing the model's applications in the clinic and optimizing patient outcomes through more precise, individualized treatment planning.

Future Studies

Currently, I am working on further developing my research experience in developing computational methods for complications prediction in cardiovascular interventions. In the future, this will be further based on the integration of advanced machine learning methods that further enhance model performance and clinical applicability. I will specifically try to fine-tune the identification of patient-specific risk factors by using support vector machines and random forests that will make robust predictions on smaller or imbalanced datasets. I would then apply gradient boosting algorithms, such as XGBoost or LightGBM, for feature selection and improvement in the accuracy of the predictions that will enable the identification of patients who are at high risk for complications more quickly and with greater precision.

I also want to study clustering techniques such as K-Means or DBSCAN, which can enable me to bring out patterns in the patient population that indicate the presence of new phenotypes linked with different HALT risks. Further integration of these results with advanced computational and machine learning methods is likely to enable me to refine the utility of the pipeline and translate this research into actionable tools aimed at improving patient care and reducing complications in cardiovascular medicine.

Access references for this paper using the QR code below.

Race-Conscious and Race-Neutral College Admission Policies: Impact on Asian Americans

Jinxia Loo[1]

Jinxia Loo is an undergraduate student majoring in History, Technology, and Society, and minoring in Computer Science. They are involved in undergraduate research through the School of History and Sociology curriculum under Dr. Brown. In the future, they hope to enter either the field of UX research or attend law school. Additionally, they hope to continue their passion for advocacy on Asian and Asian American issues.

Abstract

The pursuit of equal opportunities in higher education highlights systematic disparities, power dynamics, and the historical legacies of racial formation. Within the realm of college admissions, the dynamics of race-conscious and race-neutral policies play a pivotal role in shaping the opportunities available to different minority groups. The research question of this paper is: How do different racial groups articulate their stakes and justify their claims within college admissions processes, while also examining the broader implications of race-neutral and race-conscious policies on accessibility to higher education? The paper frames the question through the key arguments presented in Students for Fair Admissions v. Harvard in favor of and against affirmative action, and how college admissions demographics reflect diversity under race-neutral and race-conscious policies. The inquiry serves as a critical exploration into the intersection between admission policies, power dynamics, and systemic racism in understanding their shared role in either perpetuating or mitigating disparities in college admissions. Through a content analysis of the Students for Fair Admissions v. Harvard court case, the findings reveal that Asian Americans often serve as a divisive tool employed by white conservatives to maintain their power, particularly against African Americans. The results also suggest that race-conscious policies are more beneficial compared to race-neutral policies in addressing admission disparities.

[1]School of History, Technology, and Society, Ivan Allen College of Liberal Arts, Georgia Institute of Technology

Background photo courtesy of Alexis Vladescu

College Admissions Process in The United States

In the United States, the college admissions process refers to a set of procedures that prospective students undergo to apply for admission into institutions of higher education. It is a multistep journey that begins with the submission of applications containing a range of data, including academic transcripts, recommendations, personal essays, standardized test scores, and demographic information. Admission officers then consider these materials alongside their own institutional criteria to make acceptance decisions (College Board, 2023).

While the college admission process attempts to identify well-suited individuals, disparities persist. Admission rates for minority groups are often disproportionately low compared to their more privileged counterparts, with socioeconomic status and race being influential factors in perpetuating admission disparities. Data reveals disproportionate access to selective colleges along racial and ethnic lines, in which African Americans and Hispanics constitute only 6 percent of the freshman class of the 146 most highly selective four-year colleges (Carnevale and Rose, 2004).

The financial advantages of attending college make handling admissions to higher education crucial. Higher education offers pathways to lucrative job opportunities, increased pay, and social mobility. In the case of selective colleges, the associated student support, preparation, and prestige result in higher acceptance rates at graduate and professional schools (Carnevale and Rose, 2004).

Two contradicting approaches have emerged in promoting equal opportunity in higher education: race-conscious and race-neutral college admission policies. Among these, affirmative action stands as a highly contentious race-conscious strategy. The debate over affirmative action reached a pivotal moment with the 2023 landmark case Students for Fair Admissions v. Harvard, which deemed race-based affirmative action programs unconstitutional on the basis that they discriminate against Asian American applicants.

Students for Fair Admissions v. Harvard was a case brought forth by Students for Fair Admissions, a non-profit organization dedicated to ensuring that a student's race and ethnicity are not a factor "that either harm or help that student to gain admission to a competitive university" (Blum, 2023). The organization argues that race-based admissions are both unconstitutional and unfair. In the court case, Students for Fair Admissions argued that Harvard University's (Harvard) admissions process discriminates against Asian American applicants by holding them to higher standards compared to other racial groups. The court ruled that Harvard's process violated Title VI of the Civil Rights Act of 1964, stating that the use of race through affirmative action lacked measurable objectives and involved stereotyping (Supreme Court of the United States, 2022a).

The timing of the case was notable and likely strategic, as it was brought forward when the Supreme Court of the United States had a conservative majority. This majority was poised to address affirmative action, potentially overturning 45 years of precedent and previous rulings that permitted race-conscious admission policies. The ruling marked a significant shift in higher education policy, underscoring the debate around how to best achieve racial diversity and equity in college admissions.

Power Dynamics and College Admissions

Omi and Winant's (1994) theory of racial formation, with its associated racial projects, provides a framework for understanding the complexity of power dynamics in college admissions. The theory explores how the concept of race and racism has evolved over time (Omi and Winant 1994). As such, historical context is crucial in shaping contemporary racial dynamics.

Racial projects, as conceptualized by the authors, refer to efforts, both intentional and unintentional, that influence people's understanding of and the significance given to race in different societal contexts. Projects include a wide range of activities and initiatives, such as media representations, racial stereotypes, and political campaigns. In the context of college admissions, racial projects are present in the establishment of admission practices that either bolster systems of equality or inequality based on racial categories (Omi and Winant, 1994). As such, the college admission process is not a neutral system but a racial project in itself. The process reflects broader societal power structures that maintain historical legacies of systemic racism rooted in white supremacy.

Power, in this framework, is defined as the ability to control or influence the distribution of resources, opportunities, and privileges within society. In the context of college admissions, power is operationalized through various racial projects that can either reinforce or challenge existing racial hierarchies. This involves examining whose interests are prioritized in the decision-making process and how these decisions perpetuate or mitigate racial disparities within the education system. As such, issues of racism, white privilege, and power structures influence ideologies over who deserves to go to college and what admission rules should be.

The concept of college admission as a racial project recognizes that systemic inequalities and historical racial disparities significantly impact the opportunities available to different racial groups. In essence, ideas around race influence the selection and evaluation process, which can disadvantage underrepresented minority groups. Furthermore, admission policies, whether race-conscious or race-neutral, are their own respective racial projects that influence opportunities and outcomes.

Contradictory Racialization of Asian Americans

The racialization of Asian Americans is one of the paradoxes that arise in the affirmative action debate. Historically, society has racialized Asian Americans as "yellow peril" foreigners. Laws like the Chinese Exclusion Act and the Japanese-American internment exemplify this prejudiced characterization, which looked to perpetuate issues of xenophobia and dehumanization (Wu, 1995).

The influx of Chinese immigrants began during the Reconstruction era as a labor replacement for previously enslaved African Americans. The partial motivation behind the recruitment of Chinese laborers was to penalize African Americans for gaining freedom by exerting control over the conditions of employment and the wages paid in order to disadvantage them. The Chinese Exclusion Act, which had an explicitly racist agenda, sought to restrict Chinese immigration into the country. The act reflected a "xenophobic animus towards Asians as perpetual foreigners" by scapegoating the group for the nation's economic problems despite their contributions, particularly with the transcontinental railroad (Allred, 2007). Similarly, in the case of Japanese-American internment, anti-Asian sentiment resulted in the internment of over 112,000 Japanese Americans during World War II. The systemic injustice was based on racial identity and a specter of foreignness without due process, even though there was a lack of evidence suggesting disloyal conduct (Wu, 1995). These historical events of discrimination not only conserved the stereotype of Asian Americans as perpetual foreigners but are contradictory to the "model minority" myth.

The "model minority" myth characterizes the Asian American experience as a success journey. People widely use the stereotype in discussions around affirmative action in two distinct manners. Firstly, it is employed in a color-blind sense to argue against the necessity of affirmative action by emphasizing how minorities, like Asian Americans, excel without such policies. Secondly, people utilize it to claim that Asian Americans are experiencing discrimination through affirmative action (Chu, 2016).

As a racial project, the "model minority" myth attributes the success of Asian Americans to their hard work and determination. Notably, the "model minority" myth depends on white approval and assimilation, in which Asian Americans have to confine themselves to the status quo in order to be accepted into society (Lee, et al., 2016). Moreover, the stereotype positions the group against other marginalized groups, particularly African Americans, to insinuate that systemic discrimination is either not a significant barrier to success or is non-existent. The "model minority" myth undermines policies like affirmative action by placing blame on individuals for their lack of success rather than addressing systemic inequality and historical mistreatments (Lee, 2006). In this aspect, Asian Americans act as "racial mascots" in between the power dynamics of whites and African Americans by deflecting accusations of racism and maintaining the higher status of whites (Allred, 2007).

Although the "yellow peril" foreigner trope defines Asian Americans as more similar to African Americans in the racial hierarchy and the "model minority" defines Asian Americans as more similar to whites in the racial hierarchy, the two viewpoints are interconnected. Both racializations are white-centric perspectives that oversimplify the Asian American experience into convenient stereotypes that serve as tools for upholding racialized power dynamics. From using Asian Americans as a workforce to exert control over newly freed slaves to positioning them as racial mascots under the "model minority" myth, there is a repeated pattern and history of exploiting Asian Americans. The interconnectedness of these narratives functions as a racial wedge, strategically positioning Asian Americans against African Americans to preserve power structures that serve the interests of white dominance (Lee, 2006).

Arguments for and Against Affirmative Action

Race-conscious admission policies refer to policies that take into account an applicant's race or ethnicity as a factor in the current admissions process. Supporters of race-conscious admissions, such as affirmative action, often argue that these policies are needed to counteract the systematic barriers that minorities face in pursuing higher education. The historical roots of affirmative action are in ensuring nondiscrimination and promoting equal opportunity. For example, Reconstruction-era policies such as the Freedmen's Bureau are affirmative action precedents that looked to address the resistance to Reconstruction from white supremacists (Rubio, 2001). The impact of historical racism and discrimination continues to persist today. As such, affirmative action is necessary to equalize opportunities in the realm of higher education. Evidence also suggests that affirmative action benefits minorities who are qualified to succeed as a student even if their credentials are weaker in comparison to their white, male counterparts (Holzer and Neumark, 2006). Lastly, advocates argue that affirmative action helps to boost diversity and thus improve relations across racial groups by promoting diverse interpersonal interactions (Herring and Henderson, 2011).

In contrast, race-neutral admission policies do not consider race or ethnicity in the decision-making process. Opponents of affirmative action often argue that present-day discrimination plays a small role in the determination of educational and employment differences across minority groups. They attribute low skills among underrepresented minorities to weaknesses in early family and school environments. As a result, there is lower representation and poorer performance in highly paid jobs and university positions for these groups (Thernstrom and Thernstrom, 1997). There is a large fixation on meritocracy, in which gaps are attributed to individual choices.

Another argument against the consideration of race in college admissions is the claim that Asian Americans are disadvantaged

by policies like affirmative action. Opponents argue that Asian Americans are overrepresented in meeting admissions criteria due to their "model minority" status and thus are penalized by race-conscious admissions (Allred, 2007).

Additionally, opponents argue in support of the "mismatch" theory, in which those who get into schools through affirmative action end up admitted to schools for which they are unprepared, and in which they are less likely to succeed (Taylor and Sander 2012). As such, the admission of less-qualified minorities who perform poorly "constitutes an attempt to equalize results or outcomes, rather than opportunity" (Holzer and Neumark, 2006, pp. 461). The mismatch theory may also perpetuate negative stigmas regarding the abilities of minorities (Sowell, 2005). As a substitution for affirmative action, many proponents look to the implementation of race-neutral programs. The most well-known example is granting admission to a certain top percentage of each high school's graduating class, which is referred to as the "top x percent" rule (Long, 2004).

Gaps in Research

The existing body of literature on the positions of Asian Americans in the affirmative action debate, as well as on race-conscious and race-neutral admissions, offers insight into the complexities of equal opportunity in higher education. However, there are notable gaps that prevent a complete understanding of the Asian American perspective and how race-conscious and race-neutral admissions compare to one another. For instance, literature around how affirmative action impacts Asian Americans uses the group as a political wedge rather than addressing genuine concerns. This approach tends to view Asian Americans solely within the framework of a black-white hegemony (Omi and Takagi, 1996). As such, Asian Americans are consistently defined as neither Black nor white, which results in their experiences in being either "ignored or appropriated by others" when it comes to discourses around race (Takagi, 1993, pp. 115).

It is also essential to acknowledge the broadness of Asian Americans as a racial category (Chang, 2017). This broadness is problematic, considering that the "model minority" myth is primarily associated with East Asian communities. Not only does it ignore the diverse array of experiences by generalizing all Asian Americans, but it also overlooks the disproportionate success of other groups like Southeast Asians and South Asians (Wang and Wu, 1996). Furthermore, despite the extensive research conducted on the topic of race-conscious and race-neutral admission policies, there is little information on how these policies compare to one another. Often, these policies are studied in isolation from one another, which limits the potential for understanding how these policies complement or counteract each other.

Methodology

This study utilizes two primary methodologies. The first part includes a content analysis from a qualitative approach of the Students for Fair Admissions v. Harvard case. Then, to demonstrate the different implications of race-conscious policies compared to race-neutral policies, the study employs a case study approach to investigate the contrasting policies adopted by two higher education institutions: Harvard University and the University of Texas at Austin (UT Austin).

Researchers Hsiu-Fang Hsieh and Sarah Shannon (2005) define content analysis as a research method that provides a subjective interpretation of the content of a given text by systematically identifying themes or patterns through a coding process. The emphasis on viewing a text from an integrated perspective enables the identification of "intentions, focus or communication trends of an institution" (Hsieh and Shannon, 2005, pp. 1278).

Given the amount of material related to the court case, I narrowed my focus to the argument section of Brief for Respondent and the argument section of Brief for Petitioner as these sections revolve around the claims made by each respective stakeholder.

For the content analysis, the argument sections were broken down into three distinct themes related to Asian Americans and their stakes in the admission process to better identify prevalent patterns and insights within the court case. The three selected categories include:

1. *Discrimination and Equal Opportunity*
    a. This category examines arguments related to whether Asian Americans experience discrimination in the college admission process. The focus is on the fairness of the admission process and whether it provides equal opportunities for underrepresented minority groups.
2. *Diversity and Representation*
    a. This category explores the role of diversity in higher education, particularly how admission policies assess the value of a diverse student body and influence the racial demographic of an institution. The category also addresses whether Asian Americans are adequately represented within the diversity framework.
3. *Constitutionality*
    a. This category focuses on the legal arguments surrounding affirmative action and whether affirmative action is constitutional. The category includes references to the Equal Protection Clause of the Fourteenth Amendment, as well as previous court rulings surrounding the constitutionality of affirmative action.

Each text was coded for the frequency of a theme, which counted how many times a claim appeared in the text related to a given theme. Furthermore, each concept was coded as either

conscious affirmative action at Harvard against the race-neutral 6 percent plan at UT Austin through the admission statistics of each respective school.

Harvard is a private Ivy League university located in Cambridge, Massachusetts. The university has historically been an advocate for race-conscious affirmative action (Harvard University, 2023). As aforementioned in Students for Fair Admissions v. Harvard, the Supreme Court of the United States ruled that race-conscious affirmative action in college admissions was unconstitutional, forcing Harvard to change its approach to the admission process as of Fall 2023.

In contrast, UT Austin is a public university located in Austin, Texas. The university is well known for its implementation of the top x percent rule under the enactment of House Bill 588 in 1998. The race-neutral policy, aimed at prestigious institutions such as UT Austin, guarantees admission to the top x percent of graduating seniors to public state schools as a means of enhancing diversity without considering race as a determining factor (The University of Texas Austin, 2023). As of 2023, the school admits the top 6 percent of graduating Texan seniors.

Both Harvard and UT Austin are prestigious, highly-ranked institutes known for their distinct approaches to college admissions. Moreover, both institutes have been extensively studied within the context of their respective admission policies, making them compelling choices for the statistical analysis.

Results

In regard to the content analysis, some of the most prominent claims made in support of affirmative action include: its constitutionality and alignment with precedents set in previous court cases; the role that affirmative action has in promoting diversity and the positive impacts of diversity; and how affirmative action helps to ensure equal opportunity for underrepresented minority students. Thirty of the claims related to discrimination and equal opportunity, 12 of the claims related to diversity and representation, and 18 of the claims related to constitutionality (Table 1).

Some of the most popular claims against affirmative action include: discriminating against Asian American applicants; having no notable impact on diversity; promoting a racial hierarchy with African Americans and then Hispanics on the top; and that it is unconstitutional when considering the precedents set by previous court cases. Nineteen of the claims related to discrimination and equal opportunity, 13 of the claims related to diversity and representation, and 35 of the claims related to constitutionality (Table 1).

Table 1: Students for Fair Admissions v. Harvard

	For Affirmative Action (Harvard)	Againt Affirmative Action (SFF)
Discrimination and Equal Opportunity	30	19
Diversity and Representation	12	13
Constitutionality	18	35

Specific excerpts from the case provide further context to these claims, offering insights into how affirmative action is. For instance, Harvard defended its use of race-conscious admissions through the lens of discrimination and equal opportunity on the basis that there is a lack of evidence of discrimination in Harvard's admission process, reinforcing the university's stance that its race-conscious policies are conducted in good faith and carefully applied to ensure fairness.

> *Excerpt 1.1: Discrimination and Equal Opportunity for Affirmative Action*
> The lower courts found categorically that there is 'no evidence of any racial animus whatsoever or intentional discrimination,' and that despite hand-picking hundreds of admissions files, SFFA did not identify a single Asian-American applicant who was discriminated against (Supreme Court of the United States, 2022c, pp. 32).

> *Excerpt 1.2: Discrimination and Equal Opportunity for Affirmative Action*
> Harvard's regression model—which the lower courts found both 'more comprehensive' and more reflective of the actual admissions process than SFFA's model—showed Asian-American ethnicity had no effect on the chances of admission (Supreme Court of the United States, 2022c, pp. 44).

Harvard also defended affirmative action through other critical excerpts that emphasize the benefits of diversity in higher education and the importance of racial diversity to Harvard's educational mission.

> *Excerpt 2.1: Diversity and Representation for Affirmative Action*
> Grutter explained, genuine diversity 'promotes cross-racial understanding,' helps to break down racial stereotypes, and 'enables [students] to better understand persons of different races (Supreme Court of the United States, 2022c, pp. 30)

> *Excerpt 2.2: Diversity and Representation for Affirmative Action*
> Diversity—including racial diversity—is indispensable to some universities' educational missions. The lower courts credited Harvard's findings that meaningful racial diversity promotes 'learning, empathy, and understanding' and

equips graduates for an 'increasingly pluralistic society (Supreme Court of the United States, 2022c, pp. 30)

Excerpt 2.3: Diversity and Representation for Affirmative Action

The lower courts found that 'a heterogeneous student body promotes a more robust academic environment with a greater depth and breadth of learning, encourages learning outside the classroom, and creates a richer sense of community (Supreme Court of the United States, 2022c, pp. 31).

