

A Scoping Review of Pitch Perception and Matching Methodology

Part One: Portfolio

Planned Program of Study:

Context:

I have been a professional voice teacher teaching singing to children, teens and adults in the context of a private voice studio for over a decade. During the course of my career, I have encountered voice students who have trouble matching pitch. My undergraduate degree was in vocal performance and although we were required to take a single vocal pedagogy course and we were not taught on how to instruct students who had trouble matching pitch. This presented a challenge in my professional practice when I encountered students with pitch issues and no training on how to teach them. Through my own trial and error, I developed methodology to help my poor pitch singers (PPS) and my interest in the topic has led me to dedicate a portion of my master's studies in vocal pedagogy towards learning more about pitch matching. As part of my master's program, we were required to complete a preliminary assignment and I chose to write about my experience teaching a PPS. The assignment included sources on the topic of pitch matching, but due to the short length of the assignment I only included a high-level overview of relevant literature.

In this assignment, I will be conducting a literature review to examine and analyze literary sources surrounding the process of pitch matching to expand upon my previous research conducted in my Module 3 assignment (Waxer, 2024) which examined the reasons for teacher aversion to teaching poor pitch singers (PPS) through a mixed method study involving a literature review, quantitative survey and qualitative interviews. The reason for this future study will be to better understand the science behind pitch matching in terms of its complex application which combines various motor neurological processes required in hearing and producing sound.

My literature review will be cross-disciplinary and span the breadth of music, voice, medical and scientific journals to better understand the science of pitch matching and its practical

application in the voice studio. I plan on interpreting dense scientific processes and interpreting them into easier, more digestible pieces of information that can be helpful for the singer or voice teacher.

In my Module 3 assignment titled “Can we teach them to sing? Voice teachers’ opinions on poor-pitch students”, I discovered that a large gap existed in the vocal pedagogical literature in that there was nearly zero information on pitch or how to teach pitch. My study then found that voice teachers had a strong aversion to teaching poor pitch students, which could possibly be explained by the lack of pedagogical literature on pitch. Surveyed teachers showed an aversion to teaching PPS and a statistical correlation was discovered showing teachers with the most education (master’s degree or higher) having the strongest aversion to teaching PPS. In Watts *et al.*, (2003), a survey was sent to over 2000 voice teachers in order to determine teacher opinions on the greatest indicators of talent. Among all the presented choices, pitch was determined to be the most important factor according to those surveyed. The importance for teachers for students to possess good pitch matching abilities directly contradicted my survey findings of teachers having an aversion to teaching poor pitch students. Furthermore, pitch was scarcely discussed in the standard pedagogical literature such as Miller (1986) and Appelman (1967) as detailed in Table A by page number and percentage of total book.

Table A: Percentage of Vocal Pedagogy Texts Discussing Pitch (Waxer, 2024)

Author and Title	Total # of pages in textbook	# of Pages that mention the concept of pitch matching (but no pedagogical guidance)	# of Pages that mention a pedagogical solution to improve pitch matching	% of book pages that discuss intonation, pitch matching or ways to improve
Appleman – Science of Vocal Pedagogy	395	5	0	1%
Janice Chapman – Teaching and Teaching Singing	265	3	0	1%
Vennard – The Mechanism and the Technic	220	7	0	3%
Richard Miller – The Structure of Singing	292	3	0	1%
Doscher – The Functional Unity of the Singing Voice	213	5	1	3%
Phillips – Teaching Kids to Sing	355	2	12	3%

My aim for this module is to educate myself on the process of pitch matching from a neurological perspective to better understand the complex process. I will then evaluate whether this information would be useful for voice teachers to know, and if so, evaluate if an explanation of the neurological process of pitch matching should be part of vocal pedagogical training. I will conduct my research as a literature review to dive deeper into available literature and resources. I hope the information I find could be used to narrow the gap between teacher aversion to teaching PPS and the importance of singers having good pitch matching abilities.

Unlike my previous studies on pitch matching which focused a lot on literature within the realm of vocal pedagogy, journal of voice and music education journals, I plan to widen the scope of studied literature to include neurology and other science journals. The aim of my future research will be to identify, understand and analyze literature about pitch matching to find its possible application to voice teachers.

Objectives:

- Research and present a scoping review on pitch matching to discover similarities and potential discrepancies found between various fields, (I.e. voice, neurology, biology journals, etc.).
- Gain understanding of the current scientific models of pitch matching to inform my future research.
- Gain understanding of the correlation between auditory processing and singer's ability to match pitch.

Aims:

- To achieve enough knowledge to improve and create teaching methodologies in my own practice.
- To become an expert in the field of pitch matching with the intent of specializing in pitch matching as a voice professional. As an expert I would be able to speak and present on the topic at various vocal pedagogical conferences and events to help inform other voice professionals of the research.

- To become a pitch specialist to allow me to recruit new clients as well as maintain current clients.
- Provide an excellent service to my customers by improved professional practices.
- Innovate and keep up with new research and methodology for my voice studio.

Rationale for my Study:

There are many voice teachers with a large variety of experience and expertise and therefore voice teaching is an extremely competitive field. Teachers may specialize in teaching certain genres or age groups to distinguish them from others. Most of my students are middle school and high school aged students and most sing musical theater or commercial music, although I do also teach classical music and am classically trained. I found I was able to differentiate myself from other teachers by being willing to work with students who are not advanced singers or “naturally talented”. Sometimes students are rejected from voice studios due to the nature of a student’s voice.

Some of my young students had extreme difficulty matching pitch, coordinating their voice to achieve ideal tone, trouble switching between their chest voice and head voice registers. I hope that by becoming an expert in pitch matching I will gain a competitive advantage at attracting poor pitch singers to my voice studio. Additionally, if I can gather and analyze enough data to create my own methodology which helps poor pitch singers, I could create my own vocal exercises, tutorial videos or even a full course or publication. These publications could be sold to singers and potentially other voice teachers.

