Department of Music, New Bulgarian University

Sarah Jane Lobegeiger de Rodriguez

The Operatic polyglot: Routes and Techniques in Western European Classical Singing

Dissertation

Scientific supervisor: Prof. Milena Georgieva Shushulova-Pavlova, PhD

Vocal Supervisor: Dr Natalia Afeyan

Sofia, 2023

Abstract

Classical singers encounter many linguistic and phonetic challenges when mastering their instrument, the voice. Pronunciation proficiency in numerous languages is necessary alongside the requirement to achieve native diction. An integral part of voice training for an opera singer is expanding vocal range through the development of vocal registers and manipulation of resonance features to enable altered voice acoustics while balancing accurate diction alongside linguistic and artistic accuracy. Indeed, appropriate vocal resonance is often balanced by phonetic symmetry through vowel production and modifications across the vocal range, regardless of the language. Furthermore, singers manipulate their subjectivity when performing to develop and embody a character or express a sacred, profound, or figurative text on stage. Accuracy of text, declamation, prosody, and phonetics is thus a vital feature of performance mastery.

This paper will speculate and explore possible techniques and practice regimens that can build creative cognitive processes in the singer's practice studio that enhance mastery of phonetic accuracy in the professional opera/ classical singer informed by principles of motor learning, neuroplasticity and fMRI studies. This thesis will investigate approaches to developing linguistic and acoustic proficiency in performers of Western opera, sacred music and art song to become an operatic polyglot. A vital aspect of the performance process is manipulating and adjusting voice across the range to convey musical intent. What explicit approaches can assist singers in integrating phonetic and linguistic accuracy alongside musical accuracy? This research aims to evaluate the viability and sustainability of neurologically informed approaches to voice training in artists, particularly relating to phonetics, pitch and resonance adjustments, as well as prosody and speculates on new approaches to voice, language and artistic interpretation practice techniques for Western classical singers for their daily practice seeking to enhance their phonetic mastery.

Keywords: creative cognition, opera singing, phonetic tone tuning, deliberate practice, body matrix, neuroscience of singing

Contents

Abstract....2

Introduction....8

Chapter 1 : Creative Cognition and the Singer's Body Matrix 12

Chapter 2: Defining The Operatic Polyglot.... 16

Intelligibility 17

Artistic due diligence 19

Acoustic Integrity.... 19

Motor control systems for phonetic tone tuning 23

The Physical Properties of Sung Sound....24

The properties of sung syllables 24

The anatomical properties of sung segments- Phonetic tone tuning and phonetic placement....25

Resonance Properties in Western Classical Singing....29

Pitch Value....32

1) Phoneme Onset Tuning 34

2) Phoneme sostenuto tuning....34

3) Phoneme offset tuning....35

The Metric or Rhythm Value of Phonemes Set to Music....35

Phonetic Tuning Aberrations....37

Phoneme onset timing and phonetic tone tuning errors....37

Sustained duration and phonetic tone tuning errors 38

Phoneme offset timing.....39

Prosodic Stress.....40

Prosodic Stress Aberrations.....41

Sound Pressure Levels (SPL) and Phonetic Tone Tuning.....42

Chapter 3: Motor Learning, Neuroplasticity and the Operatic Polyglot.....44

The 3 AAAs and their role in Motor Processing.....44

Anticipation.....45

Attention.....45

Adaption.....46

The 4 Phases of Motor Learning.....47

The Fast Phase.....47

Consolidation phase.....53

Automatic phase.....53

Retention state.....54

The Phonetic Lexicon and the Motor Engram Hypothesis.....55

The Ten Principles of Neuroplasticity and the Daily Regime of the Western Classical Singer.....58

1. Principle One: Use it or Lose it.....58

2. Use it and improve it.....59

3. Specificity.....60

4. Repetition matters.....61

5. Intensity matters.....62

6. Time matters.....62

7. Salience matters.....63

8. Age matters.....65

9. Transference.....67

10. Interference 67

Chapter 4: Deliberate Practice and Practice Studio Resources to boost Creative Cognition in the Operatic Polyglot 68

The role of Deliberate practice in developing creative cognition for the operatic polyglot 68

Body Matrix Theory, Flow and Multimodal processing benefits for eminent performance 69

Auditory feedback and phonetic tone tuning 71

Intensity and Process 73

Autoethnomethodology and Practice Related Research 73

Using a research log to scale as an operatic polyglot 75

Enhancing Visual Processing in the Practice Studio 75

Paced timing drills for speed enhancement versus sequential drills to strengthen coarticulation of phonetic targets 78

Soundwave analysis and computer assisted pronunciation devices 79

Pitch tracking measures 82

Phonetic transcription 84

Cross-sectional inventories 86

Phonetic placement manipulation 87

Verbal phonetic placement instruction in singing lessons 88

Tapping tasks 89

Motor Imagery Tasks and Silent Practice 90

Kinaesthetic Motor Imagery 97

Conclusion and Further Considerations 101

References 106

List of Figures

Figure 1: The Interaction between the Self, the Body Matrix and the Different Body Representations 13

Figure 2: Proposed Singer's Body Matrix 14

Figure 3: The Key Elements and Interactions of Phonetic Tone Tuning 21

Figure 4: The Multi-prismic Properties of the Singer's Syllable 25

Figure 5: Segmental Properties of the Singer's Syllable and Phonetic Pitching 33

Figure 6: Syllable Components and Phonetic Tone Tuning 36

Figure 7: Markers of Temporal / Metric Precision at The Syllable Level........36

Figure 8: Motor Learning Phases 55

Figure 9: Proposed Motor Engram for Phonetic Tone Tuning........56

Figure 10: Performance Skill against Chronological Age 66

Figure 11: Audacity Sample of English versus an Italian Pronunciation Attempt attempt in a passage from Caro Nome from Guiseppe Verdi's opera Rigoletto 80

Figure 12: Audacity Sample of English Versus an Italian Pronunciation Attempt in a Passage from Caro Nome from Guiseppe Verdi's Opera Rigoletto........ 81

Figure 13: Pitch Tuning Error during Phonetic Tuning as Observed with a Pitch tracker. 83

Figure 14: Pitch Tuning Correction During Phonetic Tuning as Observed with a Pitch Tracker 84

Figure 15: A Cross-Sectional Phonetic Inventory for Italian and Australian English 86

Figure 16: Phonetic tuning According to Place, Manner and the Voicing of Alveolar sounds in two West Germanic Languages (English, German)........ 88

Figure 17: A Creative Cognitive Model for Motor Imagery Practice........95

Figure 18: Kinaesthetic Motor Imagery Map of the Final Two Syllables of Caro Nome from Rigoletto, Guiseppe Verdi........99

Introduction

The capacity to communicate through vocalisation is a fine motor skill unique to primates[1] that is predicated on a range of intelligences, including volitional control of voice behaviours, the ability to imitate and learn heard sounds with one's own voice, the capacity to react and respond to others in a meaningful way using recognisable vocal symbols, the storage and adaption of unique vocal codes among cultural groups and ability to take the spoken word and express it through musical song as a signifier or cultural, ritualistic, spiritual meaning imbued with one's own voice features and characteristics. Many questions remain unanswered in neuroscience around the aetiology of the vocal brain in humans. However, most researchers tend to agree on several intelligences that inform the human capacity to use the voice as an expressive and artistic tool to communicate. Belyk & Brown (2017) proposes a single vocal system model which unites the systems of speech, emotional vocalisation and song into a central processing network which they term the vocal system, which functions through intricate interactions between the brain's sensorimotor system which enables humans to elicit vocal output in the form of language, emotional utterances and music (p. 183).

It is incredibly complex to define precisely what allows the singer to render their artform expertly since singing is both a cognitive, motoric and affective process and thus contingent on multiple intelligences involving a "complex hierarchical network of cortical and brainstem centres, which integrate feedback from both auditory and somatosensory pathways" (Kleber et al., 2013, p.6070). Furthermore, since "vocal production in speech and singing requires the involvement of more than 100 muscles" (Kleber et al., 2010, p. 1144), numerous functional demands impact a singer's development. The process of overt singing involves the singer's capacity to integrate creative cognition in the practice studio and performance settings with finesse. Artistry for classical opera singers is thus contingent on

[1] The ability to learn vocal behaviours is an uncustomary phenomenon in animals. For example, some apes can produce sounds (like lip smacking or whistling) in response to interactions with humans; however, these sounds tend to be produced without vocal vibration and only through the manipulation of supraglottal articulators (Belyk et al., 2017, p.186).

the successful mastery of multiple intelligences. "Creativity is not comprised of one cognitive process, but of many cognitive processes, including (but not limited to) defocused attention, mental flexibility, cognitive control, and other cognitive constructs" (Jung et al., 2013, p.10).

A classical singer's artistic development is predicated by their capacity to build *creative cognition*. The term creative cognition will be used throughout this thesis to refer to singer sentience and the physiological mastery of their instrument. Mastering expert level classical singing techniques relies on the singer's ability to synchronise complex motor patterns (Ladda et al., 2020) alongside the creative psyche to develop a cognitive, visceral and sensory experience for their audience (p. 6070). Thus, creative cognition encompasses both the singer's attempts to acquire precision-tuned processes in the body (their instrument) contingent on cortical and physiological manoeuvres through the vocal tract supported by the body centre, but does not stop at sheer mechanics, also allowing for the inclusion of that which science cannot wholly define, the expression of the sublime.

Significant research exists which reveals that music-making alters the motor, sensory and multimodal representations of the brain in musicians, and there is considerable support for musicians presenting with higher interoceptive awareness than non-musicians. Since "singers use a more body-centred and visceral nature of music production, involving organs and muscles of vital importance" (Schirmer-Mokwa et al., 2015 p.2)[2], it's hardly surprising that they can control their instruments more accurately than non-singers when auditory feedback is removed (Mürbe et al., 2004, cited in Zarate, 2013, p.34) and interestingly, expert-level classical singers may, in fact, rely more on the somatosensory feedback system than the auditory system[3]. This suggests that trained singers achieve accuracy when singing more through a somatosensory feedback system. fMRI studies provide further support for this notion suggesting the need for a finely tuned somatosensory-vocal feedback loop in the development of singing skills (Kleber et al., 2013, p. 6070). However, once this sensory

[2] Indeed, creative cognition for singers is a form of embodied cognition.
[3] Lametti et al., 2012 found that in speech acts, speakers appear to rely equally, if not more, on somatosensory feedback over auditory feedback (p. 81), refuting the widespread view that audition takes precedence in in maintaining speech accuracy.

feedback loop is fully integrated (potentially at the point where the motor firing becomes automatic[4], the singer no longer requires sensory feedback to correct an error. Kleber et al., 2013 revealed that trained singers were adept at singing targets accurately despite applying anaesthetic on the vocal fold mucosa and reduced access to somatosensation in the larynx. Possibly the singers were able to engage in a feedforward model that allowed for correct production in the absence of sensory feedback. The findings of this research allude to the concept of body memory[5], possibly best captured through Guiseppe Riva's hypothetical body matrix theory, which is built upon the premise that the experience of the body by an individual is multimodal, subject to both perceptual, interoceptive, proprioceptive, vestibular motion-based and memory-based input (Riva, 2018, p.242) integrated under a proposed term body matrix.

Riva's model outlines six representations of the body with the body matrix as the integrative processor of all six representations. As the singer develops, so does their sense of self, which receives representation. Riva proposes that in this process, the body forms memories in the form of body maps that allow the individual to "enact and understand a more advanced level of intentionality" (Riva, 2018, p. 248). Neurological research suggests that intentional actions are embedded in the body memory through motor schema, which "describe the organisation and structure of the action" (Riva, 2018, p.245) and are activated in the execution of movement and imagery-based tasks[6]. Singers likely have a body memory that stores the motor schema of the complex motor processes required for their repertoire, Kleber et al., 2007 examined overt and imagined singing and identified significant activity in the inferior parietal cortex bilaterally and speculated that such neural firing could suggest "a

[4] See the next chapter on motor engrams and dormancy.
[5] French philosopher, Merleau-Ponty, referred to this concept of body memory when stating that "our body comprises two distinct layers, that of the habit-body [body memory] and that of the body at this moment [body representations]" (Merleau-Ponty, as cited in Riva, 2018, p. 95).
[6] Kleber et al. 2007 found evidence of neural firing of motor movement circuits in imagined singing that was very similar to the neural firing in overt singing (p. 27), similarly "when an individual listens to verbal stimuli, there is an activation of the speech-related motor centres" (Rizzolatti & Craighero, 2004 p. 186).

store for phonetic and intonational acoustic information contributing to the working memory system” (Kleber et al., 2007, p. 898).

The concept of the body matrix reconciles the multiple intelligences needed for expert musical performance, subsuming, and uniting the gestalt of creative cognition for the singer. This concept reinforces Merleau-Ponty's argument for body awareness informed by sensorimotor networks (as cited in Dreyfus, 2002, p.37). The singer's body memory system provides "knowledge of how to act with or towards a part of one's body” (Riva, 2018, p. 243) such that the body memory constitutes "a manifold of action possibilities allowing the practical attunement of the body to its environment” (Bermudez, Marcel & Eilan, 1995, as cited in Riva, 2018 p. 243). The Body Matrix theory proposes that this process is integrated through 6 representations (the sentient body, spatial body, active body, personal body, objectified body, and social body). Under the body matrix theory framework, body movement, music, and emotional expressiveness are intimately connected. These links may be related to the tone, tempo, and rhythm of the music, the personality of the role they are expressing or the connectedness with the wider environment. Kleber et al. 2013 found that more singers practice, the more activity noticed in the somatosensory association cortex and Guiseppe Riva's model for a body matrix is a helpful system to use to delineate the interactions of the singer's self, body matrix and different body representations vital to phonetic tone tuning[7] and indeed, masterful singing performance at large discovered from the research body so far. Ladda et al. (2020) also favour the body matrix theory as an “accessible approach to understanding the neural adaptability for optimising performance”[8] (Ladda et al., 2020, p.5).