Lastly, when it came to the constitutionality of affirmative action, Harvard's defense highlights how the Supreme Court, especially through the precedents of the constitutional text, has consistently held that universities may consider race as one of its factors in admissions.

Excerpt 3.1: Constitutionality for Affirmative Action

This Court has consistently held that universities conducting such holistic review need not ignore that a person's race—like their home state, national origin, family background, or interests—is part of who they are, and that in seeking the benefits of a diverse student body, universities may consider race as one among many factors provided they satisfy strict scrutiny (Supreme Court of the United States, 2022c, pp. 23).

Excerpt 3.2: Constitutionality for Affirmative Action

The constitutional text and history resoundingly support Bakke, Grutter, and Fisher. SFFA contends that those cases transgressed a requirement of color-blindness enshrined in the Fourteenth Amendment. But absolute neutrality has never been a universal constitutional principle, either at the time of ratification or in the Court's jurisprudence (Supreme Court of the United States, 2022c, pp. 22).

Excerpt 3.3: Constitutionality for Affirmative Action

Grutter 'carefully examin[ed] the importance and the sincerity' of Michigan's explanation that it pursues the educational benefits of diversity by considering race as one factor in admissions (Supreme Court of the United States, 2022c, pp. 35)

In contrast, Students for Fair Admissions presented claims that affirmative action policies disadvantage Asian American applicants, undermining the principle of equal opportunity.

Excerpt 4.1: Discrimination and Equal Opportunity Against Affirmative Action

This discrimination is not news to American high-schoolers: An entire industry exists to help them appear "less Asian" on their college applications... More broadly, Grutter tells universities that it's okay to treat students differently based on race—a legal imprimatur with well-known repercussions. Racial preferences, this Court has explained, are poisonous. (Supreme Court of the United States, 2022b, pp. 64)

Excerpt 4.2: Discrimination and Equal Opportunity Against Affirmative Action

While Harvard's anti-Asian penalty on the personal rating shows discrimination during the admissions process, Harvard also discriminates against Asian Americans in actual admissions outcomes. As the district court recognized, every regression model—including Harvard's—shows a statistically significant admissions penalty against Asian American applicants when the personal rating is excluded (Supreme Court of the United States, 2022b, pp. 73)

Excerpt 4.3: Discrimination and Equal Opportunity Against Affirmative Action

Harvard's racial preferences are enormous. In absolute terms, race is "determinative" for at least "45% of all admitted African American and Hispanic applicants," or "nearly 1,000 students" over a four year period. Harv.Pet. App.209-10. This is not "a small portion of admissions decisions." Fisher II, 579 U.S. at 384-85. And the size of Harvard's racial preferences dwarfs Texas's in 2008 and mirrors Michigan Law's in 2000, even though universities are supposed to be decreasing their use of race over time (Supreme Court of the United States, 2022b, pp. 79).

Students for Fair Admissions also questioned whether affirmative action truly enhances diversity, and contends that race-neutral alternatives are available, such as eliminating preferences for the children of donors, alumni, and faculty.

Excerpt 5.1: Diversity and Representation Against Affirmative Action

Besides, real diversity would not decline (and would likely improve) after Grutter is overruled, given the availability of race-neutral alternatives. The University of California, for example, boasts that it just admitted its "most diverse class ever," despite the State's ban on racial preferences (Supreme Court of the United States, 2022b, pp. 70)

Excerpt 5.2: Diversity and Representation Against Affirmative Action

Harvard has at least one workable race-neutral alternative. At trial, SFFA simulated an alternative where Harvard eliminates its preferences for the children of donors, alumni, and Harvard faculty—who are overwhelmingly white and wealthy—and increases its preference for the socioeconomically disadvantaged. Harv.JA763-65, 774-75. Under this simulation, underrepresented minority admissions rise slightly, Asian-American admissions increase, Harvard becomes more socioeconomically diverse, and academic characteristics remain excellent (Supreme Court of the United States, 2022b, pp. 81).

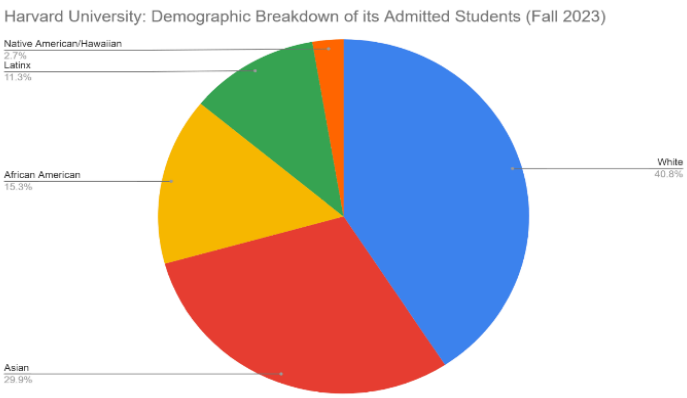


Figure 1: Demographic Breakdown of Harvard University's Admitted Students (Fall 2023)

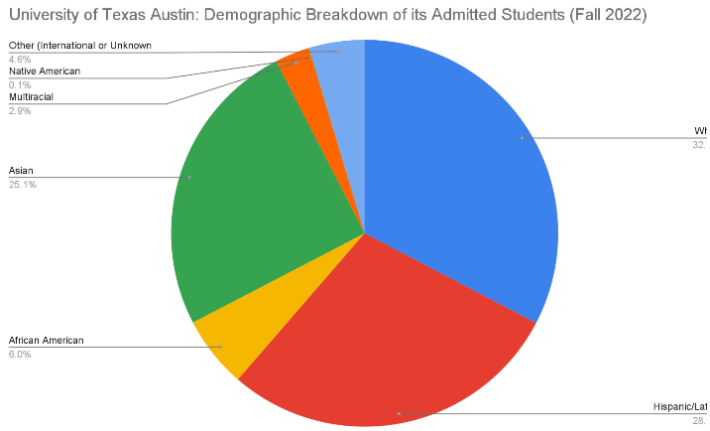


Figure 2: Demographic Breakdown of University of Texas Austin Admitted Students (Fall 2022)

Constitutionality, which was the focal point of Students for Fair Admissions' argument, focuses on the claim that Grutter v. Bollinger was fundamentally flawed, and argues that the case not only contradicts other precedents, such as the Fourteenth Amendment but also relies on racial stereotyping.

> *Excerpt 6.1: Constitutionality Against Affirmative Action*
> Grutter was wrong the day it was decided. Despite reaffirming that "all" racial classifications must satisfy strict scrutiny, Grutter held that "student body diversity" can "justify the use of race in university admissions." 539 U.S. at 325-26. That holding departs from the Constitution's original meaning, contradicts other precedents, has eroded over time, and has no true defenders (Supreme Court of the United States, 2022b, pp. 50).

> *Excerpt 6.2: Constitutionality Against Affirmative Action*
> Grutter's diversity rationale is not only uncompelling; it flouts basic equal-protection principles. Although Grutter praised the "educational benefits" of student body diversity writ large, its assumption that a university can predict, based solely on race, an applicant's "views" or "experience[s]" is pure racial stereotyping. 539 U.S. at 333; see Hopwood, 78 F.3d at 946. The Fourteenth Amendment forbids "the assumption that race or ethnicity determines how [individuals] act or think." Metro Broad., Inc. v. FCC, 497 U.S. 547, 602 (1990) (O'Connor, J., dissenting); see Bush v. Vera, 517 U.S. 952, 985-86 (1996) (op. of O'Connor, J.). If a university wants to admit students with certain experiences (say, overcoming discrimination), then it can evaluate whether individual applicants have that experience (Supreme Court of the United States, 2022b, pp. 52).

When observing admission statistics, Harvard notes that the university accepted 3.41 percent of applications in Fall 2023, which is a total of 1,966 students. The demographic breakdown of its admitted students is as follows: 40.8 percent white, 29.9 percent Asian, 15.3 percent African American, 11.3 percent Latinx, and 2.7 percent Native American/Hawaiian (Figure 1).

In comparison, UT Austin accepted 32 percent of its Fall 2022 applicants and admitted a total of 8,459 students. The demographic breakdown of its admitted students is as follows: 32.6 percent white, 28.6 percent Hispanic/Latinx, 6 percent African American, 25.1 percent Asian, 2.9 percent multiracial, and 4.6 percent other (international or unknown) (Figure 2).

Additionally, UT Austin reports its student admission statistics for students admitted under the top 10 percent rule and those not admitted under the rule. For 2015, the demographic breakdown of its admitted students under the top 10 percent is as follows: 34 percent white, 33 percent Hispanic, 21 percent Asian, 7 percent Black, 3 percent non-U.S. citizen, 3 percent other (Figure 3). The 2015 demographic breakdown for students admitted not under the rule is as follows: 49 percent white, 10 percent Hispanic, 23 percent Asian, 3 percent black, 9 percent non-U.S. citizen, and 5 percent other (Figure 3).

Discussion

Content Analysis Discussion

One general observation from the content analysis is the recurring number of arguments around the theme of constitutionality. The observance of this trend is in alignment with the central question of the case being whether or not the Supreme Court should overturn Grutter v. Bollinger, which permits the use of race as a factor in admissions. Consequently, the foundation of most of the arguments presented against affirmative action by Students for Fair Admissions fixates on the precedents established by other key court cases, including Grutter v. Bollinger, Title VI of the Civil Rights Act, and Fisher v. University of Texas at Austin.

In Grutter v. Bollinger, the Supreme Court upheld the University of Michigan Law School's admissions policy, which considered race as one of the university's factors in achieving the educational benefits of a diverse student body. The case emphasized that diversity in higher education serves a compelling governmental interest, therefore affirming a constitutional basis for race-conscious admission policies. Students for Fair Admissions' case against Harvard directly challenges this precedent under

the notion that the consideration of race inherently violates the Equal Protection Clause of the Fourteenth Amendment.

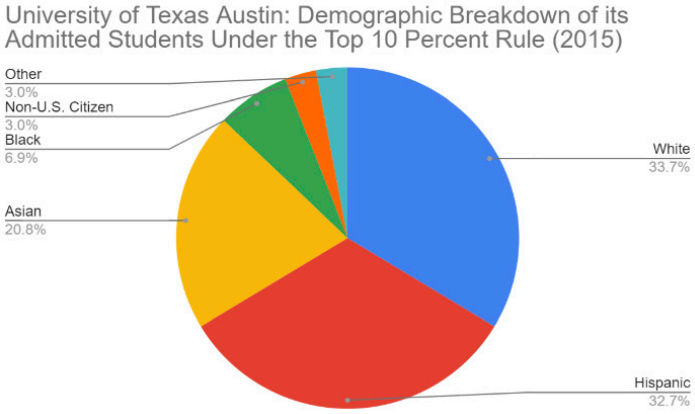


Figure 3: Demographic Break of University of Texas Austin Admitted Students Under the Top 10 Percent Rule (2015).

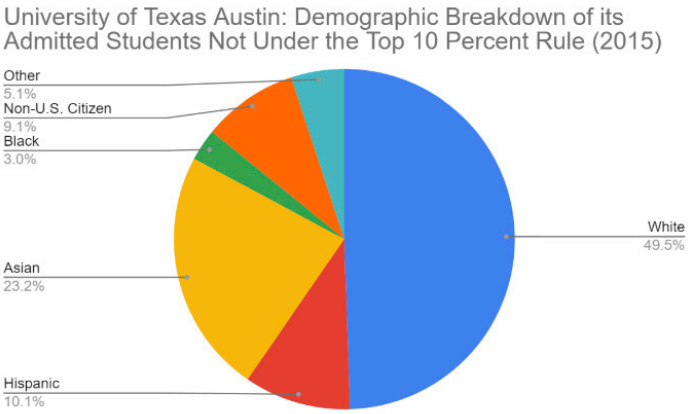


Figure 4: Demographic Break of University of Teas Austin Admitted Students Not Under the Top 10 Percent Rule (2015).

Title VI of the Civil Rights Act of 1964, which prohibits discrimination on the basis of race, color, or national origin in programs receiving federal financial assistance, is another aspect of Students for Fair Admissions' argument. In this context, Students for Fair Admissions argues that Harvard's admission policies violate Title VI by engaging in racial balancing and imposing unfair disadvantages on Asian American applicants. Moreover, Students for Fair Admissions interprets Title VI's statutory language as parallel to the Equal Protection Clause, enabling the group to claim that Harvard's practices are unlawful under both constitutional and statutory grounds.

Fisher v. University of Texas at Austin further refines Students for Fair Admissions' argument as in the case, the Supreme Court evaluated the University of Texas's admissions policy, which combined a top x percent rule with a holistic review that considered race as a factor. The case reaffirmed the constitutionality of affirmative action under the majority opinion that institutions must demonstrate that no race-neutral alternatives could achieve the same diversity goals. Students for Fair Admissions leverages his precedent in order to claim that Harvard's use of race is not necessary given the availability of race-neutral approaches that could achieve similar diversity outcomes.

Students for Fair Admissions' constitutional basis is notable since the reason that the advocacy group filed the lawsuit was initially related to discriminatory practices towards Asian Americans in the admission process. However, the shift from claims of discrimination toward constitutionality makes strategic sense, considering that these arguments predominately originate from white conservatives. By framing the issue away from its constitutional aspect, the group is able to appeal to claims of equity and gain support by positioning the lawsuit as advocating for equal treatment (Wu, 1995; Takagi, 1993). In fact, the lawyers representing Students for Fair Admissions stated that the initial hearing centered on the claim that Asian American applicants are discriminated against rather than trying to challenge affirmative action (Students for Fair Admissions, 2023). Then, by shifting the argument to focus on constitutional principles, the group is able to achieve two things. First, they are able to evade potential racial controversy by avoiding engagement in discussions on race. Second, their strategy strengthens their case by leveraging the existing legal frameworks from other cases to create a more familiar foundation rather than having to build a new, unfamiliar argument. In relation, the initial claim on discrimination by Students for Fair Admissions is likely why a majority of Harvard's arguments in support of affirmative action focus on discrimination and equal opportunity.

To continue, by consolidating their argument to emphasize the supposed negative impact of affirmative action on Asian Americans, Students for Fair Admissions can utilize Asian Americans as a mascot in pushing their own agenda. Notably, the foundation of Students for Fair Admissions as a whole revolves around Asian Americans and their college application experience, which is intriguing considering that the founder of the organization, Jay Blum, is a white conservative and adamant opponent of affirmative action (Blum, 2023). Figures like Blum exemplify the way in which white conservatives speak on behalf of Asian Americans and their stakes as a rhetorical tool to garner support for the discontinuation of affirmative action despite their disingenuous intentions.

Pew Research Center highlights that 53 percent of Asian Americans view affirmative action positively, 19 percent view affirmative action negatively, and 27 percent feel undecided (Ruiz, et al., 2023). Considering the diversity of viewpoints within the Asian American community, it is crucial that policies recognize and respect these varied perspectives. Attempting to generalize or make decisions on behalf of Asian Americans without considering the diversity of perspectives would be unrepresentative. As such, the appropriation of the Asian American experience dismisses the perspective of many Asian Americans themselves. This approach depicts Asian Americans as "innocent victims" in the college admission process, even though it may not necessarily align with the true experiences or

sentiments of the broader Asian American community and that Asian Americans are still very over-represented in admissions data (Lee, 2021). The exploitation also helps to divert attention from the advantages accumulated by white individuals and institutions by avoiding necessary discussions around equity through the victimization of Asian Americans.

It is important to highlight that there are legitimate concerns surrounding Asian American admissions. One that Students for Fair Admissions points out in particular is that Asian Americans often receive lower personality ratings. However, the narrative pushed by Students for Fair Admissions attributes these lower ratings to affirmative action, which is misleading. In reality, these lower personality ratings are not a consequence of affirmative action but rather from issues of racism and implicit bias that devalue Asian Americans as similar to one another (Kidder 2006). By manipulating the issue and redirecting focus away from the real root causes, Students for Fair Admissions is able to misguide others and undermine efforts to address discrimination within higher education admissions.

Continuing, when observing the claims around discrimination and equal opportunity, the viewpoint fuels a false dichotomy between Asian Americans and African Americans that suggests the advancements for one group must come at the expense of the other under the assertion that "personal ratings assigned by Harvard reveal a clear racial hierarchy—with African Americans consistently getting the best personal ratings and Asian Americans consistently getting the worst" (Wang and Wu, 1996; Supreme Court of the United States, 2022b, pp. 16). The claim by Students for Fair Admissions that African Americans are at the top of the racial hierarchy is problematic when considering the historical inequalities against African Americans in the case of slavery, Jim Crow, police brutality, and so on (Veysey, 1980). This misleading narrative serves as a tool to challenge diversity-promoting policies and ultimately maintain existing power structures. Once again, the diversion takes attention away from addressing larger systemic issues of inequality.

Lastly, it is noteworthy that within the Students for Fair Admissions v. Harvard case, there is a lack of transparency regarding the individuals or entities involved in petitioning against Harvard, as they chose to stay anonymous to avoid criticism (Supreme Court of the United States, 2022a). However, without clear visibility into the identity of those making the claims, there is the potential that the claims made against Harvard's admission processes may not accurately represent the real experiences of discrimination faced by Asian American applicants.

Admission Statistics Discussion

Shifting to the admission statistics, Harvard's admissions are highly competitive as the university only accepts a small percentage of applicants. The demographic breakdowns show representation of various racial groups. In particular, there is a higher proportion of white and Asian students in comparison to representation from African Americans, Latinx, and Native American/Hawaiian communities. Considering that Harvard has faced legal accusations of discriminating against Asian American applicants, it is interesting to see the notable presence of admitted Asians as it would make them the largest accepted group of minorities. Similarly, Harvard admitted 59.2 percent of people of color, which suggests that affirmative action helps in the promotion of diversity.

In UT Austin's approach, the demographic breakdown of students admitted under the top 6 percent rule shows a more diverse representation. In particular, there are higher proportions of Hispanic and Black students compared to those admitted outside of the rule. This aligns with how top x percent rules tend to promote socioeconomic diversity by drawing students from various backgrounds, including underserved regions like rural areas with significant African American and Hispanic populations (United States Department of Education, 2003).

Additionally, while it is worth noting that UT Austin admits a higher number of Hispanic students compared to Havard, this observation may not offer much significance given that Texas's population is comprised of 40.2 percent Hispanics (United States Census Bureau, 2022). As such, the demographic representation suggests that the higher count of admitted Hispanic students is a result of the state's demographics rather than attributing it to the top 10 percent rule.

To continue, 29.9 percent of admitted students to Harvard were Asian compared to the 21.5 percent of Asian students admitted to UT Austin. Considering the regions from which the majority of applications come for each institution helps to clarify the meaning of these statistics. In the Northeast region, where Harvard draws a majority of its applicants, Asians make up 7 percent of the population (United States Census Bureau, 2020). Comparatively, Texas, where UT Austin receives its applications, has an Asian population of 5.7 percent (United States Census Bureau, 2022). Contextualizing these proportions suggests a lesser impact of race-neutral policies on Asian Americans compared to race-conscious policies. The lessened impact is likely because race-conscious policies allow institutions to consider the broader context of an applicant's identity, enabling nuanced evaluations that can favor Asian American applicants outside of the "model minority" myth and whose experiences contribute to diversity beyond academic metrics (Wang and Wu, 1996). Harvard's race-conscious approach may also help to enable recognition of the diversity within Asian American communities, including socioeconomic and cultural factors that race-neutral policies might overlook. In contrast, UT Austin's race-neutral policies rely heavily on quantifiable metrics like class rank, which can disadvantage Asian Americans from competitive high schools, aligning their admission rates more closely with their demographic representation in Texas.