Methodology:

I will be conducting a scoping review of literature on pitch matching models to:

1. Identify the breadth of available information on pitch matching
2. Clarify key concepts of pitch matching models.

3. To identify the similarities and differences of information presented in voice and music journals compared to biology, neurology and other hard science-based journals.
4. To find and analyze gaps in knowledge.
5. Find and identify and prominent themes in the literature.
6. To classify the types of available evidence on pitch matching models.

Literature reviews provide a comprehensive overview of existing research on a specific topic and must include an overarching summary of existing literature and full scope (Denney and Tewksbury, 2013). One type of literature review is a scoping review, which is ideal for topics that have a large range of available literature (Munn *et al.*, 2018). A scoping review is also appropriate for my topic of interest as I intend to use my findings to inform future research on pitch matching in the vocal studio (Munn *et al.*, 2018).

According to Denney (2016) literature reviews must fulfil each of the following purposes: review and critique the literature, conduct a meta-analysis, critique and synthesize the literature, reconceptualize the topic, and answer specific questions. As I am not answering specific questions about pitch matching in my review, a scoping review is more appropriate than a systematic review, rather I want to provide a high-level overview of information that will be useful to me in my practice as well as other voice practitioners. (Munn *et al.*, 2018)

Scoping reviews are used to identify knowledge gaps and are becoming increasingly more common, as published scoping reviews have increased annually since 2012. (Tricco *et al.*, 2006). They can be used to present a broad overview of a topic, which in my case in poor pitch matching causes and how it relates to voice teachers (Tricco *et al.*, 2006).

Scoping reviews must have criteria and methods for selecting literature (Tricco *et al.*, 2006) but these criteria can be determined by the various authors allowing for a wide range of variety. My reasoning for conducting a scoping review stems from both my professional practice as a voice teacher but also my previous research as a master's student at the University of Wales Trinity Saint David.

In my Module 3 assignment (Waxer, 2024) I found many gaps in the vocal pedagogical literature when examining textbooks that are published for the college level vocal pedagogy student as well as professional voice students. The vocal pedagogy literature lacked information on the concept of pitch altogether, some books not mentioning pitch or fundamental frequency (F(0) at all. Furthermore there was no guidance on how to teach the process of pitch matching to students. Miller (1986) starts out on the premise that teachers and voice students already have good pitch matching abilities and instead focuses many chapters on diction, breathing and tone quality. I realized that there had been a gap in my own vocal pedagogy training in that I did not understand causes of poor pitch matching. Colloquially many people self-identify themselves as “tone deaf” but my previous studies have led me to discover that congenital amusia is extremely rare in the population and therefore it’s unlikely that any of my students can attribute their lack of pitch matching skills to having congenital amusia (Dalla Bella, Giguère and Peretz, 2009).

My Scoping Review Plan:

After reviewing my previous research on pitch matching and teacher perceptions of teaching pitch matching, I decided I would look for literature using both the UWTSD library and Google Scholar. I have previously saved many articles to my Zotero assistant on the topic of pitch matching. Zotero is a computer application that helps organize literature and assign proper citations.

I will be using the UWTSD library search feature and Google scholar search to find relevant literature. I will be searching for phrases such as “Pitch Processing”, “Auditory Perception”, “Musical Pitch Perception” to discover various journals across multiple disciplines. I will try to avoid grey literature, defined by Exeter as information that is produced outside of traditional publishing such as blogs, newsletters and pamphlets (Snook, accessed 2024). Rather my literature will come from academic journals and published academic textbooks. In addition to having my literature exclude grey literature I will exclude articles published before 2005 in my summary, however I will reference older materials to explain updates to the field.

Criteria for literature exclusion:

- Grey Literature
- Literature published before 2005

Literature Weight:

Journal Impact Factor will be used to evaluate the importance and accuracy of articles drawn from academic journals. DeGroote (accessed 2024) says that impact factor (IF) is a measure of frequency in which the average article in the particular journal has been cited in a particular year and IF is used to measure the importance of a journal. However, there are many articles published on why IF is not an important measurement. I am curious to see if there are trends between IF for voice and music journals compared to “hard science” journals concerning themselves with biology and neurology. I hope by avoiding grey literature and evaluating articles depending on their impact factor that I can better organize my findings.

Organization:

Scoping reviews need to have a plan for presenting the literature into themes. I chose to relate my literature to the Auditory Feedback Loop (AFL) (Figure 1), which is a way to simplify the process of hearing, processing, mapping and ultimately matching pitch (Berkowska & Dalla Bella, 2009). The downside of categorizing literature through the lens of the AFL is the possibility that literature will not neatly fall into one of the steps of the auditory feedback loop. In this scenario, I will point out how the information can be divided between the categories. My scoping review will identify relevant studies and relate them to the AFL just as scoping reviews are used to identify best practices in the medical field, I hope my scoping review will help identify best practices for voice professionals (Munn *et al.*, 2018).

Time Scale of Study:

My Module 4 assignment was assigned in January 2024 and began with a group tutorial led by our tutor. We were provided with the course syllabus and course handbook which

explained the breakdown of our assignment into two components and outlined grading criteria and word count requirements. I created a timetable to better visualize my planning and execution of the assignment which began in January and culminated in the completion of my assignment in June. As this study contained a large breadth of information it was important to be able to pace myself in terms of gathering research, critically evaluating my found literature and then writing up my findings into my assignment.

Table 1 outlines the timescale that I attempted to follow.