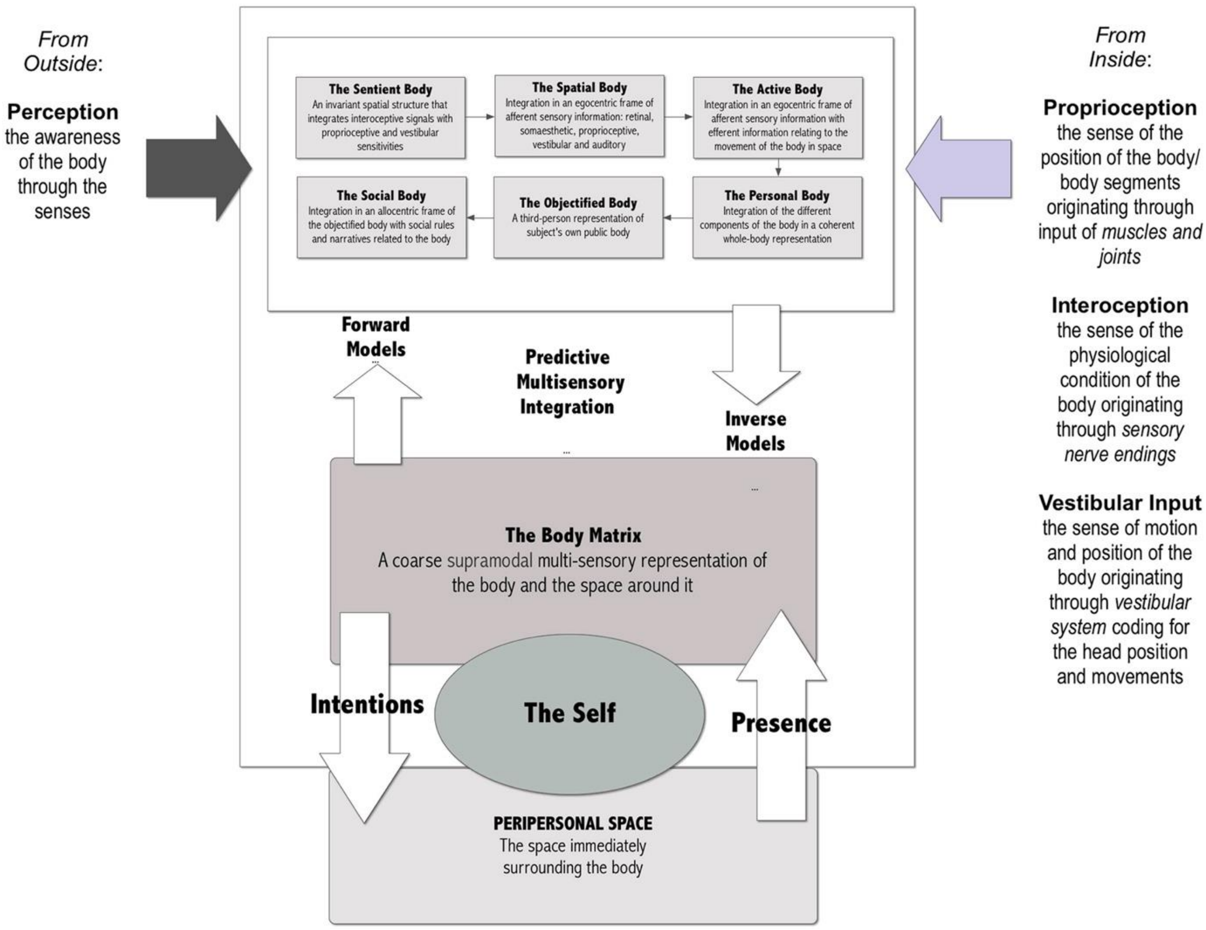
[7] More will be discussed on the definition and parameters of defining the term phonetic tone tuning in the next chapter.

[8] The body matrix theory is well aligned to creative cognitive processes. It proposes the integrative relationship between cognitive process and sensory and affective processes to reduce surprise, where surprise refers to an action-outcome disparate from the planned intention. The body matrix is thus a system that allows for error prediction and correction. It works as dynamic model that is adjusted to “accommodate unexpected sensory signals (perceptual inference and learning), and actions to confirm the predictions made… according to the intentions of the self (active inference)” (Riva, 2018, p. 249).

Creative Cognition and the Singer's Body Matrix

What follows is a proposed model adapted to singer cognitions and processing necessary for success in the integration of the multiple intelligences needed for creative cognition. Given that the singer's instrument is both a set of internal physiological processes and perceptions as much as external sensory integrations, this model can be assistive in mapping the hypothetical body memory processes that constitute elite singing, taking into account the multi-modal nature of the singing process. This model is by no means prescriptive but can be used to consider the variables at play when a singer attempts to tune their mechanism and develop the elite cognitions required for skilful singing, with particular focus on the purposes of this paper the development of phonetic tone tuning precision. Riva (2018) proposes the body matrix as a helpful theory because it can assist to account for and delineate the multiple channels of information and intricate networks that connect the entire brain (p.249).

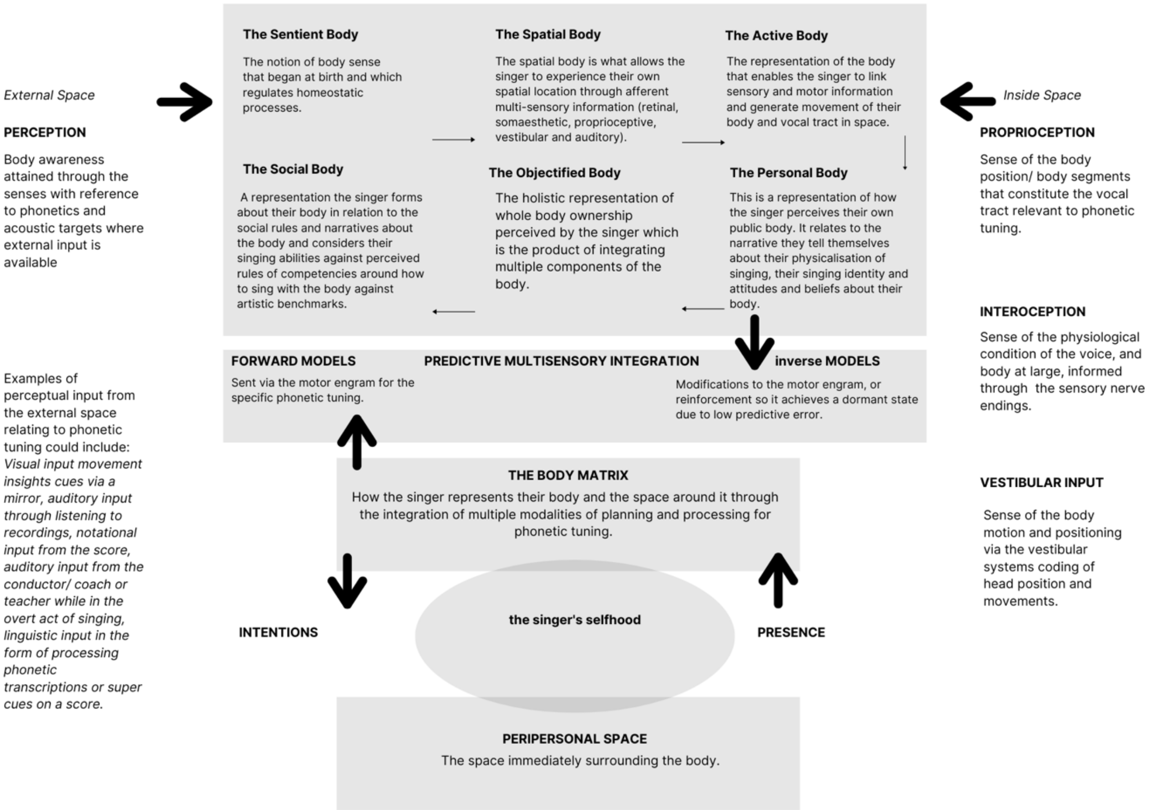
Figure 1: *The Interaction between the Self, the Body Matrix and the Different Body Representations*



Note. From Riva, G. (2018). The neuroscience of body memory: From the self through the space to the others. *Cortex*, *104*, 241-260. https://doi.org/https://doi.org/10.1016/j.cortex.2017.07.013 CC BY 4.0

Figure 2:

Proposed Singer's Body Matrix



Note. This figure is a proposed model for The Singer's Body Matrix that draws upon parameters of The Body Matrix model developed by Riva (2018). Adapted from Riva, G. (2018). The neuroscience of body memory: From the self through the space to the others. *Cortex*, *104*, 241-260. https://doi.org/https://doi.org/10.1016/j.cortex.2017.07.013 CC BY 4.0

Blanke et al. (2015) provide an overview of various studies that have used computational models proposing that when varied body inputs are combined, error risk reduces, and the presence of multi-sensory processing allows for increased perceptual precision (p. 158). Given this, the body matrix could be a viable conceptual framework through which we can consider how the singer's creative cognition is actualised concerning high-level skills like phonetic tone tuning and holistic artistic development because it integrates multi-modal domains. Further, we could propose that the body matrix is the reasoning and processing system that determines a sense of flow in performance and practice for the artist. Therefore, this model can provide hypotheses for how singers achieve the sense of optimal performance (the product of achieving their intended actions musically and artistically through the correct prediction of an outcome before its execution resulting in “a full sense of control and experiential immersion” (Riva, 2018, p. 249).

It has been suggested that "heightened attention to the body can be achieved by integrating self-relevant external (e.g. visual and /or acoustic) cues (Ainley, et al., 2013; Suzuki et al., 2013 as cited in Schirmer-Mokwa, 2015, p. 2) and indeed in light of the body matrix concepts and research around the presence of motor schema that fire with reference to both overt and imagined actions, it could be beneficial for the singer to consider sourcing super cues in their practice routine. A super cue "may have the potential to retrieve and modulate motor engrams and their corresponding feedback anticipations[9]” (Ladda et al., 2020, p. 10)”. A discussion of possible approaches for the singer's practice studio will follow to provide an overview of learning acquisition and phonetic tone tuning skills[10]. Importantly, these resources consider motor learning theories (now to be discussed), concepts of body memory and the body matrix, and the principles of neuroplasticity. The techniques can be used in the singer's studio to add to their deliberate practice techniques.

[9] Ladda et al. 2020, refer to the fulfilment of movement intent in overt dancing. The dancer modulates visual, proprioceptive information alongside the auditory rhythm and beat information to execute a version of their intended movement. In their research, they propose a model for imagery-based practice. Imagery based practice allows for creative performance rehearsal that can be "done in a more controlled environment" (Ladda et al., 2020, p. 10) allowing the performer to incorporate the benefits of multi-modal processing to scale their ability. This approach causes the artist to retrieve motor engrams with less processing effort due to the activation of multi-modal sensory associations that arise from imagined practice. Using this approach, dancers might reduce prediction error and heighten their ability to "switch attentional focus to individual feedback modalities" (Ladda et al., 2020, p. 11) where needed to fine-tune the actual performance. Ladda et al. propose that this model for imagined practice is possible through the notion of a body matrix. The following chapters will discuss this approach to strengthening motor engrams about phonetic tone tuning for the singer.

[10] While focused on developing the phonetic tone tuning required for the operatic polyglot, these resources could be utilised to build other cognitions and skills required for musicians; however, for this paper, the focus will rest on phonetic skills training.

Chapter 2 : Defining the Operatic Polyglot

A vital aspect of classical singing is the ability to create accurate acoustic information determined by both the musical score, the historical traditions of the canon of the art form, and the linguistic requirements expected of the singer while simulating the language they are singing in. With this is the expectation that the singer achieves native-like proficiency phonetically and thus become an operatic polyglot. However, unlike speech, the act of classical singing is dependent upon musical acoustics.

So, what is the musical acoustic that deems a sound phonetically accurate? It is not just obtaining the manoeuvres of the vocal tract and articulators to coordinate the phonetically distinct sound for the target language but also the ability of the singer to tune the filtered properties of the sound to encode it with both pitch accuracy, timbre and importantly, the singer's formant, which will set apart their sound as an elite singer. The singer that acquires proficiency with the musical and linguistic requirements at an elite level will be referred to in this paper as an operatic polyglot. The term polyglot is typically used to refer to a person who has command of many languages. Derived from the Greek term *poluglottos* (many tongued), the term fits the Western Classical concert and opera singer who must refine their artistry cross-linguistically through the acoustic command of multiple European languages coupled with the acoustic command language of music in a social communication feat of fine motor virtuosity. I propose the use of the term operatic polyglot as a means of defining a singer that has built their creative cognition to include the mastery of the linguistic and musical requirements of opera and western classical music with the end of expressive and interactive communication. This is a skill contingent on numerous cognitive domains and competencies of which phonetic accuracy is one small part. The operatic polyglot integrates numerous domains intricately into one gestalt-based system of embodied cognition that relies on multiple languages beyond their singing language. The singer computes and expresses through high-level proficiency in the language of music notation systems, multiple alphabet systems (Latin script, Cyrillic, the International Phonetic Alphabet), understanding of Western classical harmonic language, extramusical terminologies, engaging in the processing of semantics through varying lexicons (French, Spanish, Russian, English, Czech, German, Italian and more), diverse phonologies and phonetic inventories, varying suprasegmental and prosodies, pedagogical conceptualisations as well as an understanding of the language of gesture, non-verbal communication and empathy (the soft skills of singing). In short, singing artistry is by its very nature a multi-linguistic process achieved through communicative competence that goes beyond understanding a second language.

This paper will limit the focus of the operatic polyglot to the concept of phonetic mastery at the segmental level, and future research will explore the other domains of the operatic polyglot, particularly the semantic and suprasegmental domains of singing as well as the soft skills of singing that constitute singing cognition[11].