The same logic can also apply to other racial demographics. The Northeast region consists of 10 percent African Americans and 16 percent Hispanic while Texas consists of 13.4 percent African Americans and, as mentioned earlier, 40.2 percent Hispanics (United States Census Bureau, 2020; United States. Census Bureau, 2022). As such, the statistics indicate a higher impact of race-conscious policies on African Americans and Hispanics when compared to demographic statistics of the broader population (Lee, 2006). These demographic disparities highlight why race-conscious policies have a more pronounced impact on African Americans and Hispanics. In the context of Harvard's applicant pool race-conscious policies serve as a mechanism to ensure that African Americans and Hispanics are represented at levels reflective of their broader societal presence. For these groups, race-conscious admissions address disparities in representation relative to their demographic proportion, counteracting historical and systemic inequalities that have limited their access to elite institutions previously.

Additionally, Asians represent 21 percent of admitted students under the top 10 percent rule, compared to the 23 percent of admitted students outside of this rule. The comparison between admissions under the rule and non-rule admissions suggests a consistent representation of Asian Americans, with a marginal 2 percent difference, which implies that race-neutral policies may not significantly impact the proportion of Asian American students admitted.

It is of note that the data comparison between the two admission cycles is not from the same admission cycle. Moreover, the 2015 data from UT Austin on students admitted under the top 6 percent rule and those who were not admitted pertains to a different cycle and time when UT Austin was admitting the top 7 percent of high school graduates. Nevertheless, this discrepancy is a minor inconsistency that is not significant enough to suggest a major deviation.

Overall, when comparing the admission statistics against the claims by Students for Fair Admissions, there is little indication that affirmative action hurts Asian American admissions. Notably, a study on legacy and athlete preferences at Harvard found that 43 percent of white students who got into Harvard did so through legacy connections or because they were student-athletes (Arcidiacono, et al., 2019). As such, the racial distribution of admitted students would change significantly if Harvard removed preferences for athletes and legacies since there would be fewer whites. In this aspect, Asian Americans may be losing their spots to white students rather than African Americans.

Limitations and Future Research

One of the limitations of the research is the sampling size of the content analysis, which concentrates on one specific court case and, within that, a specific part of the court case. As such, it is a selective representation of affirmative action that omits other aspects, meaning there is limited generalizability of my findings. Moreover, while the analysis provides insight into the depth and serious implications of having either race-conscious or race-neutral admissions, the court case has a focus on Harvard University in particular, which means it is not representative of race-conscious admissions as a whole as there are case-specific factors present. However, it is important to keep in mind how significant a court case Students for Fair Admissions v. Harvard was. Similarly, both the respondent and petitioner briefs are advocacy documents written to support their respective positions, which results in one-sided arguments.

Notably, the disparity in racial categories between Harvard and UT Austin poses a challenge in comparing the two. For example, the admission statistics for admitted African Americans at Harvard also include those who are of mixed race and non-Hispanic, which can skew the data, as this category would encompass African Americans as well as mixed-race applicants. On the other hand, mixed race is a separate category that does not solely account for African Americans or Hispanics.

In consideration of the limitations within the research, I believe that the main focus of future research should address what this paper is lacking. As a starter, future research should look to get testimonies from Asian American applicants so as to view what they think their stakes are rather than having another group speak on behalf of Asian Americans. Having direct testimonies would address gaps in understanding Asian American experiences and perspectives in terms of what claims and language the group would use regarding affirmative action.

Additionally, expanding the scope to encompass cases like Grutter v. Bollinger, Regents of the University of California v. Bakke, and Fisher v. University of Texas at Austin as these are other cases around the constitutionality of affirmative action that would provide a more comprehensive understanding of affirmative action's legal landscape.

In relation to the statistical analysis, a longitudinal study that compares the impact of race-conscious and race-neutral admissions plans over time would provide a broader dataset, offering insight into the sustained efficacy of these policies. Examining multiple cohorts of students across various admission cycles would allow researchers to analyze trends and patterns and evaluate how different policies affect students from various backgrounds. Beyond admission statistics, a longitudinal study could also investigate additional factors such as first-year retention rates, graduation rates, and income levels.

Future research should also include other schools, such as the University of Michigan, which has a history of using race-conscious admissions and court cases related to its usage like Harvard, as well as the University of Florida, which is one of the universities under the Florida Talented 20 Program,

highlights variations in policies, which helps to provide insight into evidence-based recommendations and best practices for promoting equitable admission policies.

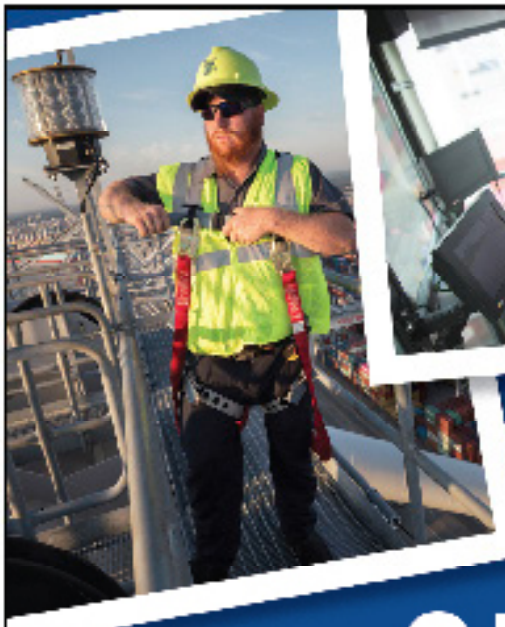
Conclusion

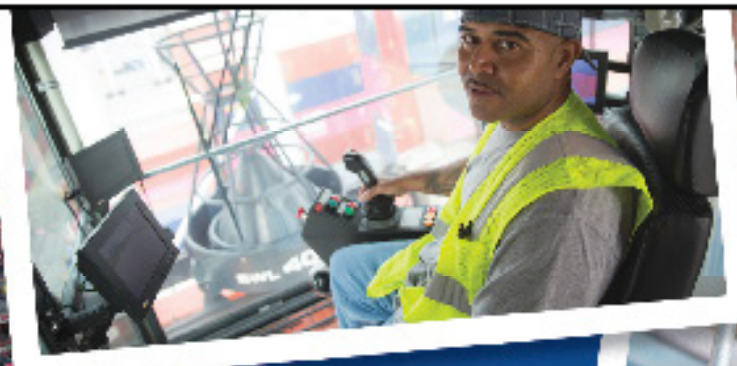
To reiterate, the findings from the content analysis of Students for Fair Admissions v. Harvard reveal how Asian Americans often serve as a divisive tool leveraged by white conservatives to challenge affirmative action policies and maintain power, often at the detriment of African Americans. The usage of racial minorities reflects a broader strategy that is meant to undermine policies designed to address systemic oppression. In the case of race-neutral and race-conscious policies, race-conscious policies are better equipped when used in a holistic admissions process to address admission disparities, ensuring more equitable access to higher education for underrepresented minority groups.

Moreover, the conclusion of this study aligns with Omi and Winant's theory of racial formation when it comes to how the establishment of race-neutral policies often perpetuates systemic racism by failing to account for historical inequalities, representing a racial project that sustains white privilege within elite institutions. Conversely, race-conscious admissions policies are racial projects that look to disrupt these power imbalances by considering the historical contexts of marginalized groups. By examining affirmative action through the lens of racial formation theory, this research underscores the importance of historical context and power dynamics in shaping contemporary debates.

In essence, the discourse surrounding affirmative action, particularly in relation to Asian Americans, requires acknowledging the complex intersection between racial and power dynamics within higher education. This research emphasizes the importance of moving beyond a black-and-white narrative and instead, highlighting diverse viewpoints that represent the experiences of all racial groups involved. Furthermore, it is crucial to prevent dichotomous discussions that position different racial groups against one another. The counterproductive process only diverts attention away from the root issues of historical and systemic oppression. Recognizing the nuances of race-conscious and race-neutral impact of various racial communities lays the foundation for creating informed and fair policies that foster diversity, equity, and inclusion.

Access references for this paper using the QR code below.





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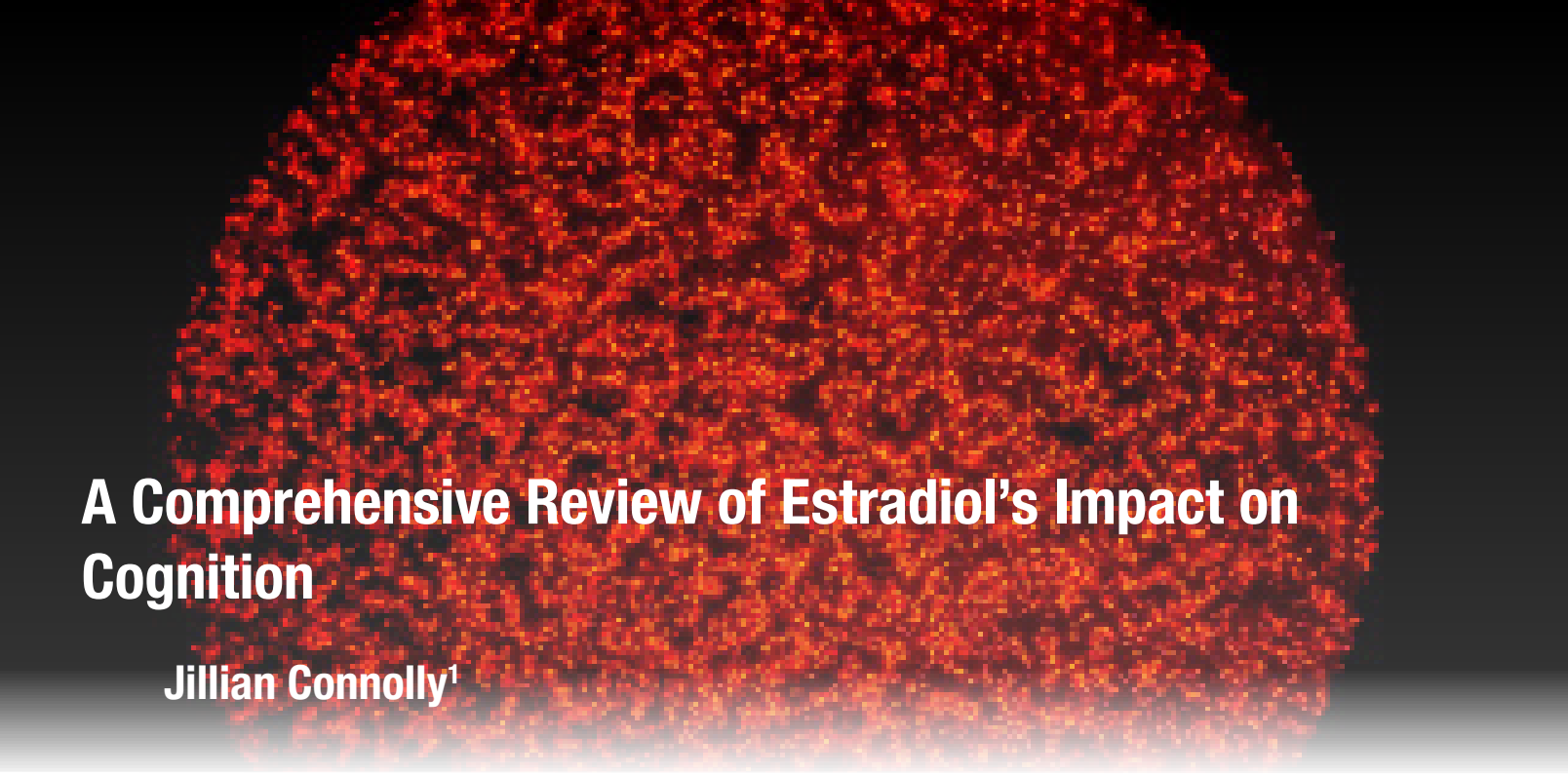

A Comprehensive Review of Estradiol's Impact on Cognition

Jillian Connolly[1]

Abstract

Estrogen's role as a female reproductive hormone has been well established over the past two decades, with great advancements made in establishing hormonal sex differences between males and females. Through this research, evidence of estrogen in supporting human cognition emerged, and recent efforts of researchers have culminated in a wide array of human and rodent studies that seek to examine the impact of this steroid hormone on cognition. Rodent research offers a unique opportunity to precisely observe cognition changes in response to estrogen manipulation; however, it is limited in the ability to measure all aspects of cognition such as verbal fluidity. Human studies focus on indirectly observing the impact of estrogen on cognition, but these studies are limited in their ability to control for external factors in the participants' lives. Since no single research study offers a comprehensive examination of estrogen's role in cognition, this review connects the existing literature in rodent and human populations to provide insights on patterns that exist in the field to establish a foundation for future research questions.

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Background photo courtesy of Alexis Vladescu

Introduction

Estrogens are a class of steroid hormones that are produced primarily in the ovaries and testes, and they function as regulators of multiple physiological functions throughout the lifespan (Fuentes et al., 2019). Estrogens can be classified into the following four categories based on their role and time of circulation in the female body: estrone (E1), estradiol (E2), estriol (E3), and estetrol (E4) (Chen et al., 2022). Estrone is the predominant form of estrogen present in postmenopausal women, while estriol and estetrol are only present during pregnancy. Many studies focus on estradiol since this is the predominant form of estrogen present in females during reproductive years. Although estrogens support both male and female health, this review will focus on the role of estradiol in female cognition.

As females enter puberty, levels of estradiol, which regulate the development of secondary sexual characteristics including breasts and pubic hair, begin to rise. (Fuentes et al., 2019). Upon reaching menarche around the age of 12, estradiol serves as a primary regulator of the menstrual cycle for the duration of the reproductive years until menopause occurs, around age 50 (Ramraj et al., 2023). During the reproductive years, estradiol also supports a vast range of functions, including promoting libido, supporting bone density, maintaining reproductive organs, regulating inflammation, and promoting brain health (Fuentes et al., 2019). Although estrogen's role in cognitive function is still under investigation, existing research studies provide a foundation for understanding the underlying mechanisms and functions.

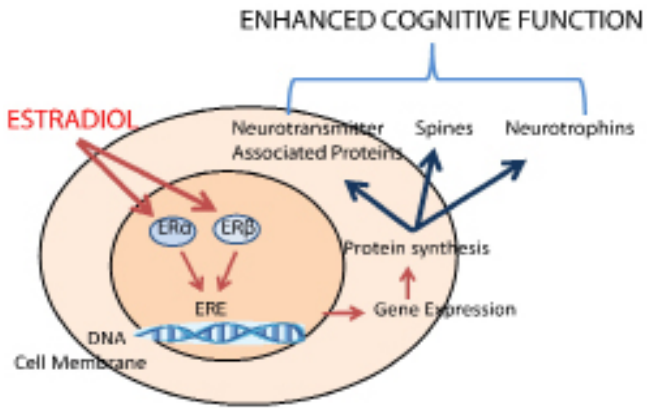

Figure 1. Illustration of estradiol's genomic mechanism. (Luine 2014).

To examine the role of estrogen in brain health and cognition, it is first important to understand estrogen's two primary pathways of acting upon their receptors: the genomic pathway and the non-genomic pathway (Luine, 2014). In the genomic pathway, estrogen binds to its intracellular receptor to increase protein synthesis that results in long-lasting changes in the body, while the non-genomic pathway involves estrogens binding to the extracellular membrane to induce an intracellular cascade of secondary messengers to produce rapid but short-lived changes. In the framework of cognition, research suggests that the non-genomic pathway may be related to working memory, while the classic genomic pathway may be related to longer lasting changes such as episodic memory over the lifetime (Luine, 2014).

Over the past three decades, studies have examined the interplay between estrogen and cognition to better understand neurodegenerative disease. For example, investigating estrogen's role as a protective hormone against neurological diseases such as Alzheimer's has shown that the presence of estrogen may reduce the devastating impacts of the cognitive dysfunction that is characteristic of this disorder (Oveisgharan et al., 2023). Furthermore, recent studies have demonstrated that estrogen is important for healthy cognitive aging. Estrogen Replacement Therapy (ERT) in clinical and research settings has emerged as a treatment for cognitive decline in post-menopausal women, although efficacy is still in question (Appleman et al., 2024). Beyond clinical applications, studies examining cognitive fluctuations across the monthly menstrual cycle suggest that females may be cognitively sharper during times in the cycle when estradiol is high, and these findings may have applications for informing policy to improve workplace productivity and educational performance (Maki et al., 2002). Due to these significant applications, this review examines the impact of estrogen, particularly estradiol, on cognitive function by analyzing human and rodent research conducted over the past three decades.

An Evaluation of the Existing Literature

Early Research in Rodents

Rodent studies provide the cellular and molecular foundation for estradiol's impact on cognition since they allow for invasive, precise manipulation of the genome and hormone level. During one of the first studies investigating the impact of estrogen on cognition in a rodent population, researchers observed the effects of estradiol administration to ovariectomized rats to determine if estradiol exposure prior to the radial arm maze task impacts performance in the maze (Daniel et al., 1997). The radial arm maze is a method used to assess working memory, reference memory, and visual-spatial memory in rodents by observing how quickly rodents can remember where the locations of rewards, oftentimes food, are located in the maze (Kim et al., 2018). The ovariectomized rats were randomly divided into groups to receive varying intensities of estradiol injections for thirty days leading up to the study and throughout the twenty-four hours during the study. The results demonstrated a strong positive correlation between estradiol level and mean correct choices made in the maze. This result suggests that the presence of estradiol promotes spatial memory in rats.

Based on this key finding, researchers asked a second question: What would happen if a second experiment was conducted in which ovariectomized rats received estradiol treatment for thirty days leading up to the experiment during training, but not in the day directly before the experiment or during the experiment?

Halting estradiol administration in s that the hormone is not present in the rats at the time of the administration of the task. Again, the researchers found that there was a positive correlation between performance on the radial arm maze task and estradiol level during training. This finding is crucial in understanding the molecular mechanism of estradiol action because it suggests that estradiol drives within the rodent brain with long-term effects. Essentially, estradiol does not need to be actively in circulation for its structural impacts that assist in cognition to remain beneficial (Daniel et al., 1997). This research laid the foundation for future research to investigate estrogen receptors in the brain and their contribution to long-term and short-term effects on cognition. The current consensus in the field is that estrogen receptors can act genomically by inducing transcription factors in the nucleus, as demonstrated in previous rodent research. In addition to genomic mechanisms, estrogen can cause rapid, short-term changes through non-genomic mechanisms by binding to cell membrane receptors to induce a secondary messenger signaling cascade (Mitterling et al., 2011). In relation to humans, it can be speculated that the short-term, non-genomic mechanisms may help support cognition factors such as working memory that are more fleeting, while the long-term, genomic mechanism may support more longitudinal cognitive functions such as episodic memory.