Timetable (Table 1)

	Start	End	Jan.	Feb.	Mar.	Apr.	May	June
Methods Research & Project Design								
Module Meeting	1/15/24	1/19/24						
Topic Approval	2/1/24	2/14/24						
Literature Review Methods	2/14/24	3/14/24						
Project Design & Outline	3/15/24	4/25/24						
Literature Selection & Analysis								
Develop Selection Criteria	4/1/24	4/11/24						
Collect Literature	4/3/24	5/30/24						
Literature: Read & Code	5/15/24	5/30/24						
Portfolio - Writing								
Introduction	4/15/24	5/15/24						
Program of Study	4/20/24	5/14/24						
Critical Reflection	5/27/24	6/3/24						
Literature Review								
Introduction	5/15/24	5/20/24						
Theories, Methods, and Practices	5/20/24	5/27/24						
Analysis and Differences	5/20/24	5/27/24						
Impacts, application, and learning	5/25/24	6/2/24						
Conclusion, References, Appendices	6/1/24	6/4/24						

Scoping Review:

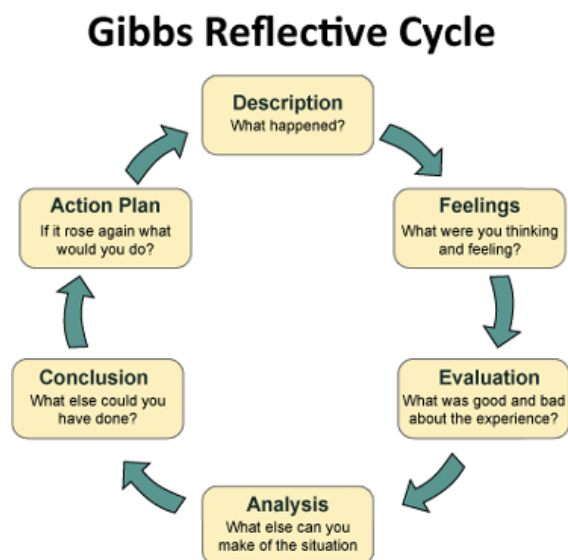
Ultimately I hope that my scoping review provides a clear picture of existing gaps in the vocal pedagogical field surrounding the causes of pitch matching in voice students and reveals solutions for helping poor pitch singers. Winter (2022) discussed the difficulty for voice practitioners writing on the field of voice related topics in that conducting a literature review in a field that combined art with science can be extremely challenging. I anticipate that due to my desire to find “hard science” articles from journals with high impact ratings this information may be foreign and unusable to voice professionals who often teach with a holistic and artistic approach. Additionally, my plan to present the information through the

lens of the auditory feedback loop may end up being limiting in terms of being able to relate that information back to information that can be digested by the average voice teacher. I also have word limits in my presentation of my research findings which require me to make difficult decisions on which literature I will include in my written report and which information I will omit.

Critical Reflection on the learning experience:

I will use the Gibbs' Reflective Cycle (GRC) (1998) (Figure 2) to guide my critical reflection due to its practical and straightforward approach. The GRC is a six-step looping process which allows practitioners to consider facts and feelings for evaluation, analysis and creation of an action plan. The 6 steps of the GRC are: Description, feelings, evaluation, analysis, conclusion and action plan. (Gibbs Reflective Cycle, 1998). In the following paragraphs I follow the outline of the GRC to critically reflect on my learning experience in this assignment.

Figure 2: Gibbs Reflective Cycle



(Gibbs' Reflective Cycle, no date)

Description:

I have learned from the literature that models of auditory perception that impact pitch perception and pitch matching are complex topics requiring knowledge of neurology, biology and anatomy to understand. Much of the jargon found in scientific journals could be confusing and overwhelming for some musicians and voice teachers to understand without having received medical or anatomical training. While many studies have been completed on amusic people (tone deaf), very few studies have been completed on poor pitch singers (PPS) who make up about 10-15% of the population. I used the auditory motor loop to help organize my research, as the neurological and motor processes used in the process of singing ended up being very complex and many scholarly articles referenced many parts of the brain that I was unfamiliar with. Additionally, there was a large gap in pedagogical literature surrounding pitch matching causes and my focus on neurology and biology did not help solve the existing gap. I would have preferred to be able to uncover new vocal pedagogical sources that perhaps address the issue of pitch matching and solutions for teachers without having to delve deep into neurological processes and the role of hearing and auditory perception.

Feelings:

I felt very overwhelmed by this entire assignment due to undertaking research which I did not understand and stressed due to the vastness of fields of study for which I could find potential literature. I ended up feeling frustrated with much of the literature in that it was hard for me to understand. Many previously studied articles indicated that pitch matching abilities are caused by both perception issues and motor issues, but in diving deeper into the literature, I found that pitch perception involves a much more complicated process than previously understood. Additionally, I felt more confused that I was going into this assignment as I do not understand so much of the neurological jargon including descriptions of different parts of the brain and various brain imaging used to study those parts of the brain and how they relate to processing and executing pitch. I was also frustrated because my plan to organize my findings based on the auditory feedback loop did not work out as neatly as I had intended because much of the research did not conveniently fit into a particular category.

Evaluation:

In previous assignments I tried to focus on literature surrounding PPS and most of those articles came from voice journals, music education journals and psychology journals. Much of the literature found in voice journals tend to focus on singer pitch matching abilities through studies on various input methods, (i.e. live voice versus recorded voice, versus instruments) and tends to place a lot of weight on motor-control being a predominant factor on cause of poor-pitch singing. I was able to discover more diverse literature by expanding my search to “hard science” journals such as neurology and biology and searching for articles on the steps of the “auditory feedback loop”. I was happy that I learned about how hearing works and the various roles of the parts of the ear, such as inner ear, outer ear etc. I also learned a lot about the roles of perception and motor planning and its distinction from motor output which I had not previously known. My plan to tie everything to the auditory feedback loop may have been short sighted and also limiting as not every source of literature fit neatly into the process.

Analysis:

I have taught several poor-pitch singers in my practice as a voice professional and devised my own methodology for improving their pitch matching abilities due to the lack of pedagogical guidance in the vocal pedagogy literature. The information I have learned has helped inform me of potential underlying causes of poor pitch singing which will better help me create exercises and assignments for my students. However, many neurological studies use imaging devices such as fMRI to study the brain. Although it was useful to learn the process the brain goes through from hearing to processing to forming sound, these concepts would be difficult to use in the voice studio and may be counter-intuitive to my students' goals.