Intelligibility

The act of Western classical singing involves the integration of melody, rhythm and text and serves as a communicative gesture for the listener (which could constitute both the audience and those engaged in the act of singing or supporting the performance of a work, like a pianist, orchestra or other singers in the ensemble). Given the communicative nature of singing and artistic expression, it begs to question, is the intelligibility of the sung text paramount? One might presume that the clarity of sung text depends solely on the singer's

[11] Given that singing mastery also has the requisite of acquiring a niche level of communication competence in working in an ensemble relationship with other artists (pedagogues, conductors, repetiteurs, other singers in the ensemble, and instrumentalists- chamber or orchestral, stage directors and intendants) research into the communicative competency needed for the art form is a suggested future topic. It would be revealing to consider whether there are behaviours innate in singers that lead to these communication requisites or does singing fire the neural networks to enhance the affective and cortical states necessary for successful interpersonal relationships needed for professional advancement. Studies show that singers are inclined to demonstrate more firing of the anterior insula, a limbic region of the brain responsible for emotional regulation, empathy and emotional intelligence (see Kleber et al., 2007 ; Kleber et al., 2010; Price et al., 2018 and Zamorano et al., 2020). Further, the study by Schirmer-Mokwa et al. (2015) reveals a statistically significant correlation between professional singers and the trait of extraversion with lower tendencies for musical performance anxiety and negative outlook among singers comparative to string players (p. 10). “The negative correlation between extraversion and trait anxiety in singers possibly reflects their ability to communicate and act on stage, which may favour the personality trait of extraversion” (Schirmer-Mokwa et al., 2015, p.10). More on singer personality traits can be found in Cameron et al., 2014 and Corrigall et al., 2013.

capacity to create an acoustic signal that denotes meaning; however, intelligibility is based on several parameters both within and outside the singer's control. The following multivariate factors determine the intelligibility of a sung text,

The environment (is background noise interfering with the listener's ability to receive the sung words? Is the space acoustic to support sufficient projection of the voice? Is amplification needed to assist the listener's reception of the sound? Is the balance of the orchestra, pianist or other musicians in the ensemble fitting to balance the reception of the sung text?);

*The singer (*does the singer have the necessary technical capacity to create a sound wave that resonates sufficiently to be received by the listener, is the singer able to create clear diction[12] across their range informed by phonetic precision/ tuning so that the listener can decode the sung words and deduce meaning if they are familiar with the language);

The listener (is the listener familiar with the language and able to decode the sound segments they hear to form word elements and thus make semantic connections to understand the text, does the listener have the vocabulary or lexicon in the sung language as well as the cultural and idiomatic knowledge to decode what is sung and make meaning from it and is the listener attending to that which is sung as salient information to decode while listening?).[13]

According to research conducted by Fine et al. (2014), professional musicians are more likely to rate the intelligibility of both familiar and unfamiliar sung text as paramount than non-musicians. If the language was familiar to the listener, intelligibility was more likely to be rated as a higher need.

[12] Later in this chapter, more will be discussed about the notion of "diction" for singers versus my preferred term, phonetic tone tuning.

[13] Not all listeners will be familiar with the sung text and able to deduce meaning. In recent years, opera houses have used subtitles to make the meaning more accessible to their audiences. Likewise, many art song concert programs may include the sung text translations alongside the original text for audience members.

Artistic due diligence

There is an argument for the importance of sung text intelligibility within the canon of Western classical music since the history of this artistic tradition is rich with compositional structures and stylistic gestures that emphasise the importance of the text. One could consider that a composer intentionally[14] selected a vocal composition for their work over a solely instrumental or orchestral composition due to the urge to set text to music rather than create a musical representation of the ideas conveyed in the text through a set of instrumental sounds in absence of words[15] (songs without words).

In performing a vocal work, a singer should apply due diligence to serve the text as much as the rhythmic and melodic notation.

Acoustic Integrity

In as much as a musical work represents the composer and artist's cognition, there is also a concrete mathematical representation underlying all music informed by acoustics. Sound is informed by principles of physics, and as such, a musical performance can also be defined by acoustic as much as visceral, cognitive and experiential parameters. Acoustic integrity is deeply considered in both the composition and performance process. The composer seeks (or sought) to render and bind in time an acoustic representation through a set of symbols that make up the language of notation in order that the performer at a later point in time can articulate and bring to life the sound properties and experience of the

[14] Interestingly, the prolific writer Felix Mendelssohn referred to the overt decision to create a work without words - *Lieder Ohne Worte*. However, despite anecdotes about how there was "scarcely a single month in which he was not occupied with song composition" (Youens, 2004, p. 189), Mendelssohn refuted Marc-Andre Souchay's attempt to sets words to his composition. Mendelssohn asserted "what the music I love expresses to me, is not thought too *indefinite* to put into words, but on the contrary, too *definite*" (Mendelssohn-Bartholdy, 2015, p. 299).

[15] Many compositions exist that abandon the sung text and instead seek to represent concepts solely through melody and rhythmic notation, omitting sung text in the form of word segments or syllables as an additional instrument in work. Furthermore, one could consider that all works are composed concerning concepts and cognitions that could be put to text; however, composers intentionally choose whether to include text or omit text as a **vital feature** (a work that includes sung text), an **implied feature** (such as or programmatic content (such as a work that strives to tell an extra-musical narrative such as Beethoven's *Pastoral Symphony Symphony No. 6*) or **absent feature** (Mendelssohn's *Lieder ohne Worte*).

work.[16] This is an eternal feedback loop involving a “non-linear process between the artist and his/her work” (Chrysakis, 2010, p.2) as much as the performer, composer and lyricist, poet or librettist.

Fulfilment the phonetic segment[17] is the feature that separates singers as unique from instrumentalists and indeed conductors (who are also involved in the sound wave creation process although not overtly contributing to the physical creation of sound by the playing of an instrument.[18] In considering the physical components and spatial acoustics, it is thus vital to note that vocal compositions and their notation refer to a tri-partite language system.

This ability, however, is not easily acquired and is only achieved when the non-native singer can, at best, strive to keep the phonetic segments that they are calibrated to in their first language "completely concealed or eliminated” (Alexander, 1974, p. 162) when singing works that are in a second language while fulfilling the harmonic, rhythmic and stylistic requirements of the score. I will refer to the process of representing the phonetic segments accurately as *phonetic tone tuning* rather than diction or pronunciation for singers. When we sing, sounds are produced within a "more precise framework of rhythms and pitches, which compared to speech places higher demands on vocal motor control” (Kleber et al., 2013, p. 6070). The term phonetic tone tuning has been used in this paper to differentiate from

---

[16] The composer Thanos Chrysakis (2010) explores the concept of sonic matter and sonic dramaturgy in his thesis “The Structural and Aesthetic Capacity of Sonic Matter” arguing that sound-material follows an intrinsic logic.

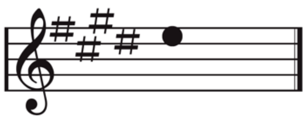
[17] This chapter will consider the phonetic segment more than the whole word unit level since failures to be precise at the segment level will account for word-level inaccuracies. Of course, this does not withstand the importance of the word and sentence to the musical phrase, line and artistic expression, but this is a topic for another discussion, possibly in the future.

[18] It would be noteworthy to consider the degree to which conductors rate the importance of the phonetic segment against the metric and harmonic segment since, typically, the latter two are under their jurisdiction. Indeed, one could argue that conductors that omit overt consideration of the accuracy of the phonetic segment might betray the score. Many conductors, however, in maintaining the precision of the rhythmic segments while conducting the singer, may indirectly provide metric feedback that assists in correcting the phonetic segment. The question remains as to whether conductors should go further to learn the phonetics of the text to deliver more specific acoustic cues to the singer in somewhat the same manner that they might request string players to produce a physical gesture correction in the rehearsal space relating to bowing, muting or other. Should the conductor have some jurisdiction in ensuring that phonetic singing is achieved? Alfred Alexander, in his book *Operanatomy: An Eclectic Introduction to the Art of the Conductor, instrumentalist, composer, producer and to score reading (1979)*, refers to this requirement of phonetic singing as “an attempt to achieve the almost impossible: the forming of overtones which can only be sounded under exceptional circumstances” (Alexander, 1974 , p.162).

diction, pronunciation or speech accuracy training. It includes the creation of the attempt of the singer to produce an accurate phonetic target embedded within the distinct overtones and resonance properties required of Western classical singing, acoustic properties that are not always present in speech signals, as well as within the rhythmic and harmonic parameters of music as outlined in Figure 3. The term designates phonetic tone tuning as a uniquely sung skill, unlike diction-related terms, which tend to disregard musical form's necessary sung sound wave properties.

Figure 3:

The Key Elements and Interactions of Phonetic Tone Tuning

		Informed by	Measured by
duration (rhythmic precision)	$\frac{3}{4}$ 𝅗𝅥. *Tempo Valse Lento*	Notation • Note value • Time signature • Other time indications ie., *Tempo Valse Lento*	♩ = 104
PITCH (intonation Tuning)		Notation • Key signature • Note on the stave	Orchestral tuning Hertz (Hz) 659.26Hz
syllable (phonetic tone tuning)	"Qua-" (Alphabet annotation of the syllable)	/kwa/ International Phonetic Alphabet transcriptions, Diacritics for the target language.	Sound pressure level of each phoneme, formant properties of the vowels, +/- Hertz for voiced phonemes

Not trained as overtly or integrated into daily drills as much as for rhytmic precision and intonation tuning.

A symbiotic relationship exists between the spatial and temporal elements that constitute music. Ladda et al. conjecture that the "exact the exact timing of movement in (instrumental space) is essential" (Ladda et al., 2020 , p.2) as much as for musical performance as for dance.

If we were to analyse this at an acoustic and physiological level, we could then state that the timing of:

- muscle movements for placement of the vocal tract and mouth cavity articulations to achieve the phonetic attributes required by the lyrics/ libretto, and,

- muscle movements for tuning of the airflow pressure and postural movements that facilitate correct valving of the vocal tract to achieve the pitch, tone and volume required for sound,

are equally important and dependent upon motor pathways firing successfully. Since the inability to regulate the vibrations per second (Hz) for correct pitch and intonation is deemed *out of tune*, and the inability to create the pulse, speed and metre indicated in the score is deemed *out of time*, it begs to question, is phonetic inaccuracy (also determined by vibrations and pressure levels per second) also out of tune and time since it denotes the intersection of aberrations in the cavity that are determined by temporal and spatial precision rather like pitch tuning and rhythmic? So, where there exists expectation that the pitch and rhythmic segment is accurate for a violinist or horn player, so too should the expectation for the singer to uphold the syllable through accuracy in the phonetic segments, since that too is in the score and part of the composer's intent.[19]

The operatic polyglot seeks to unite the physical components of the three languages (where I will refer to the symbols used to denote rhythm as the *metric segment*; the symbols that denote pitch as the *harmonic segment* and the symbols that compose the syllable unique to vocal scores as the *phonetic segment*)[20] in a score marked by notation as much as to serve the perceptual and affective dimensions.

Should classical singers thus be made overtly alert to the *phonetic tone tuning* required in representing the text phonologically as much as the vocalisation of accurate harmony and representation of precise meter? The motor concepts for *phonetic tone tuning* are not dissimilar to pitch tuning and rhythmic accuracy. Segmental accuracy is also a matter of metre and rhythmic accuracy.

---

[19] Did opera and song composers see correct pronunciation as necessary? Quite possibly. Alfred Alexander recounts a certain comical story about Bedřich Smétana, who was so apparently flummoxed with Anglo-Saxons mispronouncing his name that he set it to notation, arranging the text to Beethoven's Eighth Symphony as a mnemonic so that non-native speakers of Czech could correct the prosodic stress of his last name (Alexander, 1974, p. 165).

[20] The phonetic segment is a term I will use in this paper to denote the mechanical adjustments in the oral cavity and vocal tract required to achieve the desired sound of the language at the individual sound level.

Motor control systems for phonetic tone tuning

When a singer sings, they rely on 3 core motor control functions:[21] timing, sequencing and spatial organisation of movement. These controls relate globally to the production of musical phonations but can also be considered at the micro-level as necessary components in phonetic tone tuning.

While there is no conclusive evidence on what accounts for the human ability to time movement with precision, studies do propose the presence of a "neural clock or counter mechanism in which time is represented through pulses or oscillations" (Zartorre et al., 2007, p. 547). Zatorre et al. (2007) also make some suggestions that this process relates to movement kinematics (p. 547). It's thought that both cortical and subcortical regions of the brain coordinate movement timing, with some researchers connecting specific regions with specific skills. For example, the basal ganglia may drive interval timing across longer durations, and the cerebellum may control motor timing at shorter timescales. Researchers also hypothesise that in the processing of movement timing, there is both a timing component and an error correction loop, which ameliorates online correction based on feedback to enhance movement timing. Given the motor components of movement timing, it is fruitful to consider that musicians develop enhanced processing in this skill with the continued use of the timing network. The skill of movement timing is likely to be integrated deeply through the integration of motor and sensory processing. This process results in operatic polyglot's ability to synchronising complex motor patterns.

The pronunciation sounds of a language's phonemes are determined by mechanical movement trajectories and sound wave manipulation that are determined by the spatial organisation of the instrument- the voice.

> Singing experience enhances the integration of somatosensory information within the speech motor system, perhaps by strengthening salient bodily signals with

[21] More will be discussed on suggested parameters for motor learning in the next chapter with reference phonetic tone tuning skills.

> conscious and non-conscious aspects of expressive language production within a musical framework. (Zamorano et al. 2020, p.1)

The singer thus counts on their capacity to tune the vocal tract into precise postures and simultaneously create other vocal form requirements (voice quality, the singer's formant, correct pitch, rhythmic and metric accuracy) in an act of super sequencing.