Differences in 17α-estradiol and 17β-estradiol on Cognition

To obtain a comprehensive understanding of the mechanism through which estradiol may impact cognition, it is important to examine both isoforms of estradiol. Estradiol has two known isoforms, meaning that there are two structural versions of estradiol that differ slightly in their amino acid sequence: 17β-estradiol and 17α-estradiol. The extent of 17β-estradiol and 17α-estradiol's functional differences are not yet known, but researchers are investigating if the isoforms are correlated with measurable cognitive differences. To investigate these differences, rats were treated with varying doses of either 17β-estradiol or 17α-estradiol, and behavior during a spatial memory task was observed. Specifically, the object-place memory task recorded the time that it took for each group of mice to find an object at both a familiar and novel location to test spatial memory. The novel object recognition task was identical to the object place memory task for the first trial, but then in the second trial, one of the familiar objects was replaced with a novel object. The researchers recorded the time that the rats spent investigating the novel object, and this served as a method to measure non-spatial memory. The results reveal that the injection of either 17β-estradiol or 17α-estradiol is correlated with significant improvements in both spatial and non-spatial memory, with rats showing improvements in memory as early as four hours after treatment. These findings are consistent with previous findings in the field that demonstrated how estradiol may act through non-genomic mechanisms by inducing a cascade of secondary messengers to elicit rapid changes after binding to a receptor on the cell membrane rather than changing the genomic sequence in the nucleus, which is a much slower process (Srivastava et al., 2013). Beyond establishing a significant trend which revealed the ability of estradiol to promote cognition in rodents, this study demonstrated that 17α-estradiol was more effective in enhancing memory than 17β-estradiol (Inagaki et al., 2010). It may be beneficial for future studies to investigate the magnitude of potency differences on cognition between 17α-estradiol and 17-β-estradiol. For example, perhaps 17α-estradiol has a more powerful effect on enhancing cognition in spatial and navigational aspects, but perhaps the magnitude in the gap between the two isoforms is smaller for working memory tasks.

An Investigation of Human Research in the Field

In order to investigate how rodent results translate to a human population, an observational study followed the journey of 69 reproductive-aged females who were experiencing Polycystic Ovary Syndrome, or PCOS (Barry et al., 2013). PCOS is a hormonal condition in which patients experience higher than normal levels of androgens and estrogens. Therefore, the researchers utilized this population with naturally higher levels of estradiol in their body to observe how this condition may relate to visual-spatial memory in a 3-D object rotation task. Prior to participating in the study, blood samples were taken from the females to ensure that their hormone levels were significantly above the normal level for a female of their age. After three years of testing, the results revealed that women with PCOS scored significantly higher than a control group of non-PCOS women on the visual-spatial cognition task (Barry et al., 2013). Although this study is consistent with the results observed in rodents, the main limitation is that correlation does not indicate causation, so it is not possible to affirmatively declare that high estradiol levels in females leads to enhanced visuospatial performance.

Estradiol also appears to impact working memory for facial expressions in reproductive-aged women during different phases in the menstrual cycle (Gasabarri et al., 2008). When 56 young female adults took an emotional-facial memory test during different times in their cycle, significant patterns emerged from the data. During the follicular phase when estradiol levels are high, participants demonstrated decreased recall abilities for remembering sad and disgusted facial expressions. It is important to note that this decrease in working memory recall ability is specific only to disgust and sadness, and this impairment does not apply to other emotional facial expressions. Importantly, there were no significant differences

compared (Gasabarri et al., 2008). Similar research conducted on non-human primates, specifically rhesus monkeys, reveals a similar trend, suggesting that this decrease in sensitivity to facial expressions may be evolutionarily conserved to promote successful mating behaviors that lead to reproduction (Lacreuse et al., 2006). In contrast to the previous studies which support the role of estradiol in impacting cognition, a study investigating Estrogen Replacement Therapy (ERT) in a group of 100 postmenopausal women revealed no significant correlation between estradiol level and cognition (Almeida et al., 2006). A group of 115 female participants over the age of 70 consented to participate in the study, and they were divided into revealed no significant differences in cognitive function between the placebo pill group and the estradiol pill group (Almeida et al., 2006). One important consideration that may explain the lack of significance is that these postmenopausal women were receiving estradiol (E2) pills, and the primary form of estrogen naturally circulating in the female body after menopause is estrone (E1) (Chen et al., 2022). To better understand this limitation, future research studies must examine if the efficiency of estradiol binding to its receptor decreases in women once they enter their postmenopausal years. If this is the case, then estradiol treatment may not be the most effective treatment to prevent cognitive decline in older populations.

An interesting longitudinal study that may provide insight into estradiol's impact on aging is to perform a follow up study with the women from the observational PCOS study after menopause to see if the estrogen replacement therapy has significant or non-significant effects. If the group of PCOS women with higher estradiol levels who previously outperformed women with average estradiol levels during their reproductive years no longer demonstrate higher performance in cognitive function after menopause, then perhaps the conflicting results demonstrated by ERT studies has less to do with estradiol's inability to promote cognition and more to do with age-specific effects. If that is the case, invasive rodent research may provide more insight into the exact mechanism of estradiol's binding affinity over the lifespan.

Applications in Alzheimer's Research

An emerging area of focus in estrogen and cognition research is the examination of estradiol as a protector against one of the most common neurological diseases present in the aging population: Alzheimer's Disease. One strategy for investigating estradiol's role in protecting against Alzheimer's Disease has been to observe the effect of estradiol on protecting neurons and cognitive function in the presence of amyloid beta, a common marker of AD (Hruska et al., 2007). To achieve this goal, a group of rats were ovariectomized, and estradiol was injected into their skin followed by an amyloid beta and ibotenic acid injection into the hippocampus. The amyloid beta and ibotenic acid created a biological environment within the rodent that mimics AD. A control group was also present with only amyloid beta and ibotenic acid injected into the hippocampus without the estradiol injections. After testing the rats in the radial arm maze, results indicated that the rats who were injected with only amyloid beta neurotoxins and ibotenic acid performed significantly worse than the rats who also received estradiol treatment. These results are indicated by an increase in mean path length savings for rats receiving estradiol treatment. Based on these findings, estradiol serves a valuable function beyond reproduction in females, as this study demonstrates estrogen's role in neuroprotection against neurotoxins to preserve cognitive function.

Although human research on this topic is difficult to examine due to ethical considerations, one study compared estrogen level concentrations between a neurotypical control group and a group of individuals with Alzheimer's Disease. Preliminary results revealed that the Alzheimer's Disease group had significantly lower levels of circulating estrogen than the control group (Manly et al., 2000). One major limitation of this study is that this negative correlation does not indicate causation, so we cannot assume that lower estrogen levels lead to Alzheimer's Disease. We can, however, note that low estradiol levels are associated with Alzheimer's Disease, and this finding is in alignment with previous studies which associate low levels of estradiol with cognitive dysfunction. Further human research is needed to understand if low estradiol levels are a result of Alzheimer's Disease, or if low estradiol levels may somehow cause Alzheimer's Disease. An interesting longitudinal study would be to follow a group of postmenopausal women who are receiving estrogen replacement therapy to see if the rates of Alzheimer's Disease are lower in this group compared to the average population that is not receiving estrogen replacement therapy. If ERT is correlated with lower rates of Alzheimer's Disease, then this will be a strong avenue of future research for developing treatments to slow the progression of this devastating neurological disorder.

Current Limitations: HPA and HPG Axis Interaction

It is important to address key limitations that are present in the current literature on estradiol in relation to cognition. Many rodent studies utilize tasks that are stress-inducing for rodents such as the radial arm maze task used by Daniel et al. This stressful task may activate the Hypothalamic-Pituitary-Adrenal (HPA) axis which is the neuroendocrine axis that initiates the stress response in vertebrates (Fulford et al., 2004). This pathway leads to a release of glucocorticoid hormones, predominantly cortisol, which is the primary stress hormone in rodents and humans. The Hypothalamic-Pituitary-Gonadal (HPG) Axis, which regulates the release of reproductive hormones, may be impacted by the HPA activation. The accepted results of existing literature do not account for the rise in cortisol associated with the stressful tasks the rodents are performing. To limit the interaction of the HPA and HPG axis, future rodent studies can achieve more isolated results by placing minimal stress on the animals during tasks such as object recognition activities (Inagaki et al., 2010). With experimental design in mind, future projects can become creative in their methods of assessing cognition without simultaneously inducing stress that may taint the results.

Current Limitations: The Potential Interaction of Baseline Dopamine on Cognition

Recent research has pointed to the impact of dopamine on cognition studies in humans. The interaction of baseline dopamine on cognition jeopardizes the validity of the results of human cognition studies if the data is not adjusted for baseline dopamine levels since fluctuating dopamine levels may also lead to elevated or deflated scores for participants (Jacobs et al., 2011). Dopamine's impact operates as a function resembling a bell curve, so too much or too little dopamine will alter cognition. After testing 79 young females, a study found that participants with low baseline dopamine show improved performance on a working memory task at the end of the follicular phase when estradiol is high versus low, while participants with a high baseline dopamine level would perform better when estradiol is low at the start of the period versus high near ovulation (Jacobs et al., 2011). This research study highlights the difficulties in examining the impacts of hormones on human cognition since we cannot easily isolate these variables from each other. A more recent study argues that there is a clear interaction effect between dopamine and estrogen, stating that higher estrogen levels lead to higher dopamine levels (Hidalgo-Lopez et al., 2017). This study found that working memory was enhanced in human participants when estradiol and progesterone levels are high near the time of ovulation, but we must account for baseline dopamine levels to obtain consistent results. Female neuroanatomy and physiology are very interconnected, so it is sometimes difficult to determine if a correlation that we observe in the data is solely attributed to the variable that we assume is the clear cause. The more recent studies that examine dopamine and estradiol together argue that the results obtained by this work will produce more consistent results compared to the studies that examine estradiol alone.

Conclusion

The research performed over the past four decades investigating estradiol and cognitive function has established that estradiol serves a crucial function beyond supporting female reproductive health. The results of studies conducted in both humans and rodents establish estradiol as a key hormone in the brain that supports the proper functioning of various cognitive processes, especially spatial memory and working memory. Studies conducted in rodents reveal that an estradiol deficiency is correlated with low cognitive performance on spatial navigation tasks, indicating that higher estradiol levels are correlated with higher performance until ceiling effects are reached. Although various forms of human longitudinal, observational, and experimental studies display differences in the exact details of estrogen's role in cognitive function, most studies concur that estradiol is necessary for proper cognitive functioning in adult females. While these results are promising, future studies must account for the two major flaws that are present in much of the existing literature. First, the experiment must be designed in a non-stressful way to avoid causing the activation of the HPA axis, since this might interfere with HPG axis functioning and cause skewed results. Secondly, future human studies must account for the baseline dopamine level in participants since an emerging body of research is displaying that this factor may contribute to varying results as well.

With these two cautions in mind, researchers must investigate the emerging questions that still exist in the field. What is the impact of estradiol on cognition over the shorter 28-day cycle as opposed to over the lifespan? How does Alzheimer's rodent research translate to a human population? Furthermore, what other neurological disorders may be slowed by estradiol treatment other than Alzheimer's? More importantly, is there a successful way to administer estrogen treatment to the aging female population to slow cognitive decline?

If researchers seek to answer these questions, significant progress will be made, from clinical applications to educational techniques and workplace policy. When researchers better understand the role of estradiol in protecting against amyloid beta, breakthroughs for Alzheimer's treatment may be discovered. Expanding from this idea, estradiol has the potential to alleviate the detrimental progress of other neurological disorders such as other forms of dementia. Along a different area of focus, a comprehensive understanding of estradiol's impact over a 28-day cycle may lead to advancements in female cognitive performance by knowing when cognition is sharpest based on estradiol level and menstrual cycle phase. These findings will assist educational practices and workplace policies be designed to support women to work with the complexities of their bodies rather than against them. Although there are still many unanswered questions in the field of estradiol and cognition, the progress made over the past forty years places current researchers in a unique position to answer these questions.

Access references for this paper using the QR code below.

Impact of Maternal Psychosocial Stress on Fetal Neurodevelopment

Sarayu Ayyalasomayajula[1]

Abstract

Prenatal stress, marked by heightened maternal stress during pregnancy, profoundly impacts fetal development, with implications for behavior and cognitive deficits, as well as neurodevelopmental disorders in children. This review synthesizes research on the psychosocial influences on prenatal stress, examining stressor origins and their effects on fetal health. Studies reviewed demonstrate associations between maternal psychosocial stressors, such as socioeconomic status and environmental factors, with adverse fetal outcomes, including increased risk for autism spectrum disorder. This review also elucidates the mechanisms through which stressors alter neural frameworks in the developing fetus, impacting factors like attention span, emotional regulation, and neuropsychiatric risk. Interventions targeting maternal well being and support systems are highlighted as crucial for mitigating prenatal stress and promoting healthy fetal neurodevelopment. Future research directions emphasize the importance of inclusive samples and standardized methodologies to better understand the diverse experiences of pregnant individuals and address disparities in maternal and fetal health outcomes. By identifying the root causes of prenatal stress and consequent fetal neurodevelopment, this review underscores the need to prioritize maternal mental health to improve maternal and child well being.

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Background photo courtesy of Terry Xie

Introduction

Prenatal stress, a phenomenon highlighted by high levels of maternal stress during pregnancy, has increasingly become a topic of discussion in fields like neuroscience, medicine, and public health (Jagtap et al., 2023). Dealing with pregnancy related stress is a normal and widespread experience; yet, in many cases, elevated prenatal stress can negatively impact fetal development. In recent years, research studies have turned to look at the long-lasting effects of prenatal stress on the fetus and future offspring, noting the link between stressors and increased risk for illness (Rakers et al., 2017). These negative effects on wellbeing include a wide range of fetal outcomes, including neurodevelopmental disorders, mood disorders, and cognitive deficits that can carry into adolescence and adulthood (DiPietro, 2012).

There are many contributing factors to prenatal stress that ultimately play a role in the development of a fetus. The primary focus among these determinants centers on physiological and psychological stressors (Jagtap et al., 2023). These factors fall under a wide umbrella of chronic and acute stressors that dramatically alter the intrauterine environment. This comprehensive review aims to dissect the psychosocial influences on prenatal stress and their corresponding effects on fetal neurodevelopment. In day-to-day life, psychosocial stressors deal with situations of social stress or instability; for instance, insecurity pertaining to food, housing, and immigration, as well as the loss of relationships or jobs (Patel & Dev, 2023). These stressors can lead to heightened maternal cortisol levels, which have been associated with altered fetal brain development and potential risks for neuropsychiatric disorders (Bergman et al., 2010). Additionally, prolonged exposure to such adversities may contribute to the child's long-term cognitive and emotional well-being. Understanding these mechanisms is crucial for developing interventions that mitigate the adverse effects of prenatal stress and promote improved maternal and child health outcomes.

Understanding prenatal stress is a complex field to navigate, involving multidimensional factors that affect fetal outcomes. This review revolves around uncovering the impact of maternal stress on offspring and how to shape maternal health for the better. By increasing awareness of the innate psychosocial stress that exists during pregnancy, future mothers, healthcare providers, and social workers can find solutions to minimize the negative implications of elevated stress levels. Through such work, changes can be implemented to not only ease the stress of expectant mothers but reduce the stress-related consequences on the developing fetus. Currently, there are many modifiable actions and paths that can be taken to eliminate stressors. Therefore, acknowledging these steps is paramount to instigating significant changes within the healthcare system.

With this comprehensive review, the primary purpose is to consolidate information surrounding the widespread impacts of prenatal stress on fetal behavior, cognition, and psychopathology. Understanding the mechanisms by which behavior and cognition are altered is critical to analyzing the connection between maternal stress and fetal neurodevelopment. Moreover, examining the processes that are altered by exposure to prenatal stress allows for the recognition of potential neuropsychiatric disorders that can arise. By gathering insights from various studies, our goal is to provide a thorough examination and interpretation of the current state of research in this field, and to spearhead broader impacts and solutions for improving maternal health and wellbeing. Throughout this review, we will address distinct psychosocial stressors and elucidate the mechanisms through which they alter neural frameworks in the developing fetus.

Origins of Maternal Psychosocial Stress

Acknowledging the psychosocial contributing factors to stress is critical for gaining a multidimensional approach to prenatal stress. While the conditions related to the mother's environment and social scheme may be disconnected from the development of the fetus, these external factors are precisely more intertwined than one would think. However, when exploring social aspects, the psychological impact on the mother must also be considered. In pregnantindividuals, mental health issues are particularly prominent, due to the high levels of stress one endures by carrying a child. Specifically, many expectant mothers face extreme levels of stress, ending up diagnosed with anxiety and depression. Studies have shown that 16% or more women are symptomatic for depression, with 5% having major depression disorder (Schetter & Tanner, 2012). Uncovering the reasoning behind women's psychological distress can enable a broader understanding of the physiological alterations that affect child outcomes. Factors such as maternal sensitivity and high socioeconomic status have the potential to increase the impacts of prenatal stress, underlining the reasoning behind diving into these social factors (Nolvi et al., 2022).

In mothers, socioeconomic status plays an omnipresent role in their emotions and actions. Everything from access to doctors that facilitate the pregnancy process to exposure to prenatal vitamins is affected by one's status. People that come from more stable backgrounds can afford to buy resources like diapers and wipes earlier in their pregnancy term, rather than scrambling to find these necessities once the child is born. As a result, mothers shift their priorities from personal health to ensuring their newborn's needs are met, often at the expense of their own well being. Over time, the lack of self-care and support may contribute to long-term physical and mental health complications for both the mother and child. Financial instability also contributes to widespread stress, creating uncertainty in how to prepare for the unborn child. Specifically, issues with housing or job security may arise that burden a pregnant mother and create a balancing act between health and money. The compounding nature of these stressors causes significant effects on the fetus.

Analysis of Stressor Origins

A longitudinal study of 373 mother–child pairs, following them from pregnancy until 10 years of age, assessed the impact of socio-environmental stressors on maternal stress and consequent child behavioral issues (Amici et al., 2022). In creating the study, a few predictions were made: higher levels of stress would arise when mothers are less satisfied in their environment, and when dealing with internal problems like anxiety and poor self-estimation. The subjects were periodically evaluated with questionnaires, given to the mother at 34-36 weeks of gestation, as well as when the child was at 7, 8, and 10 years of age (Amici et al., 2022). With the questionnaire, mothers were asked to provide their satisfaction on various social and environmental conditions, such as natural environment, e.g. air quality, neighborhood safety, and presence of social areas and meeting places, e.g. playgrounds. From there, they calculated 5 indexes to measure satisfaction and compared the data set to the questionnaire answers regarding child behavioral observations and patterns. Next, linear mixed models were utilized to statistically analyze the data using the programming language R (Amici et al., 2022). The results aligned with the predicted effects, showcasing high maternal stress when dissatisfied with environmental surroundings, as well as increased reporting of child behavioral problems (Amici et al., 2022). Overall, the study was comprehensive, aiming to not only identify maternal stressors, but predict the effects that would ensue as well. The results underlined the high probability of childhood behavioral issues that arise in conjunction with social stressors that internalize and externalize behavior problems. The study also underscored the origins of maternal stressors, indicating how even a lack of self-esteem or large proximities to social gathering locations, i.e. in rural communities, can induce elevated stress levels (Amici et al., 2022).

However, it is important to acknowledge limitations within the study. For instance, controls such as family income were unable to be added to the data set for analysis, as the information was unavailable for all participants. Thus, the study could not reliably control for differences in socioeconomic status, a known cause for prenatal stress in mothers. Moreover, the cross-domain relationship between measures of maternal stress and child behavior problems must be cautiously interpreted, as there was the potential for an overwhelmingly stressed mother to wrongly perceive their child's behavioral conduct, resulting in inaccurate data collection. Despite this, the study maintained its strength through regular strategically timed questionnaires with the subjects to gather significant and noteworthy evidence.