Studies conducted on singers testing their pitch matching abilities are interesting but there are often very small sample sizes of participants in these studies, making them potentially less accurate. Therefore, it's hard to apply these findings to individual students in my studio as their reasons for poor pitch matching could be different from any conclusions found in

any of the studies. As someone enrolled in a professional practice focused master's degree, I think it's also difficult to assume that every academic discovery can be applied to someone's professional practice. In the case of my studio, I am going to be always working with new and existing students and addressing their various vocal goals and vocal issues regardless of the findings of my study. Most of my students do not have serious pitch problems so I wonder whether my choice to study pitch matching to an ever-deeper level was a good use of my time when I have voice students of many levels and with many different goals. Will my interest in poor pitch singers make me too specialized? Is it possible that I will be associated with "bad singers" and therefore some students and their parents will shirk from enrolling in my studio due to my reputation of working with "bad poor pitch singers"?

Conclusion:

My expanded literature review brought me new useful information for my practice but also brought more confusion. Due to the complex nature of the neurological process of processing sound and creating sounds, I am unsure whether this information would be beneficial for voice teachers to know, or if this information would confuse teacher. Another frustrating aspect of this assignment was that it was difficult to classify articles into only once category of the AFL as many articles seemed to fit into two or three categories. It's possible there could have been a better way to conduct the scoping review and in retrospect there could have been a better way to choose themes and present the literature review.

Action Plan:

I plan to apply my new knowledge from this literature to future studies. Despite my fear that becoming specialized in poor pitch singers could hurt my business as a voice teacher and limit future potential clients, my interest in the topic and belief that most PPS will be able to improve with the right training I am going to continue this journey of becoming an expert in teaching poor pitch singers. I plan on conducting more studies on voice teachers to better understand their knowledge of pitch and their experiences working with PPS in the studio. For my final module of my master's degree, I would like to study PPS themselves and

hopefully combine all the knowledge gained in this literature review along with my previous research study. Additionally, I open myself to an entirely expanded market in that I can help train voice teachers to work with PPS rather than just focusing on working with PPS myself. The findings of my previous study revealed the strong aversion of teachers to teach PPS and given the gap in existing resources for teachers if I publish additional studies or create materials that I can sell I can help the field of vocal pedagogy and provide a niche for myself as a voice teacher.

Personal Reflections:

This assignment was extremely challenging for me. When I started my master's course, I was extremely motivated and excited to dive deeper into vocal pedagogy studies. At the onset of this assignment, I was halfway through my program, and I had lost motivation towards my studies. This Module 4 assignment which began in January 2024 was extremely hard to execute. In addition to new sources of stress in my personal life, my graduate advisor who had advised me from the onset of my program was no longer able to be my advisor for this module and going forward. I felt like giving up on my program and had to ultimately rely on a work ethic rather than being driven by internal motivation. According to Amida, Algarni and Stupnisky (2021) between 12-26% of graduate students drop out of their programs with research showing the leading factors are program structure, relationship with advisor, inadequate institutional support, financial constraint, time management issues, lack of social support and motivation. I feel I can relate to a lot of these issues especially the loss of my advisor with whom I was very close and then a feeling of being lost and lacking institutional support. My personal issues led me to lose a big part of my social support system and my busy life created additional time management issues.

Due to the large breadth of independent study options, I initially cast too large of a net when trying to choose a topic to study and ultimately came up with nothing. It was only when I re-examined my professional interests that sprouted through my professional practice (pitch matching) and reevaluating my previous assignments on these issues did I realize that I would be interested in using this study to further examine poor pitch matching.

COMPONENT ONE WORD COUNT: 4106

Part Two – Written Assignment:

Introduction

Teaching pitch in the voice studio comes with many challenges for the voice teacher. I have taken an interest in the topic of poor pitch singers (PPS) and have been attempting to discover and create evidence based best practices for voice teachers in teaching PPS. In my formative assignment (Waxer, 2023), titled Challenges in teaching poor pitch singers, I provided a high-level overview of the difference between singers with congenital amusia and PPS and a brief overview of how Amusia is diagnosed. I briefly touched on the role of auditory perception but did not determine a potential application to the voice studio. In my module 3 assignment (Waxer, 2024) titled Can we teach them to sing? Voice teachers' opinions on poor-pitch students.

I expanded upon my previous research by designing and executing a mixed-method study which included a quantitative survey sent to voice teachers, qualitative interviews and a brief literature centered around standard vocal pedagogical resources. After statistical analysis was conducted on my survey results, a shocking result was found, in that teachers had a strong preference to not teach PPS. Additionally, an inverse relationship was discovered between an increase in teacher education resulting in a strong avoidance of wanting to work with PPS.

Limitations of Previous Research

In my previous studies, (Waxer, 2023) and (Waxer, 2024) most of my literature review has centered on vocal pedagogy textbooks and journals in the field of voice and music education. In these studies, hearing was rarely referenced as part of the process of auditory perception and the process of pitch matching. Voice studies such as (Dalla Bella, Giguère and Peretz, 2009), (Berkowska and Dalla Bella, 2013) (Bottalico, Graetzer and Hunter, 2017) centered on studying the impact of sound source such as live voice versus recorded voice impacting a study participant's ability to distinguish and identify pitches, corresponding to auditory input and perception on the AUD. Input has been found to be important, Granot *et al.*, (2013) found a hierarchy of pitch accuracy which depended greatly on the input, live

voice generated the greatest accuracy followed by recorded optimal voice, recorded forced production, recorded piano and lastly live piano.