The Physical Properties of Sung Sound

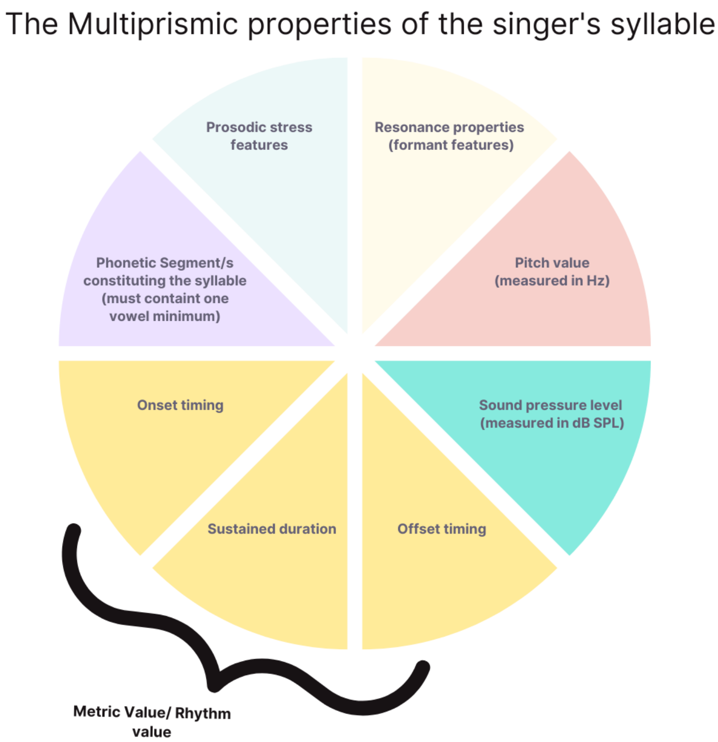
Music is a form of sound matter that can be defined by "its physical components, the spatial acoustics in which it is heard, and its perceptual and affective dimensions" (Chrysakis, 2010, p.2.). The following will discuss the measurable physical components of sung sound that is phonetically in tune. These three core motor functions are reference points in defining the parameters of sung sound and delineate the concrete properties of sung syllables. All musical sounds have temporal, sequential and spatial form, and the smallest unit of measurement for the singer in terms of phonetic tone tuning rests at the syllable level.

The properties of sung syllables

Sung syllable segments can be composed of multiple variations, which can be best represented by my proposed model of the multi-prismic properties of the singer's syllable (see Figure 3), which is informed by phonetic tone tuning.

Figure 4:

The Multi-prismic Properties of the Singer's Syllable



The anatomical properties of sung segments- Phonetic tone tuning and phonetic placement

Phoneticians usually use the term *phonetic placement* to reference the manoeuvres of the speech mechanism to articulate pronunciation sounds which has perpetuated the notion that speech pronunciation is compartmentalised under the domain of diction and reliant on overt and usually visible manoeuvres of the lips, tongue and jaw. Brown et al. 2009, refutes this long-held assumption that the spoken word is primarily an articulatory process, providing evidence of intense activation in the laryngeal motor cortex instead during speech which involves a "unique cortical-level type respiratory/phonatory coupling specific to human vocalisation" (Brown et al., 2009, p. 31). Their study showed that connected speech increases neural firing in the laryngeal motor cortex over the mouth and face area of the motor cortex. Further, activities in the laryngeal motor area related to pronunciation processes like tongue movement (at the rolandic operculum) and lip movement (seen to occur at a region lateral to the larynx area) had increased activation, thus providing a preliminary hypothesis that speech is predominantly phonatory. If this is the case, our whole notion of diction for speech and singing needs to adjust and is best supported by a new term, phonetic tone tuning. This entails that each phoneme is embedded within the phonation gesture (voiced or 'voiceless') and is built on phonation with manoeuvres and sequencing in the supra glottal structures as much as in the subglottal structures.

Interestingly this concept of phonetic tone tuning and how it emphasises the laryngeal and phonatory nature of pronunciation for speech as much as singing provides some hypotheses for why there is a higher incidence of voice disorders and vocal dysfunction among speakers while speaking a non-dominant language[22] (Järvinen, 2017). The predominantly laryngeal nature of the pronunciation system could account for increased voice dysfunction, which could be potentially triggered through adjustments to the supra glottal manoeuvres when speaking in a second non-dominant language[23]. The articulators' alternate movement sequencing and physiological positions involve communication at the laryngeal motor cortex, and slight mechanical adjustments in the form of new phonemes and phonetic requirements may directly impact the larynx itself.

Cavities vibrate according to the way they are filtered, and the placement of the articulators is an activity that tunes the cavity resulting in specific resonating properties essential for achieving the desired tone in Western classical singing, as much as rendering the text with the pronunciation features of the target language. Thus, the scope of work for a singer is expansive when it comes to singing in non-dominant languages with clarity, and the bar is set high for singers to strive to maintain the clarity at word level required for

[22] Balanced bilinguals tend to show better voice features than those that are not. Further, there is also an increased incidence of voice fatigue and dysphonia risk when speaking a non-dominant language, the vocal folds have been found to have increased tensing when speaking a second language which tends to result in a higher pitch when speaking in a non-dominant language, the vocal folds also are more inclined to pressed phonation which increases vocal load such that researcher, Kati Järvinen proposed that "it would be important to do voice exercises in a foreign language, after first learning how to produce sounds correctly in your native language and getting to know your own voice-making anatomy (Järvinen, 2017).

[23] More research is needed into whether a similar set back occurs with the singing voice when approaching works that are in an unfamiliar language.

communication with the audience that comprehends the target language as much as to achieve a certain linguistic benchmark expected.

In determining the phonetic requirements of a piece, singers may seek out a variety of methods to improve their proficiency, including;

- Instructions from their teachers.
- Work with a repetiteur equipped with insight into the language.
- Enrol in language classes.
- Work with a diction coach[24],
- Refer to International Phonetic Alphabet transcriptions of the text.
- Access to detailed books[25] on the rules of singing in the target language.
- Listening to recordings to perceive the pronunciation features of native singers.

Research is limited on the full scope of tools that modern-day singers employ to acquire phonetic proficiency in a language for the unique purpose of singing it, and more insight is needed into the challenges and barriers that singers face in this process, particularly since many languages have alternate pronunciation rules when sung.

The modifications to the vocal tract needed for singers to achieve consonant and vowel accuracy in a non-dominant language can be both subtle and drastic, the degree of which is determined by the actual phonetic inventory the singer has acquired to date. For singers to learn the pronunciation features of a target language, they need to understand the impact of micro-movements internally within the vocal tract that result in acoustic change.

Notably, the International Phonetic Alphabet can serve as an additional tool in this process. Although somewhat subjective (the symbols were initially developed in response to perceptual impressions of phonemes and suprasegmentals, rather than acoustic waveform

[24] The eminent Nico Castel devoted part of his career to instructing singers in the nuances of correct pronunciation while also performing as a character tenor at the Metropolitan Opera. Seen as “the Metropolitan’s resident standard-setter for linguistic flavour (Will Crutchfield in the New York Times, 1985, as cited in Fox, 2015), Castel was a well-rounded operatic polyglot, fluent in English, Spanish, Portuguese, French, German, Italian and Ladino, who also knew numerous dialects.
[25] Several gold standard books exist to assist singers in the art of diction such as Adam’s A handbook of Diction for Singers: Italian, German, French; Bernac’s The Interpretation of French Song.

and concrete data into physiological manoeuvres such as electropalatography), the phonetic symbols serve to code and reference how the vocal tract requirements to achieve the target sound.

Broad transcription[26] intends to provide insight into the correlating anatomical position, manner, and voicing criteria needed for phoneme accuracy on consonants in the supra-laryngeal space; and for vowels provides insight into the tongue (front, centre and back), soft palate (nasality) and jaw (opening) positioning required. However, the singer must reference diacritic details unique to their target language and any other dialectical requirements. For example, a speaker can only learn the fine details such as the variance between an Italian /t/ and an English /t/through diacritics. Diacritics[27] provide the speaker and singer with a more precise outline of a sound's requirements and allow one to potentially experience how a millimetre adjustment opens a new acoustic terrain.

In their attempts to create phonetic precision for their target language, singers learn to tune the vocal tract with the mobile articulators, valving it at best to render the linguistic features required. However, in this process, there is always room for error by virtue of insufficient insight into the target language or the sheer complexity of the movements required that are distinct from languages the singer is customarily accustomed attuned. Therefore, it is helpful for singers to be alert to cross-sectional and intersectional phonetic inventories. This process involves contrasting the first language and dominant language phoneme sounds and their articulatory requirements against target languages to predict risk with phonetic placement and make a bid to ensure the best transfer of sounds that are already present in the singer's inventory. Creating a cross-sectional and intersectional phonetic inventory will be discussed in the deliberate practice chapter alongside other

---

[26] Broad transcription is the set of symbols used in the phonetic alphabet to make general reference to the target phonemes and is typically straightforward, omitting significant detail around a sound's requirements. More often than not, broad transcription serves as a simple phonemic outline of the target (Ladefoged, 2015, p. 314).

[27] Diacritics add more precise details to broad transcription in the form of super/subscript symbols, which demarcate the target sounds' additional articulatory features.

practice studio resources for singers to boost their creative cognition and develop as an operatic polyglot.

Resonance Properties in Western Classical Singing

Unlike speech, singing requires:

> additional amplification of certain frequency partials through articulatory shaping of the resonating vocal tract subserves the production of style-specific timbre that allows the voice to be audible despite the competing sound from an orchestra. (Kleber et al., 2010, p. 1148)

In forming the vowels of the target language, a singer is thus required to consider the phonetic placement of the vowel and the tonal and timbral properties of the vowel. This results in various adjustments in the vocal tract that rely on the singer's ability to make compromises between the structural requirement of the vowel (its anatomical placement in the mouth cavity) as desired in the spoken language and the resonance requisites of the operatic/ classical voice. Typically, singers will favour tuning the oral cavity with the laryngeal chamber to ensure overlapping of acoustically beneficial frequencies. All resonators vibrate according to the frequencies that they are tuned at, so across the pitch range, the singer is constantly valving both the laryngeal mechanism (vocal vestibule) as much as the articulatory mechanism. This is a rich and complex process that counts on the principles of physics and sound wave properties, which are, in most cases, concepts that are not overtly referenced overtly in a singer's training. Each singer has a unique vocal tract comprised of varying dimensions, vocal fold lengths, spatial volume, and airflow capacity. In their training, both the teacher and student strive to create the most musically desirable tone relative to the singer's technical ability, command of the work and language being sung and overall artistic development. This is usually reinforced through the application of deliberate practice in the form of sung scales and technical exercises and error correction and refinement of repertoire.

Various researchers have explored the vocalised adjustments needed to create the desired operatic/ classical sound relative to voice type. However, despite hearty debate around the resonance principles and capacity of each vocal fach to achieve the ideal vocal, acoustic and timbre palette, evidence is limited by the unique anatomy of each singer studied.

Despite the difficulties to make concrete precisely what is behind optimal resonance in Western classical singing concerning the valving and physiological manoeuvres of the adept expert singer, some common principles have been noted which further support how there should not be as strict a demarcation between the singing process of phonation and the articulatory process of diction since the phonetic tone tuning of the vocal tract will account for the resonance properties of the waveform. The phonatory manoeuvres of the vocal folds are as much phonetic behaviours as the movements of the tongue, lips, jaw, and palate. They support the acoustic properties and resonance features of the sound wave and assist in differentiating voiced and voiceless[28] phonemes.

When the singer tunes a word element while singing Western classical music, they strive for high acoustic spectral energy to create amplifiable sound as well as a precise timbre for stylistically accurate and artistically informed[29] tone. Expert level singers produce phonations that show distinguishable enhancement of specific frequency partials. The physical properties of squillo in expert classical singers were first investigated by Johan Sundberg in his paper, “Articulatory interpretation of the “singing formant” where he found a physiological rationale for the acoustic characteristics of professional male singers in Western Opera and classical music. Later research has also mapped the acoustic correlates

[28] Given the vital role that the laryngeal motor cortex plays in both phonation and pronunciation, which constitutes phonetic tone tuning for the purpose of this paper, the term ‘voiceless’ phonemes is contradictory since the neurological correlates {Brown, 2009 #12, @31} for the vocal tract, including the articulators and vocal folds are firing and do require the overt manoeuvring of the vocal folds into an open posture to release the acoustic signal for the arguably "voiceless" sound. However, at large, connected speech shows motor activation primarily in the larynx area {Brown, 2009 #12, @35} in spite of the mix of voicing and "devoicing" at the phoneme level.

[29] Where artistically informed tone relates to the singer’s use of a certain timbre due to their service to the semantics, characterisation or mood of the text, lyrics or libretto.

found in female singers, with evidence of formant tuning[30]. The singer's formant is explained by phonetic tone tuning and is marked by the following adjustments:

- a lower larynx position than in speech
- increased jaw opening
- a frontal tongue tip position on back vowels
- increased protrusion of the lips in front vowels,

alongside a unique vocal tract tuning independent to vowel shaping lower in the pharyngeal cavity.

The sound wave properties that make one vowel distinguishable from another are determined by the frequency of the first, second and third formants. Likewise, consonants are also distinguished by the formant properties achieved **through** usually more overtly visible manoeuvres of the oral cavity.[31]

Fulfilment of the singer's formant occurs when the singer assumes a position that enables the larynx to "act as a separate resonator, the resonance of which is not affected by articulatory movements of in the rest of the vocal tract" (Sundberg, 1974, p.842). This results from a lowered larynx position, which creates a wider pharyngeal cavity, reinforcing the sound wave and creating divergence and overlap between the third, fourth and fifth formants, resulting in higher spectral energy at the 2-3Hz region. The process of formant

[30] The formant tuning process in the female soprano voice is slightly different from the lower voice types since the higher pitch range of the soprano results in already high spectral energy that is amplifiable over an orchestra. Despite this, Garnier (2012) reports that sopranos have been found to adjust the vocal tract, specifically through tuning vowels to influence resonance across their range. Sundberg (1975) states that sopranos are likely to produce different jaw and lip adjustments which are pitch dependent to benefit the amplification and creation of stylistically appropriate vocal tone. Acoustic theory denotes that vowel differentiation and intelligibility is reduced as high vocal pitches are reached due to adjustments in the formant properties of vibrations. Vos (2017) reports on the neutralisation of vowels which occurs in many sopranos at the vocal stratosphere in favour of tone quality over intelligibility.