Another study focused on both prenatal exposure to psychosocial stress, as well as environmental pollutants to recognize the mother's impact on fetal development (Perera et al., 2013). Presenting a longitudinal birth cohort study of 248 children followed from in utero until age 9, the study aimed to detect airborne polycyclic aromatic hydrocarbons (PAHs), which are pollutants generated by the combustion of fossil fuels, and their interactions with maternal stress (Perera et al., 2013). Specifically, the study derived a connection between high levels of air pollutants and measures of maternal demoralization. The study suggested that poor air quality would impact one's view of their environment, causing disdain in living conditions or resources available. (Perera et al., 2013). Thus, negative environmental influences would destruct a mother's self-perception and consequently alter stressors during pregnancy. In the study, 248 non-smoking women were randomly selected who were between the 8th and 24th weeks of gestation and had no previous exposure to high PAHs or had any mental illnesses. Between the 20th and 30th week of their pregnancies, mothers were given a questionnaire, eliciting information on socioeconomic status and stress levels (Perera et al., 2013). The mothers also had tests done to measure PAH levels. Every 6 months after birth, the mothers underwent a similar testing process to compare changes in stressors and environmental toxins.

Furthermore, the Child Behavior Checklist was used on the children periodically during ages 6-9 to test development and behavioral attributes relating to emotions, learning, and more. Analyses of maternal demoralization, environmental conditions, and child behaviors were carried out, and it was found that there was a correlation between prenatal psychological distress and high PAH exposure, resulting in behavioral issues during a child's developmental period (Perera et al., 2013). As both psychological stressors and physical toxicants are linked through common inflammatory pathways, the study noted that their interactions may potentiate each other and induce neurodevelopmental effects in children, leading to conditions like autism or ADHD (Perera et al., 2013). While the study does a promising job of considering several factors that impact maternal stress and child neurodevelopment, the researchers failed to identify and analyze socioeconomic status within the context of environmental stressors. As such, varying backgrounds can affect the mothers' perception of high air pollution due to differences in available resources, transportation, and medical benefits, provoking results that confound what was retrieved. Additionally, the focus on solely white mothers may induce biased results that cannot be attributed to the complete population of mothers, as different races face and deal with stressors in contrasting ways. However, the study propagated a unique approach to investigating environmental stressors and maintained a high level of expertise.

Behavioral Outcomes in Offspring

The repercussions of prenatal stress can significantly impact the behavioral wellbeing of future offspring, as evidenced by associations between maternal stress during pregnancy and an elevated susceptibility to neurodevelopmental disorders in offspring. Within this context, it has been noted that conditions like Autism Spectrum Disorder (ASD) and Attention-Deficit Hyperactivity Disorder (ADHD) are more at risk with the presence of prenatal stress (Manzari et al., 2019). Moreover, while in the

womb, the fetus could potentially contact the stress hormones or inflammatory responses that the mother experiences, disrupting brain development processes.

This behavioral dysfunction can also arise from hypothalamic-pituitary-adrenal (HPA) axis dysregulation, neurodevelopmental alterations, and brain structure changes due to elevated stress exposure (DiPietro, 2012). Similarly, the mechanisms involved with emotional regulation could also be disturbed due to developmental shortcomings that occur. With this, there are increasing difficulties with managing responses to stress as the offspring ages, manifesting as heightened anxiety, depression, and emotional dysregulation (Coussons-Read, 2013). Several studies have been conducted to emphasize the innate effects of maternal stress on child behavior.

Analysis of Behavioral Outcomes

One study explored the relationship between maternal mental illness and behavioral and emotional difficulties in children. (Van der Waerden et al., 2015). The study looked at 1180 mother-child pairs from a birth cohort study, following them from 24-28 weeks of pregnancy to the child's fifth birthday. During their pregnancies and when their child reached ages 3 and 5, the mothers were assessed through a Center for Epidemiological Studies Depression questionnaire that targeted the presence of depression (Van der Waerden et al., 2015). Similarly, when the children turned 5, they were tasked with a Strengths and Difficulties Questionnaire that identified shortcomings with behavioral and emotional intelligence. From there, the results showcased that children with mothers having the most depressive symptoms or distress had the greatest troubles with behavior and emotion, including conduct issues and quarrels with other peers (Van der Waerden et al., 2015). These results illustrated how persistent psychological stress during the prenatal stage induces high levels of physical aggression in school age children. There is evidence that exposure to prenatal stress induces the externalization of behaviors, creating the hyper-activation of negative behavioral solutions to stress management during early years. While the study generated informative outcomes, several limitations exist within the model. For example, there may have been potential confounding variables like family income or social support that play a role in both the existence of the depressive symptoms in mothers and the behavioral difficulties seen in children. Moreover, the study primarily used self-report questionnaires to measure maternal depression and children's behaviors, which are subjective and could potentially be influenced by factors like social desirability bias. Overall, the study provided insightful details into the behavioral outcomes in children.

Another study examined the effects of prenatal stress on the temperament and problematic behaviors of children through a combination of self-reporting questionnaires and observational data (Gutteling et al., 2005). Specifically, 103 pregnant women were given a self report questionnaire and a cortisol test to gather data on maternal stress levels, while their children after birth (at 27 months) were assessed with the Infant Characteristics Questionnaire, Child Behavior Checklist, and simple observational tactics (Gutteling et al., 2005). From there, logical analyses were performed and the results showcased higher numbers of restless or disruptive acts in toddlers with mothers presented with high cortisol levels. The study highlights how personality changes can occur within the affected offspring as they get older, coming into play during the prime developmental years (Gutteling et al., 2005). Furthermore, the findings presented by Gutteling et al. (2005) put forth ideas of how development is experience-driven, relying on both prenatal and postnatal occurrences. While this study provides valuable insights into the influences of prenatal stress on infant temperament and behavior, there are several limitations to consider. For instance, relying solely on self-report data to assess stress and anxiety levels may introduce bias with how an individual details their feelings. The mothers may under report or even over-report their stress levels to sway the experimenter's perception of them, causing the inaccurate collection of data. In addition, there may have been discrepancies in the measurement of temperament and behavior as parent reports on the Infant Characteristics Questionnaire were utilized, which may have been subject to parental bias. Likewise, other behaviors were assessed using direct observation, which may have introduced bias or inaccuracies in reporting details. Yet despite these limitations, the study displays impactful evidence that provides a nuanced perspective into potential origins of behavior in children.

Cognitive Outcomes in Children

The impacts of prenatal stress on children can significantly backtrack cognitive developmental milestones, creating problems with cognitive growth. Specifically, the widespread negative effects of stress can translate to the child's education. These impacts correlate to lower than-average test scores and diminished academic performance. As a result, prenatal stress can lead a child to face countless academic struggles and performance issues (Schuurmans et al., 2022). Outside the classroom, these effects can translate to an inhibited goal-oriented mindset, instilling a lack of confidence in these school age kids that can carry forward long term. Similarly, the impacts of prenatal stress can be extended to emotional regulation (Jagtap et al., 2023). Fetal stress introduces potential disturbances in endocrine and inflammatory activity, and can even influence epigenetic marks of genes, altering their expression in the long run. These minor reworkings of neurodevelopment can sculpt the developing fetus, influencing stress reactivity and cognition. This profound impact on emotional regulation can induce mental illness and other issues that resonate later in life.

Analysis of Cognitive Outcomes

One study drew attention to the effects that maternal stress can create on cognitive and linguistic functioning (Laplante et al., 2008). By gathering 89 children whose mothers were

pregnant during a natural disaster, the experimenters aimed to uncover the extent of the stress and its underlying impacts. All of the subjects were present at the time of the 1998 ice storm crisis in Canada, where millions of people lost access to electricity, food, and other essential resources (Laplante et al., 2008). Six months after the natural disaster, the subjects were given several questionnaires that tested the impact the event had on both their subjective and objective stress levels. Several years later, when the subjects' children were of school age, the 5-year-olds received both the Wechsler Preschool and Primary Scale of Intelligence and Peabody Picture Vocabulary Test, that analyzed both IQ and language (Laplante et al., 2008). After the tests were run and analyzed, it was found that all trend analyses were significant and curvilinear, showing a clear association between prenatal stress and cognitive functioning. Therefore, children exposed to high levels of stress during the prenatal period developed lower full-scale IQs, verbal IQs, and language abilities compared to children exposed to low or moderate stress levels (Laplante et al., 2008). While this study offered important insights into how prenatal maternal stress from a natural disaster might affect the cognitive development of offspring, it is crucial to acknowledge several constraints associated with the research. For instance, the study's findings may not be generalizable to a larger population, as the stress and experiences had by the pregnant women were unique to them.

The circumstances of the ice storm crisis may differ in severity to duration as compared to other natural disasters, leading to variations in stress and thus cognitive outcomes in children. Additionally, there seems to be a lack of control for confounding variables, as there may have been external factors that influenced the high maternal stress levels and the cognitive function of children at school age. Specifically, variables like socioeconomic status and social support play a role in how an individual deals with a crisis, which can also affect stress levels and alter the scope of the study. Similarly, shortcomings in language and cognitive development cannot be completely attributed to prenatal stress, as environmental components may play a part. Despite these limitations, Laplante et al. (2008) manufactured a comprehensive study that shows the extent to which maternal stress can impact various elements of cognition. Another study highlighted how prenatal stress acts as a risk factor for childhood emotional dysregulation (Velders et al., 2011). Through their study, the researchers aimed to identify how maternal depressive and hostile symptoms interfere with child cognition.

To test the correlation, the experimenters gave parents a self-report questionnaire to assess psychological symptoms at 20 weeks of pregnancy. All questions were hypothetical statements measuring how likely the subjects would want to take part in a specific act, e.g. having an urge to cause pain to others. This questionnaire was assessed on a 5-point scale, ranging from "0 = not at all" to "4 = extremely," and covered topics like general anxiety, phobic anxiety, hostility, depression, and obsessive compulsions (Velders et al., 2011). Next, the children were tested on emotional behavior and cognition at three years. The parents were given self-report questionnaires to identify where their child stood in various categories such as emotional reaction, anxiety and depression, somatic complaints, and withdrawn symptoms (Velders et al., 2011). Based on all the combined results, statistical analyses were run. From there, the experimenters found that prenatal stress and hostility induced greater emotional problems in children at three years of age. In some cases, the psychological distress experienced by the mothers carried over into the postnatal period, where the children began to internalize such destructive behaviors by influence. As a result, the children developed regulatory issues of attention and anger. The experimenters also reported that poor family functioning and stress during the prenatal time may have also contributed to childhood cognitive issues (Velders et al., 2011). These findings highlight the long-term consequences of prenatal stress on child development, demonstrating that early environmental exposures can ultimately shape childhood emotional and cognitive outcomes. The study presents many limitations, like the timing of assessments and parental bias, for instance. Firstly, the study assessed parental depressive symptoms, hostility, and family functioning during pregnancy and 3 years after birth; however, these assessments may not capture changes in these factors over time, potentially missing important fluctuations that could impact child emotional problems. Many variations in family lifestyle could ensue during three years, causing inaccuracies in correlating child cognition to prenatal stress. Moreover, shortcomings with the inherent biases of self-report questionnaires exist as well. The study relied on parental reports of child behavior, which could be influenced by parental perceptions to withdraw critical information. Objective measures or observations of child cognition could provide a more accurate assessment of emotional problems and reduce any parental biases that may occur. Overall, Velders et al. (2011) brought to light many of the impacts of prenatal distress on childhood cognition.

Psychopathological Outcomes in Offspring

With exposure to prenatal stress, there is evidence for increased risk of psychopathologies. For instance, contact with heightened maternal stress hormones can significantly influence the development of neural circuitry within the fetus, creating long lasting impacts on the child. Issues with anxiety regulation can arise, as well as slower central nervous system development, and increased birth complications (Walsh et al., 2019). Emerging evidence also highlights increased susceptibility to schizophrenia and psychosis. The risk factors that come about due to maternal stress are presented through defects in neurotransmitter systems and immune responses (Lipner et al., 2019). Accordingly, these disruptions leave lasting effects on the brain and subsequent structures, causing predisposition to various psychotic disorders. Likewise, exposure to prenatal stress induces the production of inflammatory cytokines during gestation, eliciting developmental reorientations of the HPA

axis.

Analysis of Psychopathological Outcomes

One study evaluated the association between ongoing maternal eating disorders during pregnancy and offspring neuropsychiatric disease risk (Mantel et al., 2022). Utilizing a population-based prospective cohort study, the experimenters identified both pregnant women with the disorder and those without. Then, the children were followed up with from one year of age for autism spectrum disorder (ASD) and from 3 years of age for attention deficit/hyperactivity disorder (ADHD). Among the 878 children, individuals with mothers presenting with bulimia or anorexia nervosa tested highest for ASD and ADHD risk (Mantel et al., 2022). The tests that were performed focused on identifying attributes to the neuropsychiatric disorders, as well as common risk factors. Eating disorders often co-occur with high levels of stress and anxiety, so the presence of those conditions during pregnancy can have detrimental effects on fetal development, including alterations in the stress response system of the developing child. Similarly, eating disorders contribute to deficiencies in essential nutrients during pregnancy, which can affect fetal development. A combination of these factors may contribute to the risk of ADHD or ASD.

These findings emphasize the complex interplay between maternal mental health, nutrition, and fetal neurodevelopment. The increased risk of neuropsychiatric disorders in children born to mothers with eating disorders underscores the importance of comprehensive prenatal care. Though the study offers valuable insights into the potential relationship between maternal eating disorders during pregnancy and the likelihood of ADHD and ASD in children, it is important to acknowledge several constraints. For example, the timing and duration of maternal eating disorders during pregnancy may influence different outcomes in neurodevelopmental conditions. The study provides information on exposure to eating disorders during pregnancy but does not explore the timing and severity of the condition in detail, creating gaps in knowledge for linking the two variables. Furthermore, potential information bias exists within the study. The experimenters relied on medical records for the diagnosis of eating disorders in mothers, and neurodevelopmental outcomes in children. These records were not obtained uniformly, which may result in differences in accurately portraying the conditions. Additionally, there could be variations in healthcare-seeking behavior among mothers with eating disorders, leading to contrasting diagnosis or reporting of outcomes. Overall, however, Mantel et al. (2022) performed a comprehensive study that focused on maternal stressors with novel findings.

Another study investigated the associations between maternal antidepressant use during the first trimester of pregnancy and adverse child outcomes like autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD) (Sujan et al., 2017). The study also investigated effects like preterm birth and low birth weight relative to gestational age. The design of the study utilized a retrospective cohort study of Swedish offspring born between 1996 and 2012, following up with the subjects until 2013 (Sujan et al., 2017). Based on maternal self reported first-trimester antidepressant use, correlations between depression and neuropsychiatric disorders were sought after. Sujan et al. (2017) found that first-trimester exposure to antidepressants led to an increase in diagnoses of ASD and ADHD, as well as increased risk of preterm birth. The study looked specifically at antidepressant usage during the first trimester, a period known for critical fetal brain development. As a result, the medications used to treat depression may alter serotonin levels, neurotransmitter systems, or gene expression patterns, inducing fundamental changes in fetal brain structure or makeup (Sujan et al., 2017). The changes that arise may play significant roles in the development of conditions targeting attention and behavior during a child's primitive years. Within the scope of the study, some limitations exist, revolving around the retrospective cohort design. Specifically, due to the retrospective nature of the study, the data may be subject to limitations such as incomplete or inaccurate recording of exposure and outcome information. Likewise, there may be several residual confounding factors that still exist due to inadequately measured variables. For example, maternal depression severity, lifestyle factors, social support, and genetic predispositions may also influence the neurodevelopmental outcomes in children. Despite this, the study demonstrated multiple strengths with its approach, ensuring longitudinal follow ups of the subjects, large sample sizes, and the use of multiple outcome measures.

Intervention and Prevention

Within the realm of maternal health, many steps can be taken to minimize stressors and the resulting negative influences on fetal development. Providing widely accessible mental health care and resources during the prenatal period may be critical to the prevention of childhood behavior and cognitive problems. Implementing comprehensive support systems that include mental health professionals and support groups can offer mothers adequate assistance to cope with stress effectively. Educating mothers and families on pregnancy, childbirth, and parenting may also alleviate anxiety and apprehensions. With this knowledge, families will feel confident about the future, reducing the physiological toll on both the mother and child. Additionally, addressing existing socioeconomic disparities related to prenatal stress—like food insecurity and unstable housing—is an important step in creating equitable maternal health outcomes (Patel & Dev, 2023). Advocating for policies that support maternal well-being, like expanded access to prenatal mental health care, paid parental leave, and affordable childcare is vital to alleviate stress. On a smaller scale, encouraging community mindfulness practices, such as meditation and yoga, may also be instrumental in regulating mental health. By addressing tactics to promote maternal well-being as well as recognizing the innate stress that exists with pregnancy, we can positively impact fetal neurodevelopment and set the stage for

a healthy childhood.

Exploring Future Directions in Maternal and Fetal Research

Future research in the realm of maternal and fetal behavior involves improving the inherent biases of current methods. Most existing research focuses on white, middle-class, and higher educated samples. However, these samples are not representative of all mothers. Many women face experiences with racism, economic disparities, and a lack of access to healthcare resources and support during pregnancy. The psychological distress attributed to such conditions is paramount and underlines many of the stressors seen today. Thus, strides must be taken to include more diverse and representative samples, including individuals from various racial and ethnic backgrounds, socioeconomic statuses, and education levels. Future research questions can take such variables into account to identify the external factors that play a role in stress. Additionally, implementing longitudinal studies that track maternal stress and child development over time could offer further insights into the ways early-life adversities manifest in long-term health outcomes. Progress within this field of research is pivotal to understanding and developing equitable maternal health policies that can improve solutions to stressors. By addressing current disparities in research and policy, we can work towards a more inclusive approach to maternal health.

Conclusion

Overall, this comprehensive review aimed to present the impact of prenatal stress on fetal development, showcasing specific effects on neural development. Going forward, we can push for more studies that test the correlation between maternal stress and the cognitive and behavioral impacts that manifest at the later stages of a child's life. Likewise, future studies can implement methodologies that focus on standardized tools for measuring behavior and cognition. Current methods utilize measures that include self-report questionnaires, eliciting several sources of bias; however, adjusting these tools to be more representative will benefit future research. Furthermore, navigating the mechanisms behind prenatal stress should utilize interdisciplinary approaches that combine neuroscience, social psychology, and public health. Understanding the connection between prenatal stress and fetal outcomes is essential to not only improving the health of future
generations but enhancing the social systems that exist today. Solving the root issues of maternal psychosocial stress by targeting socioeconomics is a great first step. Future research can also explore the efficacy of intervention programs that aim to reduce maternal stress. Social psychology and medicine are deeply connected, and finding a nuanced perspective of their intersection can drive meaningful improvements in today's medical system. By prioritizing maternal well-being and integrating policy-driven solutions, we can strive to create healthier pregnancies, improved child development, and a more equitable healthcare sphere.