Much emphasis in previously studied literature has been centered on the importance of motor-control (Belyk, Lee and Brown, 2018), (Crocco, McCabe and Madill, 2020), (Hutchins, Larrouy-Maestri and Peretz, 2014), and poor pitch matching being caused by a subject's lack of motor control and voice coordination. (Hutchins, Lafrouy-Maestri and Peretz, 2014) used a slider to distinguish pitch perception and matching abilities from the ability to sing these pitches which greatly supports the hypothesis that motor control is a major factor in a singer's ability to sing on pitch. Motor control issues correspond to Auditory-motor mapping, Motor Planning and Motor Output (Figure 1) on the AFL.

In my previous studies, literature has come from the following journals: Psychology of Music, Journal of Voice, Psychology of Music, Frontiers of Psychology, British Journal of Music Education, Journal of Research in Music Education. An overwhelming number of articles came from the Journal of Voice and music education journals. The published studies center around the practical application of singing and music education, rather than the psycho-neurological processes involved in human pitch discrimination and perception.

My intent of this independent study was to find literary sources that expand upon my previous sources by focusing on literary sources in different journals, and ideally ones in the "hard sciences". Rather than arbitrarily deciding which journals were considered more reputable, I collected and analyzed journal impact factor in able to evaluate the importance of a journal within its field; the higher the impact factor, the more important the journal is considered (Sharma *et al.*, 2014).

In the following paragraphs, I will summarize my findings, discuss identified themes, compare them to my previous research and then finally relate my findings to my professional practice as a voice teacher. I intend to discuss literature surrounding pitch discrimination, pitch matching and its application in the voice studio. The auditory feedback loop will serve as an outline of various causes of poor pitch matching.

One common trait between previously studied literary sources has been the finding that congenital amusia, also known as tone deafness, is actually extremely rare within the population, occurring in approximately 4% of people, (Dalla Bella, Giguère and Peretz, 2009), however 10-15% of the population are still classified as poor pitch singers (Pfordresher and Brown, 2007). In Mandell, et al. (2007), researchers examined if congenital amusia was actually a disorder of the auditory feedback loop, in that amusics potentially lacked the ability to make real time adjustments based on auditory feedback. This made me curious if a similar disorder of auditory feedback could be a potential cause of poor pitch singing.

Summary of Research

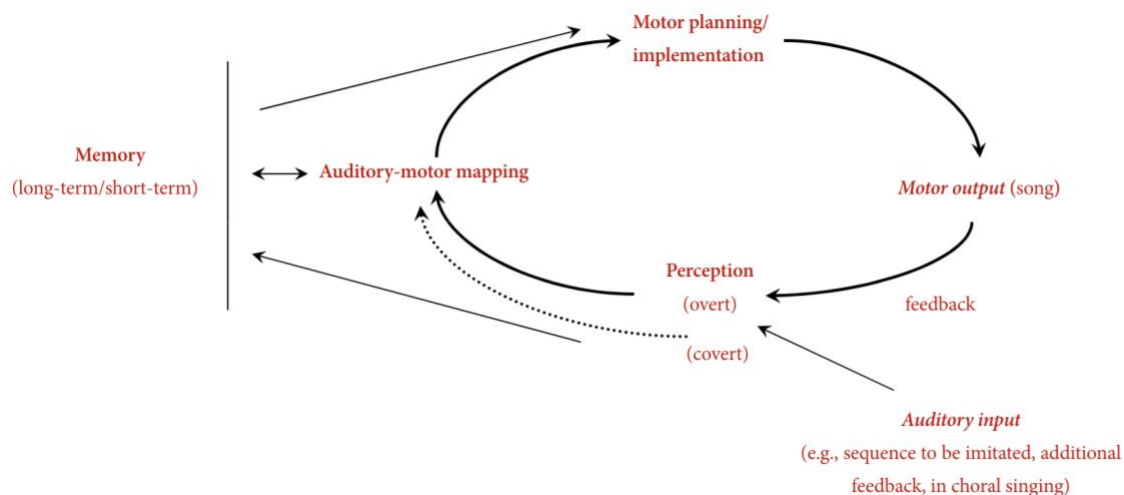
Structure of Literature Review

My literature review was focused on widening the breadth of articles for which I previously studied the causes of poor pitch matching. I wanted to examine the brain's role in hearing, perceiving, planning which ultimately results in a spoken or sung pitch. In Waxer (2023) and Waxer (2024), I briefly touched upon amusia and its prevalence and causes. While conducting this literature review, I often came across references to amusia when examining the topic of neurology in relation to the auditory feedback loop.

According to Doyle (2003) a narrative or traditional literature review must show a progressive chain of reasoning. Therefore, I decided to organize my literature by relating discovered literature to the auditory feedback loop (Berkowska & Dalla Bella, 2009) (Figure 1). The AFL breaks down the process that humans go through while hearing, processing sound, planning motor function, executing motor function and ultimately generating sound. I felt this would be a straightforward way to organize literature and present it in a way that voice professionals and lay people can understand. I had previously come across the AFL when conducting a mixed-methods study on vocal pedagogical literature and voice teacher's opinions on teaching poor pitch students (Waxer, 2024). I used the AFL as part of my presentation titled "Can we teach them to sing" which was presented at the National Teachers of Singing (NATS) Cal-West regional conference in Salt Lake City in January 2024. The AFL can be presented as a visual loop which is a good way to present the

process of hearing and creating pitch as the process is not linear (Berkowska & Dalla Bella, 2009).

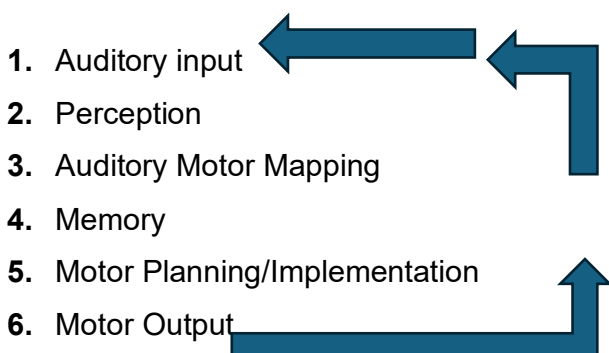
Figure 1: Auditory Feedback Loop (Berkowska & Dalla Bella, 2009).