[31] The acoustic property of a consonant is usually more complicated than vowels. Ladofoged (2015) discusses how plosive and fricative sounds adjust the formants of their surrounding vowels and liquids, and nasal sounds tend to show formant properties that are similar to the vowels around them (p. 210). Acoustic differentiation of consonants is noted due to adjustments to the formant properties of the ensuing vowel sound. An example would be /p/ and /d/, where there is no acoustically noteworthy difference in the formation of the sound. However, at the closure point of the sound, the soundwave ceases, and in the coarticulation of these individual sounds with the corresponding movement to the vowel, the acoustic difference becomes clear.

tuning often corresponds with mechanical adjustments in the vocal tract that involve pitch and vowel specific manoeuvres at the articulators. As such, this then means that there is a distinct process by which the expert singer acquires the postures of the mouth that achieve both the acoustic spectral quality required by the art form ameliorated with phonetic clarity in a process that Miller (2012) states is frequently met with compromise and negotiation in the cavity structures to uphold good tone.[32] Thus, there is a symbiotic relationship between the articulatory gestures of neighbouring consonants and vowel segments that entails precise phonetic and resonance tuning for the Western classical singer.

Pitch Value

Vocal music, unlike speech, requires a stringent regulation of pitch, and thus the singer engages additional mechanisms for this process. Although more research is needed on the process behind singing in tune, we can speculate that pitch errors on unfamiliar phoneme segments due to coarticulatory insufficiency are plausible. Singers may therefore benefit from a clear understanding of the pitching variations present at the syllable and microsegment level to increase their intonation accuracy when navigating new phoneme targets (see Figure 5).

[32]While striving for the speech gestures needed for the target language, maintaining acoustic energy and timbre of sung phonation across a singer's range entails that phonetic variation (or even deviance) will occur on certain vowels and consonants comparative to the sound wave and phonetic placement (anatomical position needed in the vocal tract to achieve a phonetic segment) features of the spoken language.

Figure 5:

Segmental Properties of the Singer’s Syllable and Phonetic Pitching

<table>
<tr><th colspan="3"></th><th>PHONETIC PITCHING</th><th>PHONETIC PITCHING RELIES ON</th></tr>
<tr><td rowspan="2">SYLLABLE PROPERTIES</td><td>FULLY VOICED</td><td>V
VV*
VC̬
VC̬
VC̬C̬**
C̬V
C̬C̬V**</td><td>Across these segments the singer is producing pitched phonemes without offset voicing.</td><td rowspan="2">1) Onset tuning - does the singer arrive on the pitched segment with the intonational accuracy needed for coarticulation from the previous segment

2) Sostenato tuning - does the singer sustain the required pitches during the sustained duration segments

3) Offset tuning - does the singer depart the segment with the intonational accuracy needed for coarticulation to the next segment</td></tr>
<tr><td>PARTIALLY VOICED</td><td>VC̥
VC̥C̥**
VVC̥
C̥C̥V*</td><td>Across these segments the singer is producing pitched and unpitched phonemes which involves offsetting voicing.</td></tr>
</table>

**As in the case of a diphthong or possibly even triphthong*
***Depending on the language, lengthier consonant clusters may occur.*

The syllable has a fixed number of segmental properties that can provide more insight into the nuances and challenges of the expert pitch tuning required at the phonetic tone tuning level.

While the syllable will always require a precise tonal pitch at the vowel, not all syllable segments can be tuned; certain phoneme segments do not require voice vibration and thus are un-pitched. Therefore, the intricate process of valving the vocal tract to produce pitched and unpitched sounds as required by the text has a higher error risk as the singer is required to expertly coordinate the speed of the folds while coarticulating phoneme segments. Any aberrations of placement tension and pressure at the fold, subject to the articulators' movement despite the singer's best efforts, can lead to intonational errors.

Three core skills are needed in phonetic tone tuning to maintain the desired pitch values at the syllable segment level for the precision required. Typically, singers may view phrases at a more global level. However, the risks of intonational aberration due to phonetic tone tuning challenges make it vital for the singer to consider the variables that can account for error removed from so called *intonation issues* and more related to the complexity of alternating and sequencing complex motor movements for less familiar or demanding coarticulatory contexts.

1) Phoneme Onset Tuning

Phoneme onset tuning is a term used in this thesis to refer to a skilful and precise entry to a pitched phoneme segment at the onset of that segment. This can be needed more than once in the syllable, and gradual aberrations in this process could amount to a domino effect creating intonation errors in the practice studio as much as in performance if not remedied.

At the onset of a voiced phoneme segment that requires voice vibration, the singer must simultaneously connect the phoneme shaping at the articulators without disrupting the desired speed of vocal fold vibration (mediated by fold tension and air pressure factors). Phoneme onset tuning can occur at the commencement of the note or within the note and must, in all instances, see the singer hit the target pitch on the desired phoneme.

2) Phoneme sostenuto tuning

Phoneme sostenuto tuning is used in this thesis to refer to the singer's capacity to maintain the phoneme segment at a fixed pitch with a sustained duration. This skill will be noticed more on the vowels in the syllable and on all sonorant consonant phonemes but is also required on voiced plosive and affricates, although short durations are only needed. Pitch clarification across the syllable counts on each vocalised phoneme segment sustaining consistent vibrational speeds at the vocal folds without any acceleration (which would make the singer sharp on the note) or reduction in speed (which would make the singer flat on the note).[33] Ladefoged (2015) asserts that all sounds have relative sonority (p. 256) and prominence peaks will be influenced by the pitching of the tone as much as the perceptual and acoustic correlates of the phoneme segment. At the coarticulatory point between

---

[33] Singers may have a higher awareness of error prediction and correction on the phoneme segments that sustain for longer durations as they enable increased cognitive processing durations for online feedback and correction while engaging in overt singing. While some research exists around the abilities and neural correlates of how singers process and plan pitch (see Kleber et al., 2013; Zatorre et al., 2007 and Ladda, 2020) more research is needed in this area about the phonetic implications on pitching at the segment level and with specific reference to whether intonational accuracy at the segment level is more challenging where a singer is less familiar with the language.

phoneme segments, voiced or voiceless, the singer can easily lose the centre pitch in their attempt to unify segments and reduce the prominence peak, resulting in a flattening or sharpening of the sustained phoneme in the syllable.

3) Phoneme offset tuning

Phoneme offset tuning refers to the singer's ability to maintain the pitch required at the offset of a voiced phoneme without adjusting the speed at the vocal folds due to changes in pressure and tension. While errors in this process can relate to a systemic issue with intonation, technique and airflow control, they can also arise from difficulties at the offset of the voiced phoneme when adjustments to the articulators result in secondary adjustments at the folds resulting in pitch error.

The Metric or Rhythm Value of Phonemes Set to Music

The metric or rhythm value relates to temporal measures of the sound stream encoded on the syllable. This can be measured concretely in seconds or milliseconds; however, it is best considered relative to the syllable values around it, which would be informed by the phrase shape, meter and pulse of the section in the work. The metric value of the sung syllable is informed by its *onset timing*,[34] its *sustained duration*[35] (the total temporal duration of the syllable)[36] and its *offset timing*.[37] The rhythm value at the singer's syllable will sometimes coincide with the individual note value but can also sustain itself across multiple notes, as in the case of the syllable unit liaising across more than one note and pitch value. These temporal components have been developed separately for this thesis and add to already

[34] The onset of the syllable is a term used by phoneticians such as Ladefoged (2015) to refer to any consonants that make up the syllable prior to the necessary vowel segment (p. 258).
[35] Sustained duration is not a term from phonetics but has been used in this paper to refer to the total duration of the syllable, including onset and offset. This is different from the nucleus, a term used in phonetics to refer to the vocalised part of the syllable (the vowel), since it references the duration of the nucleus (the vocalised portion of the segment).
[36] The temporal duration can be measured on one sustained pitch or note value or across different pitches and rhythmic values as is in the case of melisma where one syllable is held across a flourish of notes of varying pitches and at times varying note values.
[37] Phoneme offset timing is a term unique to this paper that refers to the fixed temporal moment at which the syllable is completed. This is distinct from the phonetic term- the coda, which is used to denote the final consonants after the nucleus- in that it refers to the rhythmic precision by which the coda is rendered.

existing phonetic concepts related to syllable components since the temporal and metric precision of vocal music is distinct from speech (see Figure 6).

Figure 6:

Syllable Components and Phonetic Tone Tuning

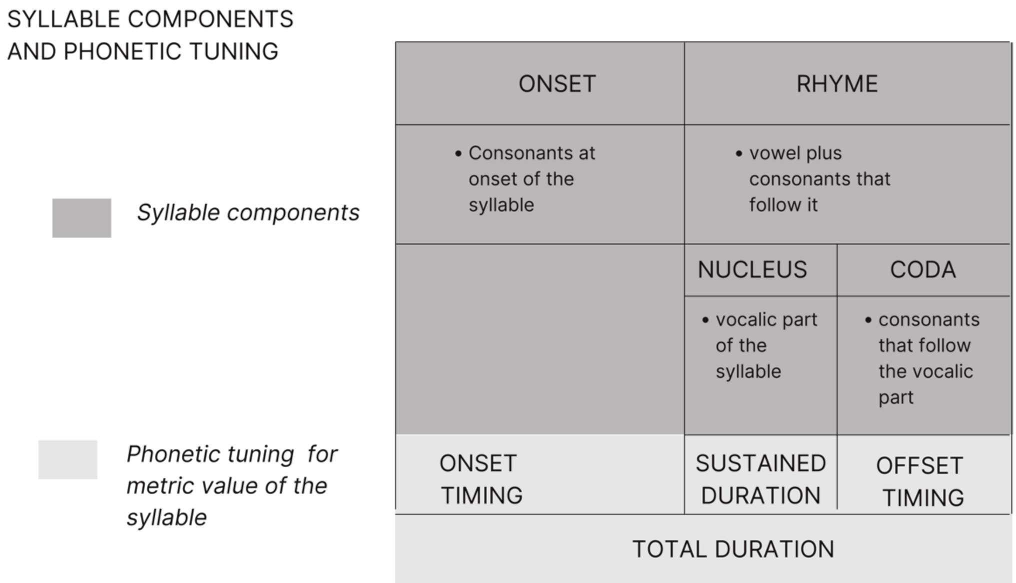
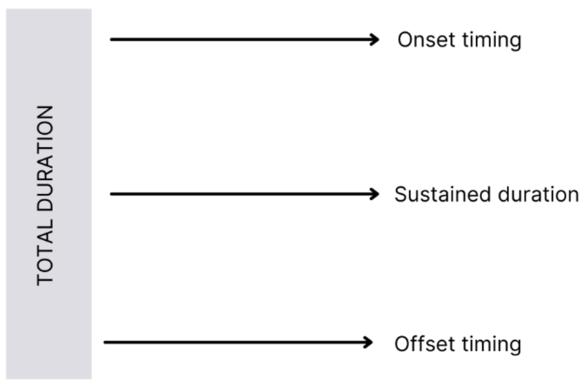


Figure 7:

Markers of Temporal / Metric Precision at The Syllable Level



Phonetic Tuning Aberrations

Phonetic tone tuning aberrations that affect the metric value can occur on one or all three elements (see figure 7) and would drastically constitute musical errors as much as linguistic and phonetic errors while impacting other elements of the desired multi-prismic properties of the singer's syllable. In some cases, these errors will be musical rhythm errors that betray the rhythmic requirements of the notation; in other cases, these errors will involve a lexical error where the representation of the phonetic properties of the word target was in error due to deviance from the syllable's metric components. Some examples of possible errors appear below regarding the three elements needed to fulfil the metric value of the syllable.

Phoneme onset timing and phonetic tone tuning errors

Onset timing can result in errors where the singer is late or too early to enter the syllable at the onset. Achieving syllable accuracy requires timely commencement of the vowel entry with the vowel's properties relative to the target language. There is variance across languages concerning the duration of like phonemes as transcribed with diacritics. For example, while the English "t" and Italian "t" receive the same broad transcription with the same symbol, /t/, however, their diacritic differences entail that the English /t/ phoneme receives decreased duration comparative to the Italianate /t̪/ due to the voicing and place differences. As such, an English native singer may make a phonetic tone tuning error on /t̪/ in their repertoire by producing a phoneme segment that is too short at the onset timing point resulting in an earlier entry to the sound stream on the ensuing vowel comparative to a native Italian singer who would indefinitely release the /t̪/ with the increased duration required afforded by voicing. Thus, the non-native singer would need to enter the sound stream on the vowel at a later and more appropriate point for phonetically in tune Italian singing on the syllable segment to avoid an error.

An onset timing error could also involve late offset timing on the preceding consonant resulting in a late entry to the target syllable segment. In this case, a conductor may note this as a rhythmic entry error where contrarily it arose due to difficulty tuning the complex motor patterns required in the vocal tract to produce timely coarticulation between the initial syllables' phoneme segments and the ensuing syllables' onset.[38] In this case, the singer's error did not arise due to a false sense of rhythm but rather motoric coordination insufficiency on the novel phoneme. A practical example of this could be a singer struggling to pitch a voiced consonant like /v/ with correct intonation, spending too long on tonal error correction during the consonant before the release of the vowel resulting in late entry to the syllable.

Contrarily, the singer could also produce a phoneme onset error pre-emptively of the metric requirements due to early cessation of the onset timing on the note prior or early entry to the syllable where coarticulation was not required (for example, entering the sound stream too early after 4 bars of rests). While this error could occur due to a false sense of pulse and meter, it might also arise in some circumstances due to incorrect phonological awareness of the onset timing needed for a consonant at the start of the syllable. For example, a singer tuning an Italianate /tr/ at the front of the syllable segment and struggling to sustain the trill for the stylistically desired duration, resulting in early entry to the vowel and thus constituting an onset timing error owing to phonetic.