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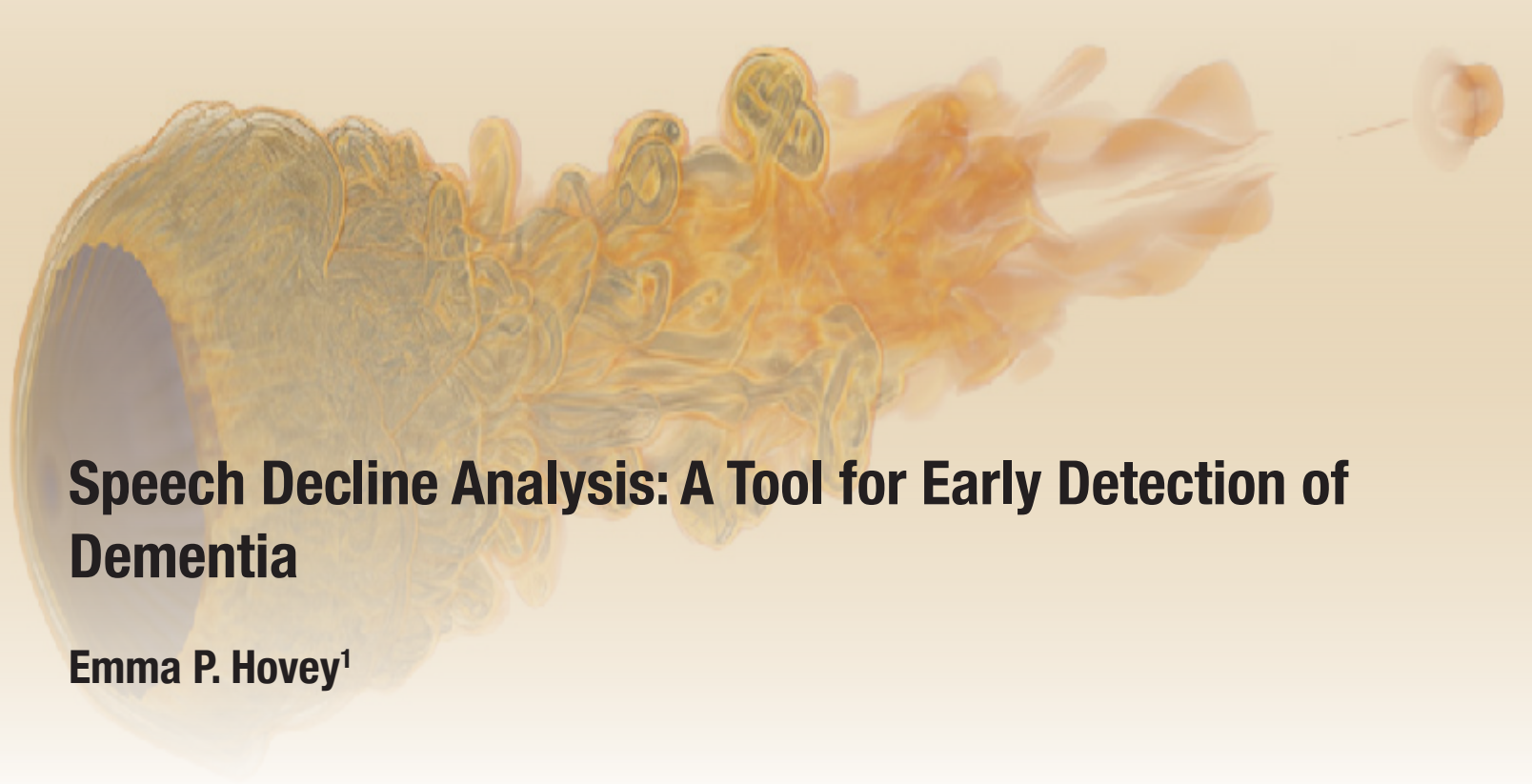

Speech Decline Analysis: A Tool for Early Detection of Dementia

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Abstract

Dementia affects millions of people worldwide. Aside from neuropsychological assessment, there exists a lack of reliable methods to detect dementia before the onset of symptoms. Because of many other boundaries to diagnosis, such as similar pathology, cost, and lack of public knowledge about the signs and symptoms of dementia, quick and early intervention remains imperative to developing a cure to insidious diseases such as Alzheimer's. This review aims to determine the value of studying speech decline seen in those with Mild Cognitive Impairment, frontotemporal dementias, and Alzheimer's disease. Speech analysis through statistical testing shows discrimination between these three groups, suggesting a promising tool for prediction of neuropsychological exam score and cognitive decline. Interview-based testing with a focus on known speech parameter deficits in dementia shows potential for a clinical approach to early intervention. Future research that includes neuroimaging to determine functional connectivity of brain regions mapped to language may also aid in determining the underlying pathology of these diseases. Machine learning shows promise in developing clinical models to help predict cognitive state from simple speech recordings, which may present a cost-effective and time-efficient solution to intervention in these diseases.

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Background photo courtesy of the Computational Physics Group at Georgia Tech

Introduction

Dementia, an unnatural aging of the brain causing cognitive deficits, affects millions of people worldwide with no signs of these numbers slowing. By the year 2050, projections show that almost 150 million people across the planet will receive a diagnosis of Alzheimer's disease (AD), the most common form of dementia (Breijyeh & Karaman, 2020). This will more than triple those currently diagnosed with AD (Ostrand & Gunstad, 2020). Not only does this present a public health issue, but dementias also reveal a burden of healthcare costs, with U.S. citizens spending trillions of dollars on dementia-based treatment (Ostrand & Gunstad, 2020). While AD shows progression of deficits over several years, certain frontotemporal dementias may cause deadly decline within a much shorter time frame (Geraudie et al., 2021). Because of the increase of dementia diagnoses, early intervention strategies may lead to a better understanding of treatment and the epidemiology of such diseases.

Researchers in the field of neurodegeneration do not currently agree on an established treatment for dementia. Perhaps this challenge comes from the difference in pathological beginnings of these diseases, which remain unknown; however, many theories exist. Current theories of AD pathology show that misfolded proteins, known as amyloid-beta plaques and neurofibrillary tangles, may lead to neuronal cell death (Breijyeah& Karaman, 2020). Behavioral differences may provide insight into the biological differences of these diseases. For example, memory deficits seen in Mild Cognitive Impairment (MCI) contrast from those in AD and behavioral-variant frontotemporal dementia (bvFTD). Nonetheless, the degradation of speech presents a commonality between the cognitive deficits seen as these diseases progress. (Geraudie et al., 2021; Martínez-Nicolás et al., 2022).

Primary-progressive aphasia (PPA), a rare frontotemporal dementia primarily affecting language processing and production, may help to establish a connection in the degradation of language pathways seen in other forms of dementia (Léger & Johnson, 2008). Insights into PPA may aid in determining the cortical circuits affected in bvFTD presentation, since PPA shows heavy reading, writing, comprehension, and speech production deficits in comparison to other dementias. Therefore, specific hallmarks of speech decline in PPA may present a tool for early detection of dementia.

This review aims to differentiate between MCI, bvFTD, and AD through the implementation of speech tasks using statistical analysis and neuroimaging techniques. The literature presented shows a variance of speech parameters that may contribute to early detection methods, as well as promising differentiation between these types of dementias. Of note, many articles focusing on interview-based speech tasks include multiple speech parameters determined by the authors, since many studies do not include every parameter. However, the field has operationally defined these parameters for consistency across studies. This review focuses on the most common speech parameters used in such studies, limiting the scope to papers that include speech flow, voice, and temporal qualities in statistical analysis.

Speech Parameters

Speech and language present a unique challenge for researchers, since methodological limitations exist for human testing; for example, researchers must use non-invasive tests, such as neuroimaging, surveys, or electroencephalograms (EEG) on human subjects. Also, communication between humans and animals differs, since humans have evolved to use language requiring proper syntax and grammar, whereas animals do not communicate in this manner. This results in a lower likelihood that invasive animal testing reproduces an accurate depiction of human speech and brain activation. Nevertheless, animals with similar brain anatomy to humans may provide a deeper understanding of the neural circuits involved in the vocal aspects of speech (Konopka & Roberts, 2015), suggesting that more invasive approaches in animal testing models may give insight into specific speech pathology in humans through cellular testing. In learning this, the field may gain a deeper understanding of the speech pathways activated and affected by dementia.

To determine the effects of dementia on human speech, interview-based approaches may best highlight the different qualities of speech in healthy individuals and those with cognitive impairments due to its non-invasive nature. Various studies focus on various traits, outlining the importance of recognizing the patterns and parameters affected when speech quality begins to degrade. Non-invasive testing techniques, like interviews, remain the method of choice for this research. Recordings processed by audio software provide a quantitative sample of aural data, like sound frequency and time, as well as linguistic data. These quantities allow for statistical analysis after processing.

Flow in Speech

To begin with, flow could emerge as one of the most important speech qualities, which researchers measure through rhythm and fluency. Rhythm relates to the syllabic smoothness of the speech and stream of words (Martínez-Nicolás et al., 2023). Reading and spontaneous speech, such as conversation, both produce their own rhythms. Researchers can easily manipulate and interrupt these rhythms during testing, making speech recordings excellent observational tools for potential cognitive decline. Rhythm, monitored through syllabic intervals (Teixeria et al., 2013), which refers to the equal timing and space between each syllable, shows association with the timing of the produced speech (Martínez-Nicolás et al., 2022). To test this, researchers monitor the timing and interaction of

the consonants and vowels in a syllable (Martínez-Nicolás et al., 2022). In healthy individuals, these present as evenly-spaced intervals, so analyzing this disturbance in flow may provide insights to the breakdown of the speech pathway in cognitive decline (Martínez-Nicolás et al., 2022).

In addition, fluency requires the ability to recall vocabulary and use it accurately (Martínez-Nicolás et al., 2022). Memory of words and their definitions greatly impacts the depth of fluency in a language (Ostrand & Gunstad, 2020). For example, using the word "splendid" or "marvelous" in place of "good" shows depth in the language, and thus a greater fluency. Therefore, decline in other cognitive functions, such as memory, may influence the decline of speech in those with dementia.

Voice Quality in Speech Production

Voice quality constitutes another major parameter of speech commonly investigated in interview-based approaches. To analyze the decline of voice quality, researchers have suggested focusing on aural traits, such as jitter and shimmer (Martínez-Nicolás et al., 2023). Jitter refers to the strength of the voice, giving a quantitative measure to descriptive characteristics like "breathy" or "hoarse." Shimmer refers to amplitude of the frequency, also known as volume. For such parameters, the general measures tend to vary from the fundamental frequency (F0), which refers to the rate of vibrations created by the vocal cords when activated in a given period (Teixeira et al., 2013). The average range of frequencies to describe the F0 derives from both gender and age to allow for better statistical analysis; however, these standardized frequencies do not account for factors such as intonation and may not accurately depict individuals within the group (Teixeira et al., 2013). The F0, also described as a cyclic measure of the opening and closing of the glottis in the larynx, impacts the vocal folds and cords (Teixeira et al., 2013). Therefore, jitter and shimmer show easily detectable differences in speech recordings related to voice quality and sound. These qualities, which show variations in the F0, can show a lack of ability to control the voice when compared to healthy individuals (Martínez-Nicolás et al., 2022), which may show decreased physical control of the larynx in conjunction with cognitive decline that impacts speech production.

Temporal Qualities of Speech

Furthermore, the time it takes to speak can also indicate an impairment in speech commonly seen in dementias (Martínez-Nicolás et al., 2022; Martínez-Nicolás et al., 2023). In healthy individuals, correct prosody reflects healthy temporal qualities of speech; this refers to the patterns of intonation, timing, rhythm, and flow of speech seen in different languages (Martínez-Nicolás et al., 2022). For example, rising intonation towards the end of a sentence in English indicates a question. Moreover, the number and spread of pauses influence temporal qualities of speech (Martínez-Nicolás et al., 2022), since this changes the total duration of speech production. To analyze this, researchers commonly ask participants to read a passage aloud or to describe a picture under a time limit. In addition, a disturbance in the cognitive mechanisms involved in creating a sentence, also known as syntactic planning, can affect the timing of speech by generating longer pauses and disrupting overall flow (Martínez-Nicolás et al., 2023). Longer recordings typically indicate increased cognitive decline, suggesting higher difficulty in producing proper sentence structure, longer pauses, and other temporal deficits.

Silence and Pauses in Speech Production

Finally, investigating the absence of speech may also provide an avenue to determine cognitive impairment during speech analysis. Researchers may analyze silence and pauses to determine a total amount of time during conversational or spontaneous speech where hesitation and the associated long and short pauses may occur (Wang et al., 2022). Verbal fluency tasks, reading tasks, and spontaneous speech tasks offer the easiest method to study the absence of speech. Even though this does not directly measure the quality of speech, a better understanding of prolonged silences in fluent speech may help with a better understanding of the decline of cognitive processes affecting rhythm, duration, and quality. As well as the duration of pauses, the distribution of silence throughout speech may also require analysis (Martínez-Nicolás et al., 2022). Silences may suggest lower cognitive performance from lowered verbal fluency, as well as limited memory of vocabulary, loss of concentration, and a decline in comprehension. As speech declines, perhaps its absence reflects the most important part of speech quality to understand.

Limitations of Speech Parameter Analysis

While these parameters cover the basics of speech, limitations still exist. To begin with, most interview-based studies cannot study all parameters at once: most researchers pick three or four major categories to analyze. In addition, many studies do not compare differences between languages. Parameters influenced by prosody, such as timing, voice quality, and flow, may look different between languages based on cultural differences in speaking, as well as the difference between grammar conventions. Also, research involving these speech parameters primarily require an interview-based approach. The lack of direct evidence observed through imaging and other direct measures may weaken the statistical analysis applied to audio recordings of speech. Some studies have incorporated task-based functional magnetic resonance imaging (fMRI) into their studies as an aside to recorded interviews (Wang et al., 2022); this measures the functional connectivity and activation of brain regions while completing a cognitive task such that identification of specific pathways involved in speech processing and communication can occur. Others have looked at retest replicability in the same individual by using fMRI in verbal fluency recall tasks (Paek et al., 2019). In the future, finding new ways to incorporate interview and speech

parameters to better understand neural networks outside of statistical analysis may help with a thorough understanding of the role of speech decline associated with cognitive troubles. In terms of diagnostics, interview-based methods should persist, as they currently offer the most-well suited method for monitoring speech production in humans. Moreover, the benefits of this method may outweigh the limitations that exist. For example, the associated cost of imaging techniques can limit the number of experimental subjects resulting in a smaller data set and thus, less robust analysis; however, researchers can conduct interviews over the phone or in the doctor's office which offers more flexibility for patients, clinicians, and researchers. Because of these reasons, fMRI may fit the lab setting better, while the field continues to learn more about the neural pathways involved in speech and how they degrade in the presence of dementia. Furthermore, many imaging techniques have temporal and spatial resolution limitations. Overall, employing an interview-based approach alongside imaging techniques may increase the replicability of results and lead to better understanding of connectivity patterns in the brain.

Mild Cognitive Impairment (MCI)

Mild cognitive impairment (MCI) presents as a transitional period of cognitive decline, where degradation has surpassed that of natural aging, but does not yet severely affect daily life (Martínez-Nicolás et al., 2022; Bolt & Giroud, 2024). This affects approximately 19% of the population aged 65 and older, and of those affected, 46% will develop dementia within the first 3 years (Cooper et al., 2015). Current theories suggest that overconsumption of alcohol as well as intense depressive symptoms may lead to the development of MCI and aid in its conversion to dementia; however, both causes show inconsistencies in prediction of dementia progression (Cooper et al., 2015). In the future, a better understanding of the early stages of MCI may provide more confidence in determining causes and potential treatments to prevent further deterioration.

MCI affects approximately one-fifth of the population, so early intervention of this disease may help prevent the conversion of MCI into other forms of dementia. Natural speech changes also occur with healthy aging, providing a baseline to determine differences when pathological deficits appear (Martínez-Nicolás et al., 2022). For instance, both healthy individuals and those with MCI struggle with vocabulary recall, demonstrating a correlation between reported difficulty of recall and cognitive ability (Martínez-Nicolás et al., 2022). Thus, it appears that cognitive impairment of a small degree directly affects higher cognitive functioning associated with not only speech production but also auditory processes involved in understanding and responding in conversation (Martínez-Nicolás et al., 2023). This begs the question: when do speech changes become pathological?

Voice Quality Differences in MCI

Interview-based approaches in initial cognitive decline testing may present a difference between healthy aging and potential cognitive decline. Many interview-based approaches require a reading task for recording and later analysis, as well as neuropsychological examination to assign participants to a cognitive group. Voice quality parameters, such as jitter, show potential as a distinguishing characteristic between healthy controls and those with MCI (Martínez-Nicolás et al., 2022; Martínez-Nicolás et al., 2023).

In reading tasks, varying semantic and structural difficulty exists inside the sample paragraph. A popular phrase, marked as a control sentence, helps to determine true voice quality, temporal, and fluency variances within participants. For example, presenting the participant with a familiar text, like The Bell Jar for English speakers (Bolt & Giroud, 2024), allows the researchers to establish a baseline audio recording. Researchers may choose two presentations for such tasks: requiring the participant to read the task aloud or requiring the participant to listen to an audio recording of the task. When the participant had to read the task, voice quality parameters, such as jitter (Martínez-Nicolás et al., 2022), showed a difference between healthy aging and MCI. However, in auditory processing paired with a comprehension quiz, electroencephalogram (EEG) results showed no difference in EEG peaks at the cortical and subcortical levels between groups (Bolt & Giroud, 2024). Also, comprehension test results showed similar findings between the two groups (Bolt & Giroud, 2024), suggesting that MCI did not affect the cognition in auditory processing of natural speech. Because of the difficulty in the retrieval of a word, as well as recalling the definition, it seems that the greatest impact in language processing in MCI comes from the use of words in conversation rather than comprehension and conversational skills. This manifests through the repetition of words and loss of specificity by using words like "stuff" and "thing" (Ostrand & Gunstad, 2020). Taken together, this suggests that auditory encoding, the cognitive process of saving sounds and words as memory, does not heavily affect the beginning stages of cognitive decline. It seems that the decline of the production of speech may have more influence, like in changes of voice control and potential cognitive deficits in fluency.

Findings related to voice quality suggest that certain characteristics, like jitter, seem to differ with natural age and gender (Martínez-Nicolás et al., 2023) unrelated to the Mini Mental State Examination (MMSE) score. The MMSE provides a baseline score of cognitive ability, with lower scores indicating more severe cognitive decline. Older subjects showed greater disparity in frequency in the voice (Martínez-Nicolás et al., 2022), potentially related to voice control changes in healthy aging rather than based on cognitive decline. This emphasizes the need for the F0 based on age groupings, since change can occur with natural aging (Teixeira et al., 2013). However, with

increased cognitive load, such as remembering words while focusing attention on the reading task, the differences between healthy controls, MCI, and AD groups grow (Martínez-Nicolás et al., 2023). This suggests that cognitive decline exacerbates voice control problems, leading to overall voice quality differences worsening between healthy individuals, the MCI group, and AD group.

Overall, further testing in older healthy adults may help to better differentiate normal and pathological frequency variances. By doing this, researchers can better align the F0 groupings with age, resulting in more robust interpretation of results. Also, other parameters in voice quality, like shimmer, may lead to more support in other voice quality findings. In those with MCI, testing and analysis of the decline of voice control may help determine the likelihood of eventual conversion of MCI to other forms of dementia.