Throughout this review I use the AFL to create a progressive chain of reasoning which hopefully breaks down a quite complex process into a format that voice professionals like me can understand. In addition to explaining how the auditory feedback loop works under normal circumstances, I will also touch upon common problems that arise throughout the AFL which contribute to hearing and vocal production problems.

Auditory Feedback Loop

The AFL can be shown as an image such as in Figure 1 but can also be enumerated in a list. It's important to note that some of the steps can occur simultaneously and are not necessarily occurring in this exact order or independently.



7. Feedback

Due to the complex process of the auditory feedback loop, it's helpful for voice teachers to understand each element and how each play a role in vocal production as well as identifying deficits that could cause problems in the voice studio. In my module 3 assignment (Waxer, 2024) I discovered that only 1-3% of pedagogy textbooks had any reference to pitch at all. The auditory feedback loop was not mentioned in any of the examined texts: Appelman (1967), Chapman (2016), Vennard (2018) Miller (1986), Doscher (1988) or Phillips (2013) However the combination of hearing, perception, motor control memory, motor output and feedback and vital in the production of human sound and the ability for humans to control their voices (Mandell, Schulze and Schlaug, 2007).

Auditory Input: Sound and Hearing

The Auditory Feedback Loop begins with auditory input which comes in the form of acoustic signals such as music and voices (Braun Janzen and Thaut 2019). To understand causes of PPS at the input level it's important to understand the process of hearing. All sound waves have an amplitude, a measure of intensity and frequency, which determines pitch. (Yost, 2008). Pitch, which is generally referenced by fundamental frequency (F0) in scientific terminology, is determined by the number of cycles per second. The cycles per second are measured in Hertz (Hz) and pitches are classified by Hz when referenced in scientific writing rather than note names (i.e. Do, Re, Mi or C, D, E). (Yost, 2008).

When sound waves reach the ears, acoustic energy is received by the outer ear and transmitted to fluids within the inner ear. Once the signals have been transmitted to the inner ear, the energy is translated into neural activity. The neural analysis of the sound gives the listener information on the sound such as amplitude and pitch as well as the tonal quality, such as if the sound comes from a human voice, a musical instrument or an emergency siren (Yost, 2008 Pg. 65).

Yost (2008) points out a few causes of deafness including overstimulation due to a lack of protective mechanisms of the inner ears. Other common causes of hearing loss are age,

diseases and infections, accidents and heredity (Yost, 2008 pg. 253). A loss of hearing would contribute to a disruption in the AFL, though medical interventions such as cochlear implants exist that can help a person regain or improve their hearing (Yost, 2008 pg. 265). Thus, impaired hearing could be a cause of PPS and something that teachers should be aware of. Also, teachers may need to adjust the volume of presented pitches for their students to be able to hear properly.

Perception

Perception is the brain's process of interpreting sound waves, such as recognizing pitch, which would be translating the input into sound which the brain identifies as pitch. The two predominant theories of the 20th century for how pitch was perceived in the brain are Place Theory and Volley Theory (Yost, 2008). Place theory was the dominant theory between the 1940s and the 1960s. Place theory stated that the place in the nervous system with the highest amount neural activity, was the location where the nervous system forms the concept of pitch. (Loui, 2016). Temporal theory or "volley theory" states that temporal properties of neural response are what allow the determination of pitch. Von Bekesy won a Nobel prize for his work on place theory and its method of frequency coding through inner ear mechanics (Yost, 2008).

Improvements in brain imaging technology have allowed for neurologists to study the human brain and its specific function in perceiving sound. (Braun Janzen and Thaut, 2019). The human auditory cortex processes fine-tuned and specific details of sound such as frequency, tone, and amplitude and completes spectro-temporal modulation (the conversion of sound into neural activity) which is how the brain translate the sound into a perception of pitch (Braun Janzen and Thaut, 2019). Several studies that included brain imaging research sound the lateral Heschl's gyrus as the specific area that pitches are processed and understood. (Braun Janzen and Thaut, 2019).

This information is useful for voice teachers in that studies have shown a variety of pitch matching accuracy depending on the type of input, showing that input type can influence pitch perception. In a Peretz *et al.* (2009) a study of amusics found electrical activity in the brain was normal when detecting pitch irregularities (right auditory complex) but electrical

brain activity was not normal when detecting melodic differences from musical keys compared to the control group. Amusics may be able to perceive pitches but do not listen in the framework of a tonal system and do not hear out of key tones as “wrong” as would be detected by a non amusic person (Peretz et al. 2009). Do PPS merely lack a tonal framework due to lack of musical education?

Studies have been conducted on whether sound source type, i.e. human voice, versus recorded voice versus piano impacted a study participants ability to recognize and match pitch. Edmonds and Howard (2023) compared the accuracy of pitch between participants matching their own voice versus external sounds. In Nápoles *et al.* (2019) participants were presented with the same pitch delivered across different sound sources: pitch pipe, piano, vocal hum and two conditions of tuning forks. Participants had the highest level of pitch accuracy when listening to a piano compared with the other sources. These differences would be explained through the perception part of the cycle. Teachers can benefit from this information by using a variety of pitch sources (i.e. piano versus live voice) to see if students show greater accuracy with one source over another. Pianos are often used in the vocal studio to accompany students and its possible that musical aptitude and the ability to match pitch improves by singing along with a piano throughout musical training and voice lessons.

Auditory Motor Mapping:

Motor mapping is how the brain tells the voice how to produce a certain sound. A deficit in auditory motor mapping would lead to a person having speech impediments or possible issues with singing. An example of auditory motor mapping's importance would be in the case of non-verbal autistic people in which the autistic person is able to understand language but unable to form a concept of how to verbalize words (Chenausky, et al., 2022).