Sustained duration and phonetic tone tuning errors

A phonetic tone tuning aberration could also result in an error that affects the sustained duration of the syllable. A typical example would be an error in the designated duration assigned to the duration affected by deviations in the required onset or offset timing on the syllable that would either increase or decrease the sustained duration required. This type of error is a secondary error caused by failure to achieve the onset or offset timing. Errors that would be solely aligned to the sustained duration of the syllable include errors with the diphthong segment durations required on the target syllable. For example, a singer singing a melismatic passage across an /eɪ/ vowel may allocate an increased temporal

[38] The correlate of this for an instrumentalist (who lacks the phonatory syllable unit) would be an error caused by poor finger sequencing or bowing (also achieved through by complex motor sequencing) such that late entry occurs.

duration in the melisma to the /ɪ/ vowel rather than situating the /ɪ/ vowel at the required offset timing point, resulting in a slip up with the alignment of the following syllable segment. This not only causes a domino effect to the offset timing of the syllable and the following onset timing, but it will also represent a phonetic misalignment within the syllable. Diphthong durations vary depending on the target language. For example, in Italian, the first vowel of the syllable in both spoken and sung Italian will always take an increased time value relative to the second vowel of the diphthong, unlike in spoken English. Similarly, a time extension error on a schwa vowel relative to other syllables within a word will also result in a lexical stress and phrasing error. This would also have a spill-on effect at the suprasegmental level, as discussed in the next prosodic stress section.

Phoneme offset timing

Offset timing at the syllable level concerns the phonetic tone tuning ability to cease the syllable constituents symmetrically at the right moment, ready for the next musical element (more sung syllables or rests). An offset timing error could result from a delay due to an over articulation of a phoneme within the syllable, resulting in late cessation of the syllable unit, which could impact the rhythmic accuracy as much as phonological accuracy or the late release of the final sound segment of the syllable. Some examples of possible phonetic tone tuning errors on each element include:

- An overly lengthy extension of the vowel and vocalised elements of the syllable (nucleus) could result in late articulation of a final consonant at the demarcation of the syllable resulting in both a coarticulatory timing error and/or a metric timing error. A typical example could be the late insert of the final voiceless consonant in a consonant cluster that contained both voiced and voiceless sounds at the coda.
- This form of error is also common in moments where a phoneme segment within the syllable could be seen as amibisyllabic or also where there is a doubling of the same

phoneme, and the offset timing has resulted in a tardy entry to the ensuing syllable unit create a ratio that does not favour the vowel duration as needed in singing.[39]

- Late-onset timing on a voiced plosive consonant at the offset such that the syllable segment is concluded too late and outside of the time sequencing needed to activate voicing resulting in a phonetic tone tuning error based on voicing aberration where the voiced consonant is instead devoiced due to insufficient time allowance to create phonation in the segment.[40] This could also result in pitch tuning (where the sound segment does not contain phonation as needed and loses its resonant Hz value) or a semantic error where an alternate word is perceived due to the voicing variation at the coda.
- Offset timing errors can also affect the schwa vowel when it is the final phoneme segment of the syllable resulting in word stress errors and musical pulse errors due to the use of an extended duration on the phoneme relative to the other vowels of the word.

Prosodic Stress

Several factors inform prosodic stress[41] in vocal music. First, the singer needs to apply the target language's word, and phrase-level stress as well as consider the harmonic

---

[39] Kleber et al. (2010) states in their paper, *The Brain of Opera Singers: Experience -dependent changes in functional activation* that "in singing, word production is reduced in favour of vowel production as the carrier of melodic content" (Kleber, 2010, p.1148) however this is not the case, word production is not reduced in favour of vowel production, since vowels constitute words and while the musical phrase is composed of phoneme segments made up of consonants and vowels which form the syllables, examining music and text at a phrase level elevates the word and text focus of singing. It is better to consider what is favoured in terms of durations in singing, where phonetic tone tuning for the singing requires that the vowel element is given an accurate duration ratio against the onset and offset segments of the syllable duration. Vowels are just as important in word level speaking; research concurs that the bulk of the speech articulation system is phonatory in nature. This is supported by fMRI studies that map the detailed activation of the laryngeal motor cortex in speech. Brown et al. (2009) in their neuroimaging study of the phonatory components of speech and singing established the "under-recognised presence of phonation in imaging studies of speech production" (Brown et al., 2009 p. 31, and suggested that the laryngeal motor cortex plays an involved role in "mediating the melodicity of speech" (Brown et al., 2009, p.31).

[40] Voiced plosive phonemes take up a longer voice onset time than voiceless phonemes since they involve oral cavity restriction (closure) for the plosive release followed by the onset of vocal fold vibration, where voiceless plosives do not need the vocal folds to coordinate and vibrate and are produced with pure air pressure release into the sound stream after oral closure.

[41] Often referred to as the supra-segmental level of acoustic phonetics for speech, suprasegmentals can be transcribed for speech with superscript symbols. Since music notation does not include this type of

and metric shifts represented in the notation, specific musical symbols or instructions on the score to mark stress (such as a fermata, accent mark, instruction for stringendo across the syllables of a phrase), phrasing, pulse and the designated note values. Stress is usually achieved by increasing the sound pressure level, sustained duration, varying onset timing variations, or by the singer's timbral modifications.

Prosodic Stress Aberrations

Typical aberrations of prosodic stress triggered by a phonetic tone tuning error could include:

- The phonation of the syllable at an equal sound pressure level where instead a contrast was required resulting in a lexical stress error.
- Increased duration on the final vowel of a diphthong in a Romance language where typically the first vowel would receive the core duration for sostenuto and the second vowel would occur at the offset timing point.
- The incorrect metric value assigned to a vowel due to late motoric adjustment for the following consonant of difficulty caused by groping errors. For example, a singer who struggles with the articulation of the Czech /ř/ háček may enter the next syllable late while groping to position the tongue correctly thus adding late offset timing to the preceding syllable, increasing its sustained duration and creating the perception of syllable stress on the prior syllable where not required due to the position of the syllable at the end of the bar, neither occupying a downbeat or point in the score that required stress or being situated in a word segment that needed emphasis.

---

detail on the syllable unit, singers tend to refer to phonetic transcriptions of target languages to make decisions, particularly around features like primary and secondary word-level stress, vowel length, syllable breaks and linking. However, music notation does have some symbols that do have a suprasegmental impact in the form of slur lines, staccato markings, accent markings, fermatas and even written musical instruction for singing styles like *Sprechstimme* that inform the singer of the instructions that are suprasegmental in nature. Similarly, diacritics for speech tones (levels and contours) denote the suprasegmental information related to the intonation requirements at the spoken word level in tonal languages. Similarly, note positioning on the stave also serves as a form of musical prosody for sung texts. Unlike tonal languages, however, the pitch value of the sung syllable does not provide lexical differentiation between two words with the same phoneme elements (as for languages like Cantonese or Mandarin) but instead serves to colour the setting of text to a melody.

Sound Pressure Levels (SPL) and Phonetic Tone Tuning

Different vibrational speeds (as measured in Hertz) will have varied carrying power and volume sensitivity. The Sound pressure measurement is the best objective way to determine the acoustic strength of the signal. This measure aligns with the perceptual correlate of loudness (Long, 2014). SPL errors may often arise due to poor coordination between respiration, phonation and resonance. Phonetic tone tuning aberrations may also occur due to the influence of the singer's first language on the target language since each language can have distinct or idiosyncratic different SPL level requirements across phonemes.

For example, the phonetic placement features of a trilled /r/ sound and a flapped /ɾ/ sound will affect the sound pressure level. The word *perro* (Spanish for "dog") and *pero* (Spanish for "but") will receive lexical differentiation through the accurate phonetic target but also sound pressure differentiation since /r/ emits more sound pressure than /ɾ/. If a singer over generalises a trilled /r/ where not required, the result will be both a sound pressure error that also affects the phonetic tone tuning of the syllable metrically by delaying the offset duration (/r/ sustains longer than the flap /ɾ/) creating a meaning and acoustic breakdown.

Sound pressure levels will also affect lexical and phrase-level stress. For example, a standard error for non-native singers of German is to release the schwa vowel /ə / with equal or increased sound pressure relative to its neighbouring stressed or non-schwa vowels. This will result in a lexical stress aberration as much as the likelihood of a phrasing error where the pulse of the phrase is incorrect, which is required to be unstressed comparative to other syllable units in a word segment.

Sonority[42] also influences the sound pressure level, particularly when the singer is striving for a legato line. At this moment, a singer seeks to unify the prominence[43] of the phonemes across a phrase. Achieving legato considering the unavoidable presence of prominence by virtue of the distinction between phoneme segments according to their phonetic and acoustic properties as much as factors around the notation requirements set up by the composer in terms of pitch, harmonic movement, and metre and pulse accounts for why achieving legato is a higher-level skill that takes deliberate practice and might be accelerated through notions of phonetic tone tuning.

Prominence peaks arising between one phoneme segment against another can also make it more challenging for a singer to adhere to the score markings indicating the dynamics. The prominence peak sensitivity of different phonemes accounts for the need for relational adjustments with sound pressure levels to achieve relative pianissimo or forte renderings. As such, the onset of a new phoneme segment against another may cause a noticeable sound pressure flux or influx that is unintended and could, at worst, alter the dynamics of the following musical phrase.

Phonetic tone tuning is subject to multiple properties, as has been demonstrated in this chapter. Aberrations can occur in the performance and practice studio, which necessitates deliberate practice that involves phonetic tone tuning to ensure the multi-prismic properties of syllables are aligned to the desired target. Accuracy in achieving the multi-prismic properties of the sung syllable and the work at large rely on complex neural interactions between the brain and the vocal tract. The next chapter will discuss the theories behind the acquisition of vocal motor control required for phonetic tone tuning according to motor learning and neuroplasticity principles.

---

[42] Sonority refers to the "loudness of a sound relative to that of other sounds with the same length, stress and pitch" (Ladefoged, 2015 p. 318).

[43] Prominence is a term used by phoneticians to describe the "extent to which a sound stands out from other sounds because of some combination of its sonority, length, stress and pitch" (Ladefoged, 2015 p. 318.

Chapter 3: Motor Learning, Neuroplasticity and the Operatic Polyglot

Creative cognition regarding phonetic mastery for the operatic polyglot pivots around motor learning and counts on principles of neuroplasticity. However, singers and their teachers are not students of neuroscience, even if their capacity to refine their art form counts on motor learning- in fact, the daily regime of a classical singer is built around motor learning by virtue of the activity of practice. “Many characteristics once believed to reflect innate talent are actually the result of intense practice extended for a minimum of 10 years” (Ericsson et al., 1993 p. 363). Since “motor learning is the process through which we come to perform actions effortlessly after practice and interactions with the environment” (Gatti et al., 2013, p. 37), we can easily say that the act of daily musical practice by the artist is a “means of motor learning [through which] we continuously extend our motor repertoire” (Gatti et al., 2013, p.37).

The 3 AAAs and their role in Motor Processing

This process relies on the singer to be able to coordinate the following three motor processing behaviours described by Keller (2014): 1) Anticipation, 2) Attention and, 3) Adaption (The 3 AAAs); albeit with incredible velocity and agility. The speed of this interface is brisk, in fact, according to one study from Timmers et al. (2020) finding that artistic movement interactions are coordinated within a timing of 50ms. These three motor processing behaviours are vital to the integrity of the motor system and mastery of complex motor skills and can be accountable for reducing error risk if the performer can produce the desired outcome.

We can ask various questions of the three AAAs and behaviours concerning the operatic polyglot’s ability to perform at an elite level across the multiple domains required of them (for example, stylistic mastery, musicality, artistic expression, characterisation and more) however for this purpose; we will focus on the questions raised if we consider the motor processing moment in terms of *phonetic tone tuning*. Each of these three behaviours occur within the singer's practice space as much as in live performance while engaging in overt singing.

Anticipation

In the moment of participation, the individual about to engage in a complex motor task anticipates the actions needed to produce the outcome. For the classical singer, when engaging in overt singing (practising, rehearsing, coaching sessions, live performance, recording sessions), we could ask both macro and micro questions:

- Gestalt informed questions around how the singer should anticipate the phonetic requirements of the note, phrase and work while also aligning the other domains required of them (for example, stylistic mastery, musicality, artistic expression, characterisation and more).
- Structuralist informed questions, two examples of which could be:
    - How does the singer anticipate the tongue, mouth and palate position on the /e/ vowel while sustaining a D6 without increasing jaw tension and altering the singer's formant and access to the stratospheric pitch comfortably and aesthetically?
    - How does the singer anticipate the voiced consonant onset with correct tongue positioning for an Italianate /t̪/ to increase their phonetic tone tuning where they are still inclined to calibrate an English aspirated and devoiced /t/ at the onset of words while maintaining the correct pitch at onset as well.

Attention

In live performance, how should the singer attend to the phonetic requirements of the note, phrase and work? For the classical singer engaging in overt singing in the instant moment of singing, we could an unlimited array of questions, for example, questions not limited as:

- How does the singer attend to the maintenance of the airstream at the end of the phrase?

- What predicts vowel integrity while engaging in *messa di voce* without aberration to the phonetic tone tuning (alongside all other requirements, such as the singer's formant)?
- And many more.

Adaption

In live performance and post-performance, how should the singer adapt the phonetic requirements of the note, phrase and work to improve accuracy? For the classical singer engaged in over singing, in the instant moment of singing, we could ask questions such as:

- How does the singer correct the overspreading of a vowel in the *passaggio* once they note it to ensure phonetic tone tuning as well as the production of the desired resonance properties and secure the tone in a swift mechanical correction? Can the singer adapt to phonetic tone tuning error moments when inaccuracies enter their stream of consciousness in situ?