Cognitive Load Effects on Speech Production in MCI

Patterns within the speech flow category, such as the rate and rhythm respectively, showed significant difference in those with MMSE scores indicating higher cognitive decline compared to other groups (Martínez-Nicolás et al., 2022). Many of these results showed a trend towards speech decline correlated with lower scores in speech flow in addition to voice quality. Also, syllable-timed languages, such as Spanish, have a repetitive flow that researchers can observe as disrupted in MCI (Martínez-Nicolás et al., 2022), making this an easy characteristic to study. Discrimination between speech changes at all levels of cognitive impairment and healthy aging may help to develop better early-diagnosis screening methods, since these changes in flow occur before it becomes pathological.

Other studies have focused heavily on differences between MCI and AD, which may result in effective early intervention of neurodegeneration. While MCI may not greatly affect daily life before conversion to other dementias, those with MCI typically experience structural difficulty with language, as well as word-meaning loss leading to a decrease in fluency (Martínez-Nicolás et al., 2023). Speech flow and voice quality parameters seem greatly affected in those with MCI, where disease progression leads to more detrimental effects. For example, those with MCI produce more monotone, slow, choppy speech (Martínez-Nicolás et al., 2023) due to the degradation of voice quality and speech flow characteristics.

Along with changes in spontaneous speech, tasks that increase cognitive load also affect speech production, which may present a new method of predicting the cognitive state of participants (Martínez-Nicolás et al., 2023). Machine learning models that analyze audio recordings of those with cognitive decline also show that more severe decline results in less specific language, indicative of vocabulary retrieval problems associated with MCI, as well as frequent reuse of words (Ostrand & Gunstad, 2020). These findings suggest that greater cognitive deficits result in noticeable changes in speech patterns in conversation, especially when engaging other cognitive processes, and thus, a potential method for clinical monitoring of speech decline.

In a study focusing on the effect of cognitive load on speech degradation, researchers collected two recorded samples: the first involved reading an excerpt of Don Quixote, and the second involved completing a sentence about the game Parcheesi (Martínez-Nicolás et al., 2023). The study required this particular task because the participants should recognize the cultural reference in the sentence and then pick the appropriate answer. This tests the semantic load and verbal recall (Martínez-Nicolás et al., 2023). Mathematical models created after data analysis could then differentiate between pathological cognitive decline seen in AD, MCI, and natural aging (Martínez-Nicolás et al., 2023). The predictive quality of these equations may work for the early intervention of cognitive deficits by allowing monitoring to begin before more detrimental higher-order functioning impairment.

Limitations and Future Directions of Speech Analysis for MCI

Because of the spike of diagnoses of MCI in recent years, there exists a demand for better clinical screening technologies between languages as well as gender. As previously mentioned, most speech studies prefer speech recordings as the main methodology for statistical analysis because they allow for a greater sample size. For example, the Don Quixote study features 400 participants and focuses on native Spanish speakers (Martínez-Nicolás et al., 2022). Since many studies do not show comparisons between languages using the known speech parameters associated with MCI, future studies comparing different language families, like Germanic and Dravidian languages, may provide key insights and patterns in the language pathway degradation. Also, further study into gender differences of speech parameters should occur, since research has shown speech parameter differences between men and women (Teixeira et al., 2013). This suggests that statistical analysis of both genders together, rather than sex-differentiated groups, may give less valid results. This will further determine presentation of MCI in males versus females, including the onset of speech differences, specific speech quality degradation, and speech flow differences while also providing more accuracy in current modeling methods.

Again, many studies do not include methods such as fMRI or EEG to determine neuroanatomical and functional connections between speech parameter decline and MCI. Without this, biological markers and connectivity patterns associated with these qualities lack anatomical definition. Perhaps future studies will include EEG in conjunction with interview-based approaches, since this will preserve the large sample size and low-cost of these language studies.

In the future, machine learning models show great potential as an evaluation method. Some models have accurately predicted neuropsychological exam scores 12 months after taking a speech sample (Ostrand & Gunstad, 2020), while others have used feature extraction of specific speech parameters to determine the level of cognitive decline (Ceyhan et al., 2024). This suggests that upon training with the model, clinicians may intervene in treatment before diagnosis of MCI. Currently, most machine learning research uses English speakers; however, Ceyhan et al. (2024) included a Turkish-speaking data-set and verified both their English and Turkish datasets. Both of these models made predictions with approximately 75% accuracy. Also, languages of the Indo-European language groups may benefit from their research, since similarities exist within the group (Ceyhan et a1., 2024). As the field of machine learning improves, algorithms will become more reliable, and thus implemented more widely in the clinical setting.

Behavioral-Variant Frontotemporal Dementia

Behavioral-variant Frontotemporal Dementia (bvFTD) presents as a degenerative disorder characterized by behavioral, personality, and social cognitive decline (Geraudie et al., 2021). This differs from other types of dementia because degradation warps personality and behavior rather than memory, as seen in MCI and AD. As one of the top forms of dementia in those 65 and older, bvFTD affects both the frontal and temporal lobes (Bott et al., 2014). bvFTD has many presentations, which can lead to complications in diagnosis. Overlooking, under-reporting, and misdiagnosing symptoms of bvFTD happens because it can resemble other forms of dementia. This highlights the need for better clinical screening tools and understanding of functional connectivity discrimination between different forms of dementia. Furthermore, recognizing symptoms may heavily rely on observations of family members and friends, since those affected may not notice changes in personality and emotional state. Current diagnostic criteria reference symptoms such as loss of sympathy or empathy, resulting in an apathetic emotional affect, in conjunction with functional deficits (Bott et al., 2014). Confirming a diagnosis of bvFTD requires imaging that shows atrophy of the frontal and temporal lobes, but clinicians may also implement post-mortem testing (Bott et al., 2014). In general, bvFTD seems to present more in males than females, with a strong genetic component also seen in other frontotemporal dementias (Bott et al., 2014).

Unlike other forms of neurodegenerative diseases, bvFTD presents with little to no memory problems during onset; however, this disease heavily affects cognitive processes like language production (Geraudie et al., 2021). Atrophy in regions critical to speech and language align with many of the symptoms observed, which can often become overlooked as an early predictor of bvFTD diagnosis (Geraudie et al., 2021). Current theories suggest a correlation with specific characteristics of bvFTD, the specific deficits in speech, and the extent of speech impairment (Geraudie et al., 2021; Ash et al., 2019). More research into this link will produce a better understanding of frontotemporal dementias, considering their rapid onset and progression in comparison to MCI and AD makes them especially devastating.

Primary Progressive Aphasia versus bvFTD

Primary progressive aphasia (PPA), another frontotemporal dementia, presents as the sole disestablishment of language functions (Léger & Johnson, 2008). Other functioning impairment may result as the disease progresses; however, the first few years of decline must only present as an impairment in language processing and production (Léger & Johnson, 2008). In this specific pathology, the differentiation between PPA and bvFTD lies in the lack of behavioral symptoms associated with bvFTD. The elimination of an AD diagnosis occurs because of the lack of memory impairment. Even though those with PPA struggled in memory tasks related to word-lists, the preservation of the following memory-related cognitive tasks prevails: the recall of daily events, normal executive functioning, and normal social functioning (Léger & Johnson, 2008).

Neuroimaging Paired with Speech Tasks

Since clinicians and researchers primarily use imaging in the diagnosis and understanding of bvFTD, functional near-infrared spectroscopy (fNIRS) (Metzger et al., 2016) and MRI (Ash et al., 2019) have shown cortical differences in those with bvFTD and healthy controls. These methods measure cortical areas of activation while completing a speech task that increases cognitive load (Metzger et al., 2016; Ash et al., 2019). For example, participants had to name a noun starting with a specific letter (Metzger et al., 2016) or describe a picture for one minute (Ash et al., 2019). Tasks like these require spontaneous speech which simulates conversation. fNIRS data showed a significant difference between healthy controls, AD, and bvFTD (Metzger et al., 2016). Those with AD showed a decrease in activation during verbal fluency tasks when compared to healthy controls; however, both groups showed the same activation patterns (Metzger et al., 2016). In contrast, functional connectivity seen in those with bvFTD activated Broca's area, rather than areas like the superior temporal gyrus (Metzger et al., 2016), even though both regions help produce language and process auditory information, respectively. Perhaps this arises as a compensation mechanism, where the brain adapts to damage of these circuits in the temporal lobes. Moreover, this may arise due to the differentiation between neurodegenerative patterns, where those with bvFTD experience worsening disarray of the frontal lobe pathways and processes (Metzger et al., 2016).

Evaluation of cortical thinning through MRI in a similar task revealed neurodegeneration resulting in a loss of brain volume as the disease progresses (Ash et al., 2019). Insights into PPA may aid in determining the cortical circuits affected in bvFTD

presentation, since PPA shows heavy language degradation in comparison to other dementias. Those with bvFTD do not show the same level of speech decline as those with PPA, but they do show deficits in temporal speech parameters (Ash et al., 2019). MRI results showed most degeneration occurs in the left hemisphere, which manages language processing and comprehension; currently, the field does not know if compensatory mechanisms in the right hemisphere, which focuses on emotional and auditory processing related to language, affects language reorganization in those with PPA in comparison to bvFTD (Ash et al., 2019).

Overall, imaging techniques like fNIRS and MRI present non-invasive measures to better determine the underlying pathways and circuits affected by frontotemporal dementias and how changes in these cortices affect speech at the onset and progression of degeneration. In both of these studies, differences between healthy controls and those with bvFTD suggest that degradation of these pathways results in speech decline. In the future, the study of bvFTD in conjunction with PPA may open an opportunity to determine how the language deficits in bvFTD differ from the pathology of AD and MCI, since other studies have shown similar activation patterns between degraded AD pathways and healthy controls (Metzger et al., 2016).

Furthermore, because bvFTD and AD have many different symptoms, as well as cortical pathway differences in speech production, comparison to other frontotemporal dementias may help to decipher the ways that speech decline occurs. Between those with bvFTD and PPA, similar deterioration occurred in comparison to healthy controls, with less degeneration shown in bvFTD (Ash et al., 2019), which may result in the preservation of some language processing seen in those with bvFTD. Future studies should include more neuroanatomical mapping between subtypes of PPA and bvFTD, as well as non-frontotemporal dementias like AD. This will help to establish the different pathways damaged in language production in these populations.

Limitations of Neuroimaging

While frontotemporal dementias require neuroimaging, especially for diagnosis, a demand exists for more discriminatory neuropsychological batteries. In the studies mentioned, both place heavy emphasis on imaging of these diseases, with a lack of focus on known speech parameters in interview-based methods associated with cognitive decline. Because of this, recruitment of participants results in a smaller sample size in comparison to studies using less costly methods. For example, the Don Quixote study of MCI, conducted solely through interview, saw a sample of 400 participants (Martínez-Nicolás et al., 2022), whereas both neuroimaging studies had a sample size less than 50, potentially due to the cost of testing, travel, or availability of equipment. Also, depending on the cognitive decline of the participant, they may require hourly care which can affect their ability to get to the testing site.

Overall, replication of these novel studies in longitudinal, cross-sectional studies should aim to verify and solidify the current hypotheses regarding neurodegeneration in frontotemporal dementias mapped with language. Also, the lack of information about the neuroanatomical differences between subtypes of frontotemporal dementias makes discrimination between PPA (and its variants) and bvFTD challenging. Thus, many studies, including the MRI study by Ash et al. (2019) combine participants from these groups into one experimental group compared against healthy controls, which may result in less compelling evidence.

Alzheimer's Disease (AD)

Perhaps the most well-known and most common dementia, Alzheimer's Disease, presents as a loss of cognitive function involving memory. Current theories suggest that memory loss in AD occurs because of degeneration in neural cell tissues due to the presence of tau tangles and amyloid-beta plaques (Breijyeh & Karaman, 2020). As these proteins accumulate, apoptosis causes synaptic pruning, affecting the limbic system and cortices involved in memory. Early-stage AD results in concentration problems accompanied by trouble in daily activities. As the disease progresses to the final stage, thinning of the entire cortex ensues, which causes memory consolidation and recall decline (Breijyeh & Karaman, 2020).

Approximately 50 million people suffer from AD, with numbers projected to double in the near future (Breijyeh & Karaman, 2020). Those diagnosed with MCI may develop dementia within 3 years — most notably AD (Cooper et al., 2015). Outside of its cognitive effects on those afflicted, AD also affects family members, who may become caretakers as loss of cognitive function occurs (Breijyeh & Karaman, 2020). This places a great burden on society, due to the lack of early diagnostic measures.

Speech Parameters associated with AD

Previous studies have established that speech deficits occur in the earlier stages of AD, where cognitive impairment begins. Typically, these deficits occur in relation to semantic and lexical language production, or the interpretation of words and phrases through the nuance of different languages (Pistono et al., 2021). Research of precursors to AD, like MCI, have shown differentiation in interview-based speech parameter analysis of semantic and lexical recall in further cognitive decline as well. Further decline results in worsened semantic and lexical recall (Martínez-Nicolás et al., 2023).

In addition, some studies have focused on functional connectivity of these language pathways to determine deficits as the disease progresses. For example, in an fMRI study of those with AD, potential language deficits in word-meaning and retrieval may occur due to increased connectivity in language pathways even when cortical volume has otherwise decreased (Pistono et al., 2021). Of various language and speech tasks, those with AD showed difficulty in recall tasks, but no significant difference in speech flow when compared to healthy controls. Also, results showed no significant differences in language pathway connectivity between the control group and those with AD (Pistono et al., 2021). This reinforces the idea that this pathway degrades as the condition worsens, rather than restructured activity in different areas as a compensatory mechanism to degradation.

Other studies have shown that interruptions of flow, such as pauses, may aid in the diagnosis of MCI or AD in comparison to healthy controls. Task-based fMRI shows pauses in speech production may also alter pathway connectivity, leading to mechanistic compensation, which help preserve functioning when damage occurs to certain regions (Wang et al., 2022). Integration of imaging studies, such as fNIRS (Metzger et al., 2016) and fMRI, with interview-based speech parameter analysis may reveal the sensitive qualities in AD that distinguish this disease from other dementias, leading to more accurate diagnosis (Wang et al., 2022). In terms of duration of samples, those with AD showed less speech production, suggesting a potential difficulty in word-recall and sentence structure abilities (Bae et al., 2023). Also, those with AD produced more jitter than healthy controls, correlating to the loss of control of the voice seen in the progression of cognitive decline (Bae et al., 2023). Overall, these results support previous findings that worsening temporal speech parameters present in the later stages of cognitive decline, such as after AD diagnosis (Martínez-Nicolás et al., 2023). In contrast, focusing on voice quality parameters, where studies have shown differentiation between healthy aging and MCI, may have more potential for early detection of pathological cognitive changes.

Cognitive Load and Speech Decline in AD

Again, since widely known symptoms of AD include speech and language difficulties (Wang et al., 2022), the current literature suggests that cognitive load will increase deficits in speech production. For example, one study conducted phone interviews constructed of three different cognitive load tasks of varying degrees (Bae et al., 2023). The study tested recall of daily activities, repetition, and recall of specific details to determine what speech parameters change with the addition of cognitive load (Bae et al., 2023). The results of this study aligned with the results of the cognitive load tasks in the MRI study by Metzger et al. (2016): taken together, deterioration of temporal characteristics and voice quality (Bae et al., 2023) show correlation between brain pattern connectivity issues because of the progression of AD. The impact of memory tasks on speech trouble in those with AD seems to form a negative feedback loop, where difficulty in recall leads to further trouble speaking and forming sentences, suggesting potential neuroanatomical deficits in areas involved with planning speech.

Conclusion

As more people present with pathological cognitive decline unrelated to normal aging, an opportunity to improve clinical tools, as well as neuropsychological evaluations for detection, presents itself. Speech differences in interview-based settings may best fit the need for early detection methods, since interview and analysis procedures have robust research. The interview-based model also has the least invasive interaction between participants and researchers or clinicians, which makes it the most convenient method. Perhaps clinicians can incorporate the use of speech analysis as a supplement to neuropsychological assessment, further strengthening current survey-based batteries, like the MMSE.

Limitations exist within the field currently, especially in terms of methodology. fNIRS, fMRI, and EEG all have limited temporal and spatial resolutions; however, they present the best option for non-invasive techniques. Neuroimaging methods all require in-person testing in a lab or clinical setting as well, which requires the participants to travel to the testing site. For those with more severe dementia, this may require a caretaker to transport them. Methods like fMRI and positron emission tomography (PET), which also shows functional connectivity, have high cost in terms of money and time. In the future, the development of new techniques with better resolution may help determine neuroanatomical connections, while also considering portability of testing devices.

Currently, research points towards the clinical use of machine learning for neuropsychological assessment and thus, diagnosis of dementia. Some studies have used machine learning to further understand the speech parameters heavily involved in dementia, while others have used this as a predictive model of clinical scores on neuropsychological exams. In the future, machine learning algorithms may have greater accessibility to clinicians, and provide a quick and easy analysis of a sample speech recording. This eliminates some of the subjectivity involved with questionnaire-style examinations, such as the MMSE. As these models continue to develop, a larger population may have access to clinical evaluation, since interviews can occur over the phone. Furthermore, clinicians could easily implement these tasks into standard primary care visits after 65 years old, where quick processing of speech analysis may catch MCI before onset of more severe symptoms. Currently, practicing preventative medicine requires the early detection of a disease. Therefore, recognizing the early on-set of symptoms with high accessibility to the population may provide insight to determine new therapies that can limit the progression of these devastating diseases.

Access references for this paper using the QR code below.

"Education is not preparation for life; education is life itself."

–John Dewey

Congratulations Graduates!

From a Friend of the University

Lunar Eclipse

by Terry Xie

In the early hours of March 14, a group of friends and I gathered beneath the Georgia Tech Campanile, cameras in hand, ready to capture the 2025 total lunar eclipse—the first visible in the U.S. since 2022.

A lunar eclipse occurs when the Earth aligns perfectly between the Moon and the Sun, casting its shadow across the lunar surface. This blocks direct sunlight, causing the Moon to darken and take on a striking reddish hue. This "blood moon" effect results from Rayleigh scattering—the same phenomenon that makes the sky blue. While shorter-wavelength blue light scatters more easily in Earth's atmosphere, longer-wavelength red light travels through more directly. During a lunar eclipse, the only sunlight reaching the Moon has passed through this atmospheric filter, painting it in deep red tones. The more dust, clouds, or other particles present, the richer the red coloration.

Unlike solar eclipses, which require precise location and timing to view, lunar eclipses are much more accessible. Because the Earth's umbra—the darkest part of its shadow—is significantly larger than the Moon, an entire hemisphere can witness the event. This meant I didn't have to travel far to capture it. While I could have simply taken photos from my apartment balcony, I wanted to add a distinctive Georgia Tech touch. Using data on the Moon's trajectory and a bit of creative intuition, I chose the Campanile as my foreground. Its elegant structure, one of the most recognizable landmarks on campus, provided the perfect contrast between technology and nature's grandeur.

Despite the Moon's large apparent size, its immense distance—238,855 miles (384,400 km) from Earth—made capturing fine details a challenge. To magnify the Moon's surface, I used a telephoto lens, ensuring clarity despite the dim lighting. The darkness of totality required a slow shutter speed (around 1/5 of a second) to gather enough light, but this introduced the risk of motion blur due to Earth's rotation. To counteract this, I used a tripod to keep the camera stable. After carefully adjusting angles to align the Campanile's spire with the Moon, I captured the shot I envisioned.