A therapy called Auditory Motor Mapping Therapy (AMMT) was developed to help non-verbal autistic children learn how to speak. The study involved having the children sing a two syllable target word while tapping on electronic drums that were tuned to the same sung pitch (Chenausky, et. al, 2022). The children who partook in a series of therapy sessions showed vast improvements in their ability to speak the trained words (Chenausky, et al.,

2022). I wonder if therapy like AMMT could be used in the voice studio to help PPS better “map” their motor functions when matching pitch. However, ethical issues could arise if teachers label the therapy as AMMT because voice teachers are not trained medical professionals and would not be qualified to administer official therapy.

Mandell, et. al, (2007) examined brain images of amusic (tone deaf) people and observed grey matter volume variations in areas of the brain and hypothesized that it’s conceivable that amusic individuals may have an impairment in the auditory-motor feedback loop or auditory motor mapping system.

Ishihara *et al.* (2020) study illustrated the relationship between cardio-respiratory fitness and general physical fitness with working memory which would support the importance of motor mapping to proper control of the singing voice. Most motor processes take a lot of time to develop and singing is a very physical and complex process even though its often perceived as something everyone can do naturally. He *et al.*, (2016) found that initial motor variability can increase the speed of motor learning whereas sensory uncertainty slows down the speed of motor learning. Applying the concept of physical fitness and muscle memory to fitness (Ishihara et al, 2020) to singing shows that controlling the singing voice can be an extremely complex process and therefore can elicit sensory uncertainty in singing. Therefore, the motor learning process for singing may be extremely slow especially if the PPS has trouble at the hearing, perception or feedback stages. Through the process of voice lessons students can develop coordination to improve their pitch accuracy through vocal exercise that integrate visual cues (Blanco et. al., 2021), essentially “mapping” their physical coordination to their generated pitch.

Memory:

To understand tonal memory, it’s important to outline human memory in general. Human memory is comprised of several parts: short-term memory, working memory, long term memory and sensory memory (Jäncke, 2019). The difference between short-term memory and working memory is that the working memory completes a process of manipulation including problem solving, creativity and important to this study, music comprehension (Jäncke, 2019). When music is heard a serial-to-parallel conversion takes place as music

information is stored temporarily and then manipulated in real time (Jäncke, 2019). An experiment conducted by Gaab et al. (2003) showed an accurate tone recognition rate of 66 percent even among non-musicians with a positive correlation between hemodynamic responses in the supramarginal gyrus and dorsolateral cerebellum during pitch matching tests (Jäncke, 2019).

To identifying underlying causes of PPS, I think it's useful to look at studies conducted on people with absolute pitch (AP), a rare phenomenon found in only 1% of the population. Listeners with AP were found to have strongly activated frontotemporal areas during tone memory tasks. Perhaps, the opposite would be found in PPS.

Working memory also seems to be an issue for amusic people according to Lévêque *et al.* (2022) which found worse working memory for pitches among amusics compared to the control group. However, amusics and non-amusics alike did better when remembering pitches based on the tonal system versus atonal input. I would like to further study if lack of exposure to music would contribute to PPS generally due to much of western music being based on the tonal system. If a link is discovered, it could be beneficial for PPS students to be exposed to music both in and out of lessons to improve their tonal memory and pitch.

Motor Planning/Implementation

Braun et al., (2019) states that listening to auditory rhythms increases auditory motor-brain connectivity and that the coupling between cortical motor and auditory areas improves with musical training. The communication between auditory and motor regions is essential for production of timed movements. An example of this motor planning would be neural activity in motor areas when pianists watch videos with no sound of pianists playing a silent keyboard (Baumann *et al.*, 2007). Motor planning in the context of singing would be the planning the brain implements when translating the sound into from auditory regions to motor regions. A relevant example of this in the voice studio would be having a student look at sheet music and try to "sight read" silently while imagining how the sound should sound and to mimic breathing and vowel formation following the text and music without singing. This potentially helps train the motor planning so that when students then repeat the same passage practiced silently but now sung out loud. Potentially the earlier planned

coordination would improve their overall pitch on the sung passage. Students could also play piano keys along with their vocalizing to match their sung tones to played piano tones to “map” the idea of these pitches to the desired note.

Motor Output:

In Zarate and Zatorre, (2008) a study of singers and non-singers was conducted using fMRI technology while singing a simple tone and singing a pitch-shifted tone where subjects were instructed to ignore or compensate for the shifted feedback. Notably, during vocalization, the acoustic change complex (ACC) reduces activity in auditory cortices. During vocalization the ACC and superior temporal gyrus (STG) work together to integrate vocal motor control with auditory processing (Zarate and Zatorre, 2008).

Many studies done on PPS have focused on potential issues with motor output due to the fact that PPS have been shown to differ from amusics in that they are able to successfully discriminate tones but are often unable to sing pitches in tune, suggesting motor function being the most common cause of PPS (Hallam Susan et al., 2014). The literature seems to suggest that amusic people may have actual impairments in the auditory processing loop leading to their amusia whereas PPS likely have normal processing and need to develop better motor coordination. I have witnessed this in my own practice with PPS who initially cannot match pitch with accuracy, but with a lot of practice and guidance they have become much more accurate singers.

Some studies that examined the relationship between perception and motor control are: Pfordresher and Brown (2007), Berkowska and Dalla Bella (2013), Pfordresher and Halpern (2013) and Pfordresher and Mantell (2014). Hutchins et al. (2014) isolated the issue of pitch matching from motor control by implementing the use of a slider tool in which students adjusted a physical dial up and down to match presented pitches. Participants were also asked to sing the same presented pitches. Overall, the participants showed greater pitch accuracy with the slider than when singing showing that the pitches were properly perceived, but the students had trouble coordinating their voices to match the pitches accuracy. Voice teachers could run a similar experiment in the studio to see if students have an issue at the perception level or the coordination level.