This process comprises the singer's ability to engage in a three-step integrative motor process defined by Gatti et al. (2013), the success of which this thesis will define by the singer's ability to:

- Process and retrieve sensory information related to an action.
- Decide which movements to perform and what sequence to follow while performing them.
- Apply control processes during the motor performance.
    - Feed-forward processes through which the singer maps out the action of the articulators and vocal tract before execution.
    - Reactive control in which the singer responds to the execution, fine-tuning their creation while in execution.
    - Biomechanical control through which the singer plans and primes movement patterns to achieve a fixed target.

The 3 AAAs relate to the overt singing moment, through which the singer experiences, learns and optimises their skill in immediate acts of singing in situ. Given the rigorous routine of a classical singer and their practice, these immediate acts of singing in situ unfold across a longitudinal period and have a cumulative impact on motor learning. Thus, there is a lengthier aspect of singing development that we can best consider by regarding how motor learning is acquired across prolonged periods of study and practice.

The 4 Phases of Motor Learning

Motor learning is said to occur across four crucial phases. An example of each phase has been provided below concerning the act of singing and the development of creative cognition.

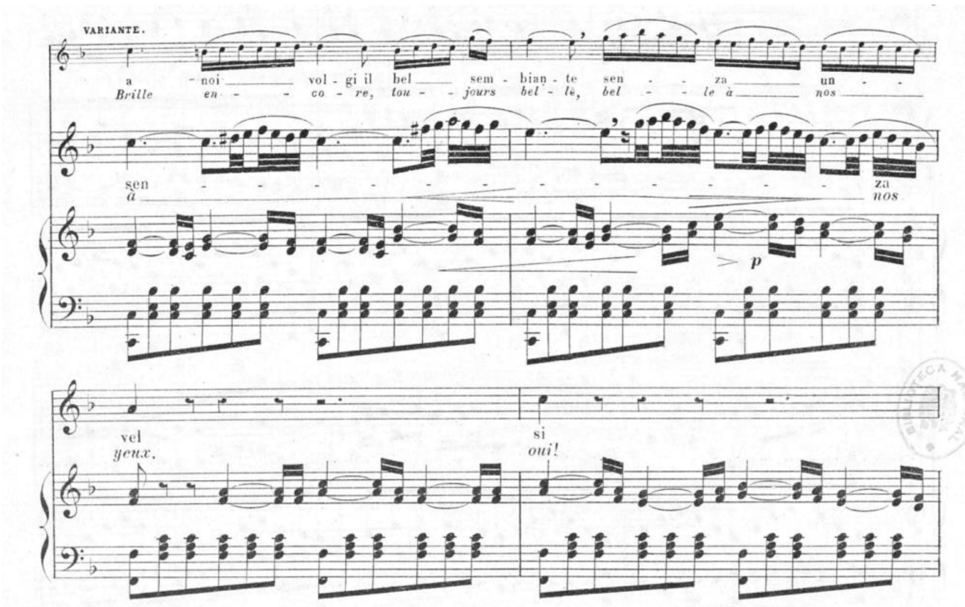
The Fast Phase

This phase relates to the singer's first session working through a complex motor pattern independently or with their maestro/a, repetiteur or diction coach. This would relate to the first cogent attempt to achieve phonetic integrity of an excerpt of music (where the singer strives to coordinate the correct motor movements, sequence and speed required linguistically and musically through the intersection of lyrics/libretto and the musical notation). The fast phase would link to one fixed moment where the singer obtains knowledge, feedback and the chance to produce their desired target either alone, with their repetiteur or singing teacher. This phase would also count on the 3 AAAs for high-level motor learning.

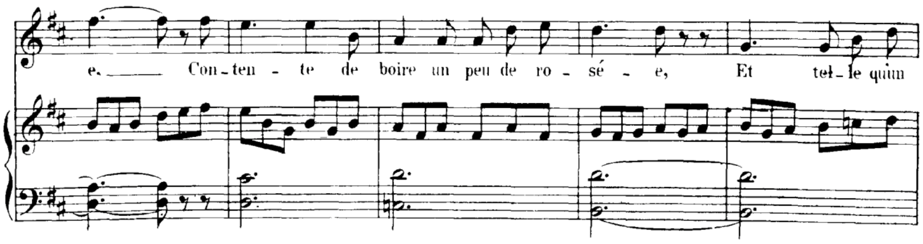
Some examples that involve phonetic proficiency instruction and correction in the fast phase could be:

- Correcting intonation in a melismatic passage while ensuring an Italianate open /ɛ/ vowel is maintained across the range of the melisma with appropriate timbre in the run from Bellini's **Casta Diva**

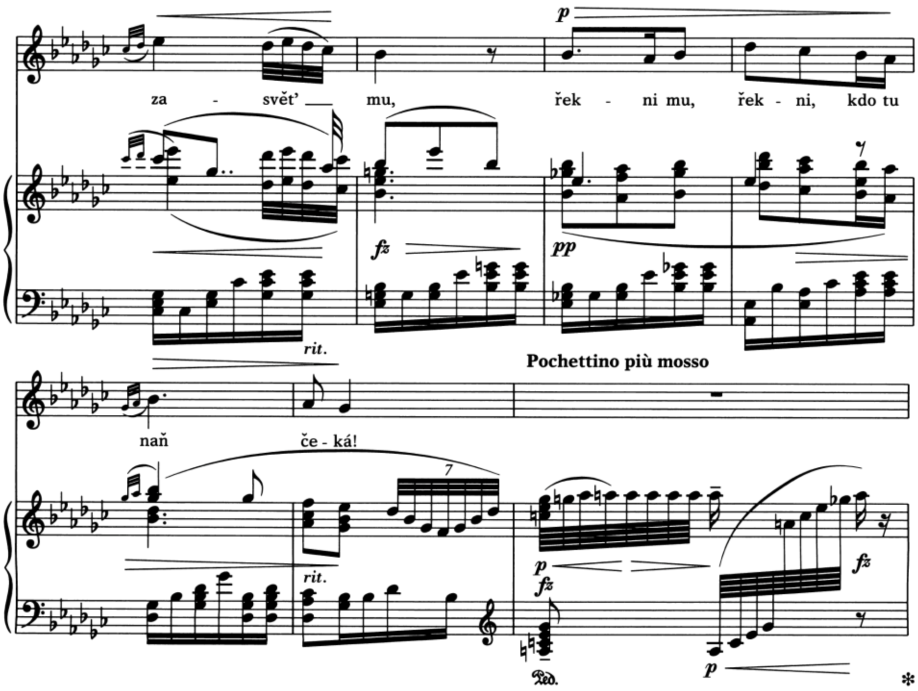
    "bel senza un vel..."

    /bɛl sɛntsa un vel/

- Successfully articulating nasalised French vowels across a phrase in all instances where required for a passage in Chausson's La Cigale (Chausson, 1890).

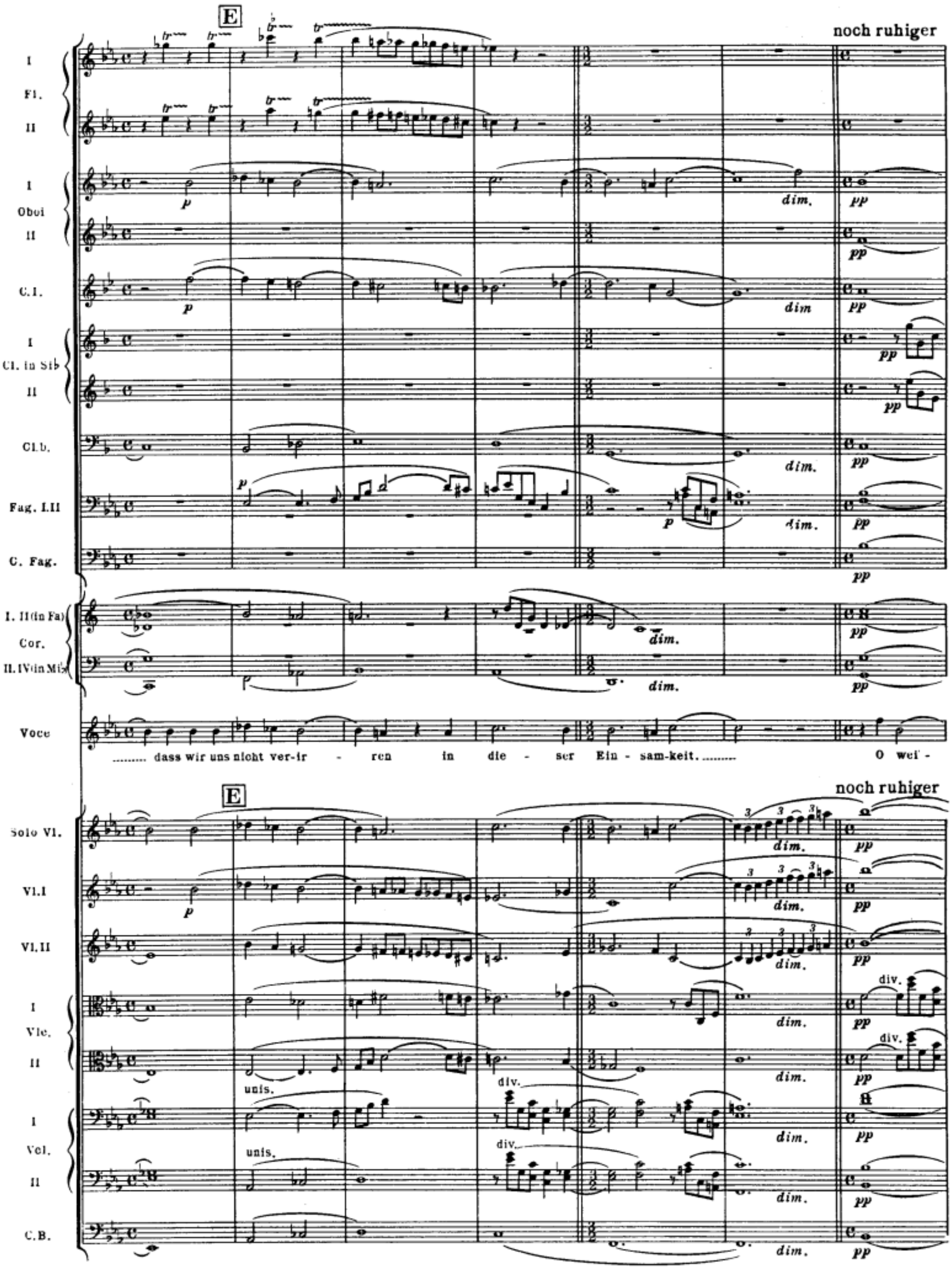
  "Contente de boire un peu de rosé..."

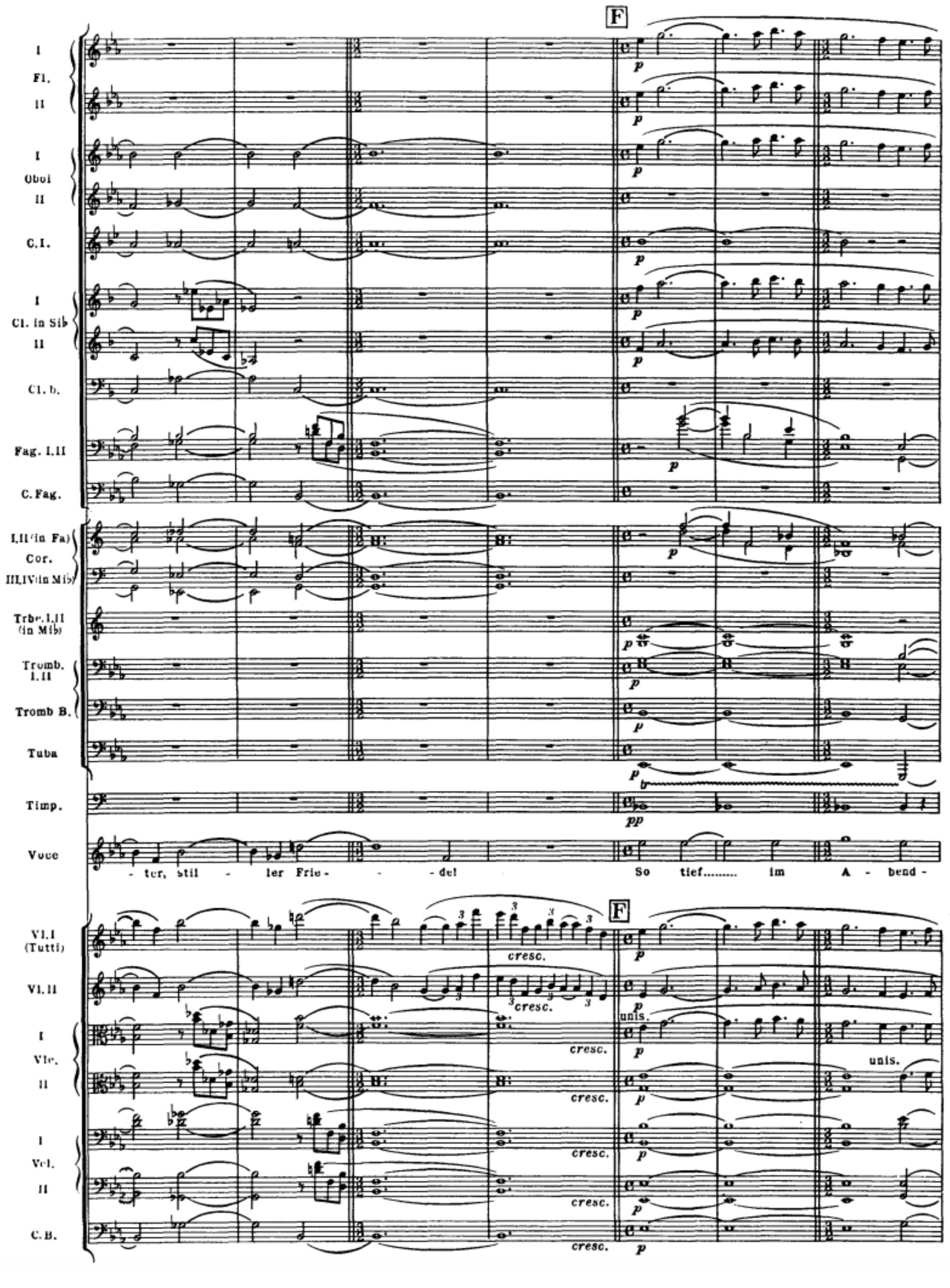
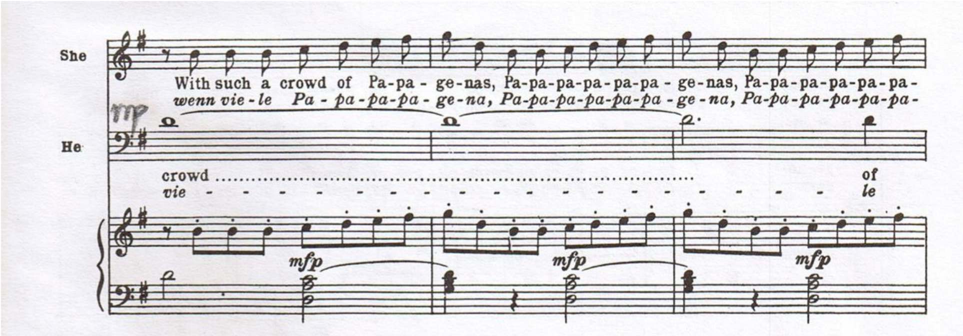
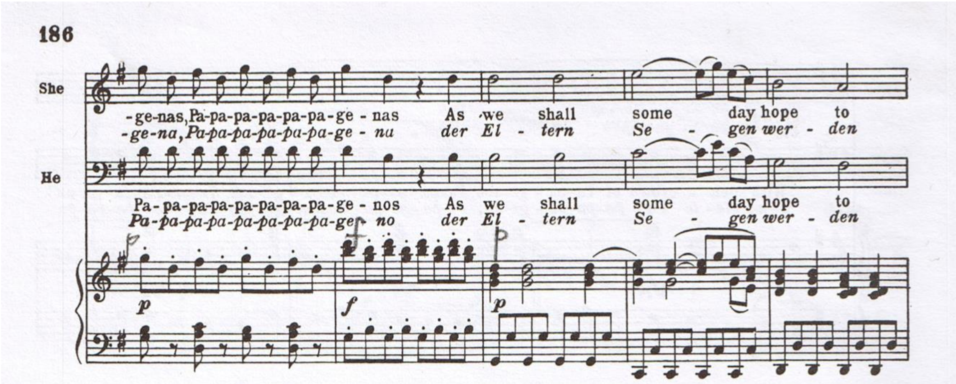
  /kɔ□tɑ□tə də bwa œ□ pø də roze/