While lunar eclipses may not have the dramatic spectacle of their solar counterparts, they offer a quiet, awe-inspiring beauty. Their longer duration and widespread visibility make them an accessible celestial event worth experiencing. That night, I wasn't just focused on "getting the shot"—I was immersed in the moment, appreciating the vast mechanics of our universe. The next total lunar eclipse visible from North America will occur on August 12, 2026, so when the time comes, step outside, look up, and enjoy the show!

Access references for this paper using the QR code below.

Making a Change: Meet a PURA Awardee

Ananya Pasunuri

At Georgia Tech, research is not just something you read about in class — it's something you can do. Every semester, Georgia Tech awards a select number of students a President's Undergraduate Research Award — better known as PURA. Through programs like PURA, students aren't waiting until graduate school to make discoveries of their own. Behind the acronym — and the stipend — is a real chance to grow as a researcher, thinker, and contributor to change.

To understand what PURA looks like beyond the application form, we sat down with one of the recipients.

Meet Esha Dhabuwala. A third-year biology major at Georgia Tech, minoring in Health and Medical Sciences, Esha received PURA for the Fall 2024 semester to support her research at the Medical Image Research and Analysis (MIRA) Lab. PURA supports undergraduate researchers with a $1500 stipend to work on faculty-mentored projects during either the fall, spring, or summer semesters. For many students, the award serves as both a recognition of their contributions and a financial incentive to deepen their research.

In Esha's case, the award supported her ongoing investigation into the neurological impacts of long COVID. She joined the MIRA Lab at the beginning of her second year after connecting with her mentor through PairMe, a student-mentor matching platform run by Georgia Tech's Undergraduate Research Opportunities Program (UROP). UROP provides students with resources, workshops, and one-on-one guidance to get involved in research early in their college careers. Throug PairMe, students can submit their interests and be matched with faculty members looking for undergraduate researchers. That's how Esha found her way into the lab and into a project that would shape the next two years of her undergraduate experience.

In the MIRA Lab, Esha's research focused on long COVID, a condition in which individuals continue to experience symptoms even after recovering from their initial infection. Her project investigates a particularly common symptom: brain fog, which manifests as difficulty focusing or having persistent mental fatigue. Using a technique called quantitative susceptibility mapping (QSM), Esha helped extract data from MRI scans and quantify the magnetic susceptibility of different brain regions. Through these results, the team believes that higher susceptibility values may be linked to iron dysregulation in the brain—an effect that could explain the neurological symptoms some post-COVID patients report. Her work compares three data sets: post-COVID patients with long COVID symptoms, those who recovered without symptoms, and a healthy control group.

Esha Dhabuwala is a third-year Biology major at Georgia Tech with a minor in Health and Medical Sciences.

Background photo courtesy of Alexis Vladescu

The lab is preparing to publish their findings this summer, and as Esha puts it, "This was a very unique opportunity, and with what I achieved with this, I can apply to more datasets."

Esha first joined the MIRA Lab for academic credit, but as her involvement deepened, she decided to apply for PURA funding in Spring 2024. With guidance from her graduate student mentor and faculty advisor Dr. Chuan Huang, she began the process of drafting her proposal. The application required her to articulate a clear research question, outline her methodology, and explain the significance of her work.

"This project definitely set a more clear framework for what I was supposed to do," she explained. "Even drafting the proposal—for example, the background research I had to do—gave me more insight into my own research." Through multiple meetings and rounds of revision, Esha worked closely with her mentors to refine the proposal. "We had meetings and edited my proposal together—I sent them different drafts. That definitely helped me gain research writing skills, which are useful now as we're drafting our manuscript."

Receiving PURA funding for Fall 2024 allowed Esha to focus more deeply on her research. Compensation also made a significant difference. "Typically, undergrads are not paid for research, but it is a big time commitment—it's normally 10 hours a week. It was nice to have that," she shared.

Beyond the financial support, Esha sees the award as a meaningful step forward in her academic journey. Now applying to medical school, she credits PURA with helping her grow in three distinct ways. First, the process of writing and submitting a formal proposal helped her build critical research and communication skills. Second, the award itself serves as a credential that strengthens her post-graduate applications. And third, the experience connected her more deeply with the undergraduate research community—she's now a part of URA (Undergraduate Research Ambassadors), helping other students get involved.

As for what is next, Esha and her team plan to publish their findings this summer. She also hopes to expand the QSM pipeline she worked on to other neurological conditions, such as Alzheimer's disease and chronic fatigue syndrome. "This was a very unique opportunity," she said, "and with what I achieved with this, I can apply to more datasets."

For students considering undergraduate research, Esha encourages taking the leap—especially with PURA. "You actually make progress during the semester, because you have these deliverables and you have to meet them," she said. Writing a proposal at the beginning and submitting a final report at the end keeps students accountable and gives structure to their work.

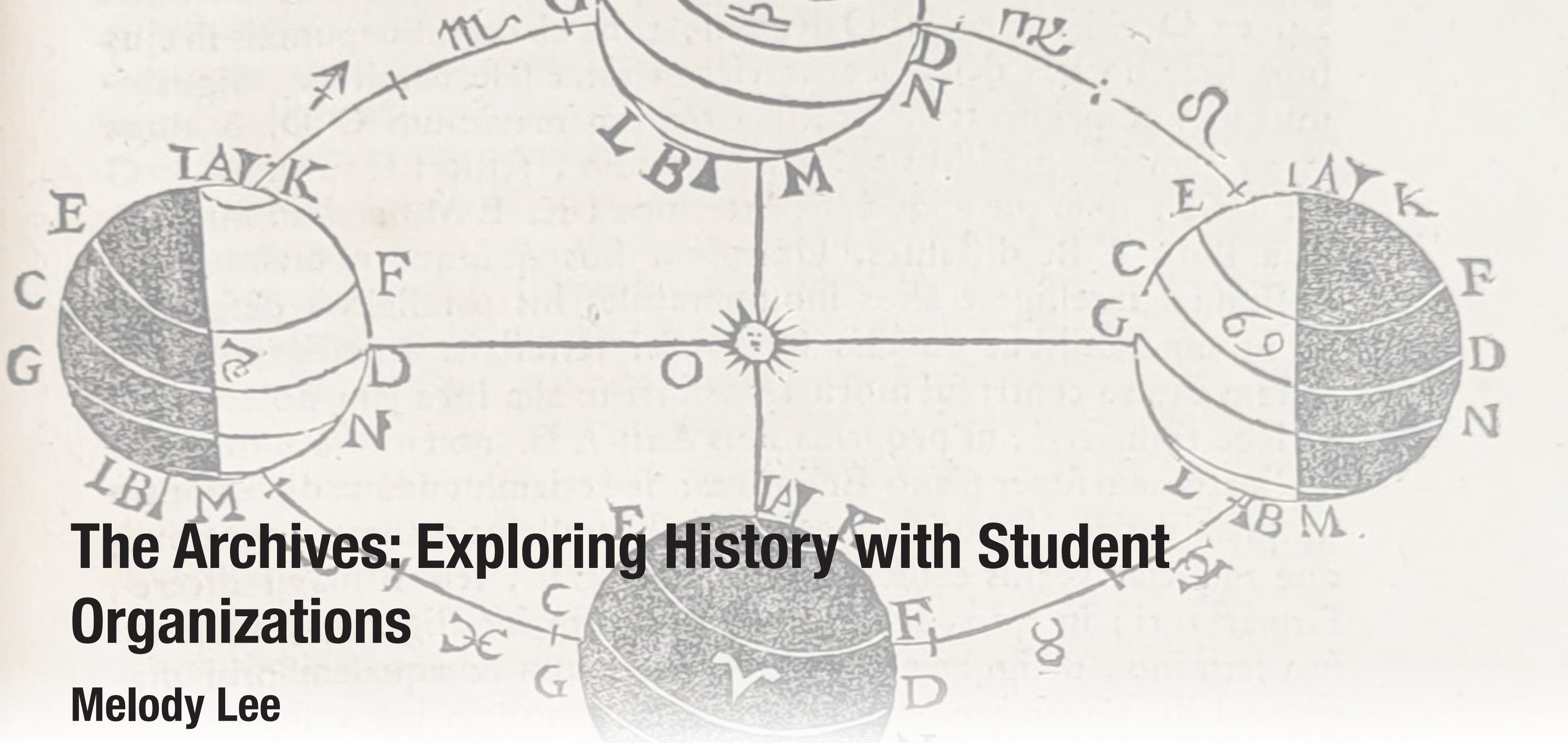
But the benefits don't stop there. "It can help you get other research opportunities, with post-grad opportunities or med school," Esha explained. And perhaps most importantly, it helps students build a foundation—both technically and professionally—for wherever their path may lead.

Opportunities like PURA do not just support student research—they redefine what it means to be a researcher at the undergraduate level. From discovering a passion for inquiry to building skills that carry far beyond the lab, students like Esha Dhabuwala show what's possible when curiosity meets support. At Tech, research isn't reserved for later. For many students, PURA is how it begins.

A special thank you to Esha Dhabuwala for generously sharing her time and experience with The Tower team. Additional thanks to Georgia Tech's Undergraduate Research Opportunities Program (UROP) and the Undergraduate Research Ambassadors (URA) for providing continued support and resources to students across campus.

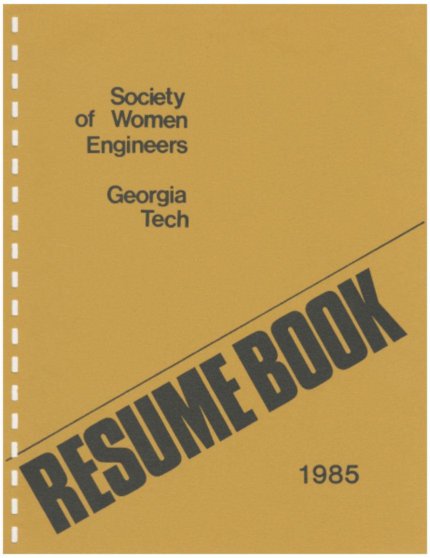
Interested in Applying for PURA? Here's How:

1. Find a Research Mentor: Use UROP's PairMe platform or attend info sessions to connect with faculty looking for undergrad researchers.
2. Draft a Proposal: Work with your mentor to write a clear and specific research plan. Identify what can realistically be done in one semester.
3. Start Early: "Schedule a meeting with your mentor to clarify your exact goal," Esha advises. "Sometimes this is difficult, because you have to come up with a very specific research question."
4. Use Campus Resources: Connect with Undergraduate Research Ambassadors (URA) for help reviewing drafts. Attend proposal-writing workshops through UROP.
5. Apply—even if you're unsure: "Even if you don't get it the first time, applying teaches you something," Esha said. "They really do try to give a lot of students the opportunity."

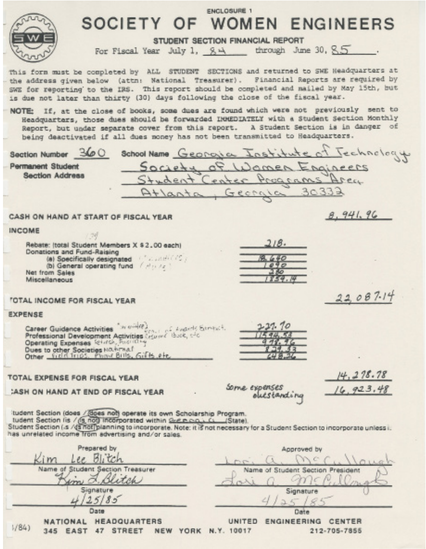


The Archives: Exploring History with Student Organizations

Melody Lee



The Society of Women Engineer's Resume Book contains a collection of members' resumes, a snapshot of female engineers' activities and commitments from the year.



ENCLOSURE 1

SOCIETY OF WOMEN ENGINEERS

STUDENT SECTION FINANCIAL REPORT

For Fiscal Year July 1, 84 through June 30, 85.

This form must be completed by ALL STUDENT SECTIONS and returned to SWE Headquarters at the address given below (attn: National Treasurer). Financial Reports are required by SWE for reporting to the IRS. This report should be completed and mailed by May 15th, but is due not later than thirty (30) days following the close of the fiscal year.

NOTE: If, at the close of books, some dues are found which were not previously sent to Headquarters, those dues should be forwarded IMMEDIATELY with a Student Section Monthly Report, but under separate cover from this report. A Student Section is in danger of being deactivated if all dues money has not been transmitted to Headquarters.

Section Number 360 School Name Georgia Institute of Technology

Permanent Student Section Address: Society of Women Engineers, Student Center Programs Area, Atlanta, Georgia 30332

CASH ON HAND AT START OF FISCAL YEAR		8,941.96
INCOME		
Rebate: (total Student Members X $2.00 each)	218.	
Donations and Fund-Raising		
(a) Specifically designated	18,640	
(b) General operating fund	1090	
Net from Sales	280	
Miscellaneous	1859.14	
TOTAL INCOME FOR FISCAL YEAR		22,087.14
EXPENSE		
Career Guidance Activities	227.70	
Professional Development Activities	11594.53	
Operating Expenses	978.96	
Dues to other Societies	829.33	
Other: Field trips, Phone Bills, Gifts, etc.	648.36	
TOTAL EXPENSE FOR FISCAL YEAR		14,278.78
CASH ON HAND AT END OF FISCAL YEAR	Some expenses outstanding	16,923.48

Student Section (does / does not) operate its own Scholarship Program.
Student Section (is / is not) incorporated within Georgia (State).
Student Section (is / is not) planning to incorporate. Note: it is not necessary for a Student Section to incorporate unless it has unrelated income from advertising and/or sales.

Prepared by	Approved by
Kim Lee Blitch	Lori A. McCullough
Name of Student Section Treasurer	Name of Student Section President
Kim L. Blitch	Lori A. McCullough
Signature	Signature
4/25/85	4/25/85
Date	Date

(1/84) NATIONAL HEADQUARTERS UNITED ENGINEERING CENTER
345 EAST 47 STREET NEW YORK N.Y. 10017 212-705-7855

A copy of the 1984 financial report from the Society of Women Engineers, retrieved from the Georgia Tech Archives.

Photos from the Georgia Tech Society of Women Engineer's and Archives' collaborative event in February 2025.

Background photo courtesy of Alexis Vladescu

There's a glass room on the first floor of Crosland Tower, home to the Georgia Tech Archives Reading Room. If you've never been there, it's worth a look.

The Georgia Tech Archives & Special Collections contain close to 15,000 processed collections. These are stored across three major locations: the basement of the Price Gilbert Memorial Library and two storage facilities external to campus. Hidden among these is a vault containing the Library's rare book collections, featuring pivotal works such as Isaac Newton's Principia Mathematica and Benjamin Franklin's Experiments on Observations on Electricity. Moreover, the Archives contains one of the largest known science fiction collections in the United States, with over 13,000 science fiction and fantasy novels, and well over a thousand magazines and fanzines.

In addition to storing incredible works from around the world, the Archives also serve to preserve texts that provide an intimate look at Georgia Tech and Atlanta history. This includes architecture plans for current and formerly standing Tech buildings, research papers authored by past faculty, and more. The Technique collection, for example, dates from 1911 onwards and occupies 42 linear feet in space – the equivalent length of a school bus. The Georgia Tech Digital repository also provides access to the Institute's scholarly records online, including Ryan Gravel's pivotal thesis on the construction and design of the Atlanta Beltline. Cumulatively, these tens of thousands of documents construct a complete historical snapshot of Georgia Tech through time.

Dedicated staff share the richness of this material with the rest of campus, curating exhibits, managing documentation, and hosting events. Every semester, Georgia Tech archivists offer orientations and sessions in partnership with courses on campus. In some cases, these sessions transform into student research projects or term papers.

Over the last few years, the Archives staff have taken steps to get student organizations more involved with ongoing work. Alex McGee, the Georgia Tech university archivist, connects with student organizations, from the Ramblin' Reck Club to the Georgia Tech Flying Club. For some, these events are a source of inspiration. For instance, Alex pulls together collections describing Atlanta-specific history for the Georgia Tech Pride Alliance every year. By comparing events held in years past with the upcoming calendar of activities, Pride Alliance members are spurred to revive events.

Preksha Jain, the president of the Society of Women Engineers at Georgia Tech, describes the process. Club leaders first initiate a conversation with Alex and the Archives staff. After outlining what the vision for the collaboration is – whether it be a research project, event, or presentation – Alex pulls relevant documents from the shelves.

These documents are reviewed by the student organization: the final collections for display are decided based on feedback. "You can tell them, 'I want this box to be put out,'" Preksha explains. On the day of the event, the materials will be set out for attendees.

This months-long back and forth culminated in an organization-wide event in February of this year. SWE members gathered around the tables, wandering from folder to folder of documents and talking about their findings. In one folder, annual reports describing the business side of the "annual banana-split eating contest" were organized into a neat stack.

Yet, amongst the chatter, the impact of these materials was not lost. In the words of Alex, as she opened the floor for the members to explore: "We are here to remember why we need organizations like the Society of Women Engineers."

The Archives offers an unending opportunity for students to explore the histories of their own organizations, hometowns, and identities. The door remains open for anyone and everyone interested in taking a look.

Alexandra McGee is the Georgia Tech University Archivist.

Thank you to the Georgia Tech Archives and the Society of Women Engineers for allowing the editor team to follow along during the event planning and hosting stages. A special thank you to Alex McGee from the Archives and Preksha Jain for sitting down with The Tower editors to answer questions.

Editor Biographies

Alexis Vladescu

Alexis is a second-year biomedical engineering undergraduate on the pre-health track. She is part of the Laboratory for Synthetic Immunity where she focuses on optimizing CAR T cell therapy and aspires to pursue a career in surgery.

Ananya Pasunuri

Ananya is a first-year, Mechanical Engineering Major/AE Minor, Interested in sustainability within the Aerospace Industry especially in propulsion and rocket systems.

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Angelina is a second-year Physics and Computer Science double major. She studies ultra-high energy neutrinos and loves writing fiction!

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Erin is a fourth-year biochemistry major and on the pre-health track. She works with two research labs, the Botchwey lab which studies muscle regeneration and the Fernandez lab which studies metabolomics.

Jonathan Feldman

Jonathan is a first-year Computer Science and Mathematics double major from Fort Worth, Texas, with an interest in AI and its applications in various fields, especially biomedicine. He is very excited to be part of editorial team!

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Isabel is a second-year biomedical engineering major. She is currently conducting research on cystic fibrosis treatments and innate immune responses to tuberculosis. Additionally, she leads three international research projects in sub-Saharan Africa.

Kathy Peng

Kathy is a first-year neuroscience major and CS minor. She is very passionate about the intersection of computer science in neuroscience research and its potential in improving ethical and sustainable practices!

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Melody is a second-year undergraduate student studying Computer Science, with minors in math and physics. Her research is mainly in quantum algorithms for applied science.

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Mirielle is a third-year Biology student with a minor in Health and Medical Services. She is on the pre-medicine track, and hope to become a physician. Currently, she is doing research in regenerative medicine and wound healing.

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Shreya Iyer is a first-year electrical engineering major, with a focus in signal processing and robotics. She researches at the Electro-Optical Systems Laboratory on resilient GPS-denied Positioning, Navigation, and Timing for challenging environments.

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Tvishi is a first-year biomedical engineering major with an interest in immunoengineering and DNA research. Outside of academics, she enjoys doing henna, baking, and NYT mini games!

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