Feedback:

Loui (2016) outlines the importance of auditory feedback to singing on pitch. Disrupted auditory feedback has been associated with delays in speaking such as stuttering and within music, a 250-millisecond delay in auditory feedback led to disrupted playing of musical instruments, whistling and hand clapping. Auditory feedback has been shown to be essential for accurate speaking and singing, adults with severe hearing loss often have difficulties controlling their pitch, speaking rate and vocal productions (Jones and Keough, 2008). The lack of feedback seems to play a role in the inability to sing in tune as the mapping between sounds and motor plans is disrupted.

In Jones and Keough (2008) singers and non-singers were recruited to sing a $f(0)$ feedback on /ta/ while the $f(0)$ was gradually lowered. The singers were better able to maintain the original pitch whereas the non-singers' pitches would gradually lower to match the auditory feedback. The study suggested that singers can rely on internal models rather than relying on the real time auditory feedback in the situation where the $f(0)$ is being altered (James and Keough, 2008).

Mürbe *et al.*, (2002) hypothesized that a loud accompaniment may mask the singer's auditory feedback. They studied the significance of kinesthetic and auditory feedback by having students sing patterns with and without masking noise to compare the number of impairments. Masking resulted in an average of pitch impairment by 14 cents which led to the conclusion that auditory feedback is extremely important to a singer's ability to sing on pitch (Murbe et al., 2002).

In Paney (2015) students were introduced to a video game which provided immediate feedback on their singing. In previous studies seeing spectrogram of their voice while singing resulted in greater singing accuracy than seeing only a keyboard. (Hoppe et al, 2006). Students who received teacher feedback over a period of time had improvement in their pitch matching abilities compared to the control (Murbe et al., 2002). This suggests a solution that is relevant to my practice in that teacher feedback regarding pitch to students in voice lessons would lead to eventual improvement.

Critical Analysis

In looking at the neurological processes of the auditory feedback loop (AFL), I struggled with the density of the texts and difficulty in reading and understanding neurological and anatomical jargon with which I am unfamiliar through my practice and training as a singer and voice teacher. There was a large gap between articles published in psychology journals with a psychology of music focus and articles published regarding neurological topics. Many publications included figures and drawings of the human brain which helped me visualize and understand the various areas referenced throughout the neurological texts.

I was also very surprised how psychology and neurology both have significant journals and literature published but with very different foci. Overwhelmingly the journals centered on neurology and neurobiology had higher impact ratings and I gained my greatest understanding of the auditory feedback loop through such literature.

It was also more difficult than expected to categorize studies into sections of the AFL because many studies combined various aspects of the AFL and were not completely divorced from other parts of the process. For example, James and Keough (2008) dealt both with feedback as well as motor planning/implementation, so it was difficult to decide where to place it.

One reoccurring theme was that amusia is studied often in the available literature and much of the brain imaging done on amusic people, although helpful, it's frustrating that similar imaging has not been done on the PPS population. It would be helpful to my research and practice to know whether PPS have similar neurological differences from normal and from those considered good singers or trained musicians.

In examining the Impact Ratings of a variety of journals from which my literature was drawn, I noticed a large range of impact ratings from 1.1 to 14.08 (Table 2). I was glad to see that literature from journals centering around the brain, both neurology and psychology, had impact ratings of at least 2, with a few being greater than 3. It is a bit concerning that the Journal of Voice and various Music Education journals have comparably low impact rating

scores, however the majority of the studies on voice are published there. This is a concerning trend as specific studies on the voice would be helpful to my research and practical application in my studio.

Reflections & Conclusions

The combination of shortcomings in vocal pedagogy literature and lack of teacher training contribute to the difficulty of teaching PPS in the voice studio (Waxer, 2024). Throughout this literature review I learned about the process of hearing, perceiving and coordinating and producing sound and why this can be a complex process for singers. Winter (2022) points out the dilemma faced by voice practitioner researchers who stand at the intersection of science and art and I this independent study tested those limits as I constantly analyzed my research findings and evaluated their usefulness to voice teachers. Ultimately, poor pitch singing could be caused by a variety of reasons and due to voice teachers' lack of access to brain imaging resources teachers would need to discover students' lacking's through trial and error anyway. Studies on auditory input type are useful as well as the fact that motor control in singing can be an extremely difficult and complex process for students to master. I do think it would be useful to include aspects of my findings in the standard vocal pedagogy literature taught to singers and vocal pedagogy students at the collegiate and graduate level. Vocal pedagogy courses and textbooks could include an overview of the auditory feedback loop with images to help instruct teachers on the various causes of pitch matching. However, providing dense chapters with detailed neurological jargon might create more trouble than good for the voice professional in that this information could cause confusion and be superfluous. Ultimately, does it really matter what parts of the brain are involved in the various processes of the feedback loop? Or is it more important for the teacher to understand that pitch matching issues can stem from a variety of issues shown in a simplified in the feedback loop, and merely providing teachers with a straightforward troubleshooting guide might be the best solution for success with PPS in the voice studio.

Table 2: Impact Ratings

Journal Name	2022	2021	2020	Average of available data
International Archives of Otorhinolaryngology	1.1			1.1
British journal of music education	2	1.179	0.892	1.257
Oxford Handbook Music and the Brain	1.7			1.7
Journal of research in music education	1.4			1.8
Psychology of Music	1.7	1.904	2.2	1.93
Journal of Brain Research	2	-	-	2.1
Journal of Voice	2.2	-	-	2.1 (5 year)
Journal of neurosurgery		2.21	2.104	2.157
Brain and cognition	2.682	2.3	2.5	2.494
Journal of Speech, Language and Hearing research	2.6	-	-	2.9 (5 year)
Brain Research	2.9	3.61	3.252	3.254
Frontiers in Psychology	3.8			3.8
Annals of the New York Academy of Sciences	6.499	5.691	4.728	5.6
Brain	14.5	15.255	12.501	14.083

COMPONENT 2 WORD COUNT: 4641

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