Thesis Project Portfolio

Lost in Compression: Who's Heard and Who's Blurred in Digital Voice Communication?
(Technical Report)

Gender Biases in Digital Audio Coding: Impacts on Female Vocal Representation and Listener Perception

(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Elizabeth J. Recktenwald

Spring, 2025

Department of Systems and Information Engineering

Table of Contents

Executive Summary

Lost in Compression: Who’s Heard and Who’s Blurred in Digital Voice Communication?

Gender Biases in Digital Audio Coding: Impacts on Female Vocal Representation and Listener Perception

Prospectus

Executive Summary

Introduction

Both my technical Capstone project and STS research paper explore how digital audio compression can unintentionally reinforce bias, particularly regarding gender disparities in speech representation. Although the two projects were developed independently—one through empirical signal analysis and the other through a sociotechnical lens—they converge around a shared concern: how the technical design of audio codecs impacts real-world communication.

My Capstone project investigates whether widely used voice compression codecs (OPUS, CODEC2, and AMR) introduce statistically significant distortion disparities between male and female speakers. Meanwhile, my STS research approaches a related question from a different angle, using historical and theoretical frameworks to understand how design decisions in digital audio coding have produced and reinforced gendered outcomes. While the Capstone emphasizes measurable technical outcomes and the STS project emphasizes interpretive, cultural consequences, both were motivated by the goal of identifying and addressing inequities embedded in communication technologies.

Capstone Project Summary

My technical Capstone project focuses on the analysis of how digital voice communication codecs affect the clarity and intelligibility of speech for speakers of different demographics. Voice communication tools such as Zoom, Microsoft Teams, Discord, and emergency radio systems rely on lossy compression techniques to reduce bandwidth usage. These compression algorithms (codecs) simplify audio data by removing certain frequencies based on assumptions about human hearing. However, concerns have emerged that such assumptions may not apply uniformly across all voice types, particularly with respect to gender.

This project tested three commonly used codecs—OPUS, CODEC2, and AMR—across a wide range of bitrates to examine whether compression disproportionately distorts speech from male or female speakers. The study utilized a voice dataset of 2,953 individuals, balanced by sex, and applied 14 signal processing metrics to evaluate the degradation of audio quality between the original and compressed versions of each voice.

Preliminary results suggest a bitrate-dependent disparity: at lower bitrates (6–16 kbps), female voices (which generally have higher fundamental frequencies) are more degraded than male voices, while at higher bitrates (24–48 kbps), male voices are slightly more affected. These results imply that existing codec designs may not offer uniform intelligibility for all users, especially when bandwidth constraints necessitate aggressive compression. The work contributes actionable insights for audio codec developers and provides a foundation for further research into inclusive, bias-aware codec design.

STS Research Paper Summary

My STS research paper, “Gender Biases in Digital Audio Coding: Impacts on Female Vocal Representation and Listener Perception,” investigates how compression algorithms such as MP3 and AAC disproportionately affect the clarity and emotional resonance of female voices. Drawing on theories of Social Construction of Technology (SCOT) and Technological Momentum, the paper explores how historical and cultural forces have influenced the development of audio coding standards that prioritize certain vocal characteristics—often those associated with male speakers.

The study examines how lossy compression techniques remove high-frequency content in ways that tend to disproportionately degrade female speech, and it considers how this affects listener perception and engagement. Through a synthesis of literature on auditory signal processing, speech intelligibility, and neural responses to vocal stimuli, the paper reveals how algorithmic distortions can produce unintended sociotechnical consequences.

Ultimately, the research argues that audio compression technologies not only reflect technical limitations but also reproduce cultural biases embedded in their development.

Concluding Reflection

Working on my Capstone project and STS research simultaneously offered a rare and valuable opportunity to view the same issue—bias in digital audio systems—through two fundamentally different lenses. On one hand, the Capstone required careful attention to signal analysis, statistical software, and objective performance metrics. On the other, the STS paper demanded critical reflection on the broader sociotechnical systems in which those metrics exist, including the assumptions, priorities, and histories that shape technical design.

The most important insight I gained from this dual approach is that technical excellence alone is insufficient when developing systems intended for broad human use. Codec designers may not intend to embed bias in their algorithms, but by failing to account for demographic variation in vocal traits, they risk reinforcing patterns of exclusion. At the same time, recognizing these biases requires both empirical evidence and a willingness to ask sociotechnical questions—questions about who benefits from a technology, who is marginalized by it, and why certain design decisions persist.

By integrating these projects, I've developed a more holistic understanding of audio technology and a deeper appreciation for interdisciplinary problem-solving. This experience has shaped my future interests in inclusive engineering practices and the ethical design of digital systems. Most importantly, it has taught me that meaningful technological progress requires not only precision and rigor, but also critical reflection and social responsibility.