- Obtaining correct phonetic placement while coordinating pitch and metric accuracy on the ř sound in Dvorak's Měsíčku na nebi hlubokém such that a raised alveolar non-sonorant trill is achieved.

  "řekni mu, řekni, kdo tu naň čeká"

  /r̝ekni mu r̝ekni mu gdo tu naɲ tʃeka/

- Tuning the schwa /ə / vowel in German repertoire to ensure it has the formant frequency and that it is differentiated from the cardinal vowels and occupies a central position, such as in this passage from Im Abendrot from Vier letzte Lieder, Richard Strauss (Strauss, 1950).

  "O welter, stiller Friede!"

  /o vɛltə ʃtilə fridə /


E
noch ruhiger
I
Fl.
II
I
Oboi
II
C.I.
I
Cl. in Sib
II
Cl.b.
Fag. I.II
C. Fag.
I. II (in Fa)
Cor.
II. IV (in Mib)
Voce
.... dass wir uns nicht ver-ir - ren in die - ser Ein - sam-keit. ....
O wei -
Solo Vl.
Vl.I
Vl.II
I
Vle.
II
I
Vcl.
II
C.B.
dim.
pp
p
div.
unis.

- Coordinating consonant vowel "pa -pa…" (CV) segments in Bei Männern welche Liebe fühlen from Die Zauberflöte (Mozart, W., p.186) at speed with timely articulation of each consonant onset.



Other examples might include;

- Inserting glottal stops as historically required for German diction or choosing to omit them for modern interpretations.
- Voicing consonant sounds that require it.
- Reducing air stream pressure for an Italian /t̪/ to prevent anglicised plosive /t/ at word inset and position it at the laminal-denti alveolar location.
- Coarticulating patter extracts with agility.
- Ensuring the upper register is intelligible at the word level.

Some motor learning will occur, and improvements will be noted at the first training session. Indeed, specific errors or deviations from the phonetic and musical target may be corrected; however, in some cases, the singer will need to work the error correction further in their deliberate practice as well as assimilate the entire work metrically, harmonically and artistically through the subsequent phases of motor learning.

At this phase, the singer's creative cognition is expanded. The singer becomes alert to the risk of error and starts to consider techniques and strategies to solve potential problems to facilitate high-level motor learning. They should start to track the rules at play to master the work metrically by considering the phonetic tone tuning, among other things, to anticipate potential errors and troubleshoot adaptive movement patterns to secure their phonetic accuracy to work towards high-level motor mastery.

Consolidation phase

After the initial fast phase for the particular motor target, improvements are said to occur on that particular moment of motor learning within a time contained window of 4-6 hours from the first practice session, without the additional practice of the task, provided there has been no competing task interference.

Thus, the benefits of the motor learning system go beyond the direct practice activities, extending into the enhancements of the skills practised during offline learning. Individuals that have engaged in motor based learning and deliberate practice appear to receive an indirect enhancement of their skill after a “latent period of approximately 6 hours” (Rienzo, 2016, p. 2) despite not engaging in more practice, provided other complex motor tasks have not interfered between the practice session and the period of latency. Offline learning or indirect learning also seems to occur after a night of sleep, after which participants appear to demonstrate performance improvements. Considering these findings, it is fruitful for singers and all musicians to carefully consider the timing and sequencing of their deliberate practice sessions to amplify the impact of offline learning. Further to that, we have this notion of seemingly invisible learning that does not involve overt singing. Indeed, within the practice regime, there is scope for the deployment of other behaviours and activities that support motor learning without overt singing, and these concepts and techniques will be explored within the next chapter.

Automatic phase

At this stage, the singer’s creative cognition is reliant on applying a set of explicit rules to master [the] novel task (Dreyfus, 2002).

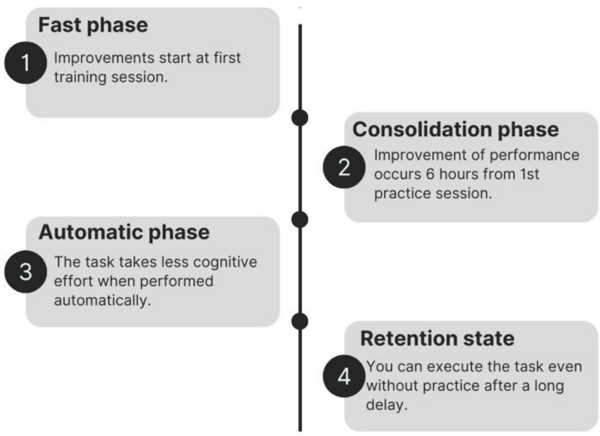
Once the singer reaches the automatic phase, the execution of the piece would take less effort cognitively. In this instance, the singer will be less likely to devote strong focus to the movements required to sing the piece aptly. We can anticipate that this phase has a remarkable impact on the singer's creative cognition through its effect on the 3 AAAs. By this phase, the singer has singer experienced the attention behaviour extensively regarding their complex motor task (either that for a specific phonetic target or global singing skills), which may allow them to achieve what is coined by Ladda (2020) as attention gain (p. 11). Attention gain would entail that the singer can sustain attention towards error detection without utilising a heavy cognitive load because the singer has become more adept at processing mismatching information (for example, the singer can process the discrepancies between producing the incorrect phonetic target against the desired phonetic target) and swiftly engage in the behaviour of adaption. Little time is lost confirming whether the error is correct or incorrect because the automatic phase has cemented highly reliable error predictions. The singer no longer must split attention and use increased processing time to anticipate the entire scope of possible errors, as they might in the fast phase. Consequently, the singer can now devote attention to adaptation on a single error, and their expertise expands, owing to the impact of "repeated experiences [which] lead to the creation and updating of likelihood mappings of associations between actions and their respective associated feedback" (Ladda, 2020, p.9).

Retention state

This refers to the phase at which a singer may cite their aria feels 'sung into their voice'. Here the singer can execute the work comfortably despite what Doyon et al. (2005) discusses relating to a long delay between practice and execution of the work (p. 161).

Figure 8:

Motor Learning Phases



Note: Across the motor learning phases, the learner is assimilating and refining their performance in a problem-solving process with the aim of enhancing the configuration of movement to achieve the best outcome.

The Phonetic Lexicon and the Motor Engram Hypothesis

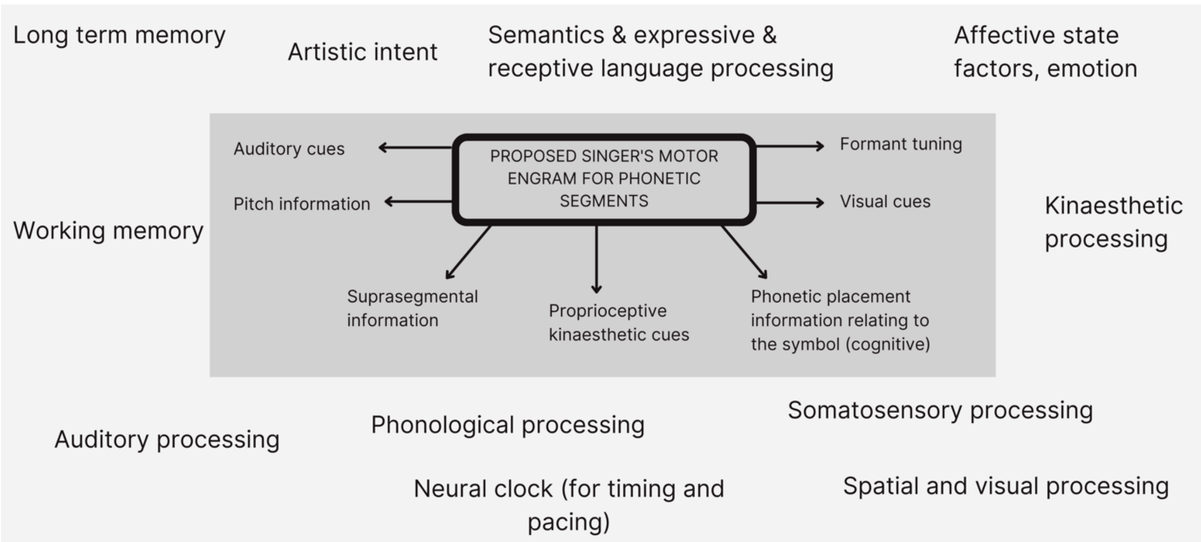
The singer, when engaging in motor learning attempts to solve their artistic and technical problems in the practice context as well as the performance context retains their attempts to enhance each attempt for mastery. This information is processed during the overt act of singing and also retained and integrated for later attempts allowing for the singer to ameliorate their skill by drawing on knowledge of prior outcome attempts which are integrated into a processing system. This process results in a "persistent change in the brain due to [the] specific experience or coding" (Hamano, 2020, p. 27) which is termed an engram. The phonetic lexicon of the opera singer (among other motor skills) is potentially encoded in numerous motor engrams[44] that allow the singer to retain and retrieve the

[44] Where a motor engram refers to "memorised motor patterns used to perform a movement or skill, that are stored in the motor area of the brain" (Kent, 2007). The concept of engrams has been present

complex movements and sequences needed for singing with speed and accuracy. Given that "repetitive training of movement patterns increases their precision, it's thought that the body begins to create engrams of movement patterns {Ladda, 2020 #24, @3}" through the strengthening of synaptic connections which are adjustable online when error correction is needed. Research suggests that these motor engrams for complex and precise sequences are retrieved with speed in trained experts and rely less on working memory and more on a sensori-motor networks. As such forming multimodal sensory associations during the learning of complex movements may be a mechanism for minimising the processing demands during retrieval of the motor engram such that the motor engram results in being dormant when the skill is tightly assimilated and mastered.

Figure 9:

Proposed Motor Engram for Phonetic Tone Tuning



These motor engrams are potentially coded, corrected, optimised and stored in the singer's motor area arising from interconnective processes (see Figure 9) in the singer's studio, rehearsal and performance activities. Possibly, it is in the formation of sensory

since the term was first coined by Semon (1859-1918) however solid proof of the engram in neural imaging studies has proved challenging, although a paper by Josselyn et al. (2015), does provide evidence of both engrams and the control mechanisms that adjust it through a review of recent progress to locate engrams and cite evidence of their presence particularly through the findings of certain rodent studies.

associations that we cement and make possible the complex demands of retrieving a motor engram discussed by Ladda (2020) by way of storing the movement in the sensorimotor loop to lessen the working memory burden (p. 10), leading towards a retention state.

According to Josselyn et al. (2015), motor engrams are marked by 4 traits: persistence, ecphory, content and dormancy. Engrams constitute a persistent change in the brain and are “expressed behaviourally through interactions with retrieval cues, which could be sensory input, ongoing behaviour or voluntary goals” (Josselyn et al., 2015, p.521).[45] Each engram is encoded with detail about past attempts allowing it to assist in outcome prediction and error correction when retrieved and once memory is embedded, the engram may become dormant due to mastery and integration of the skill for the learner.[46]

The formula for classical singing expertise[47] is not easily defined and scientists are yet to research or even completely prove the presence of motor engrams accounting for singing skill and artistry, however the well-known principles of neuroplasticity likely account for the capacity of a singer to harness their cognitive cognition, specifically with reference to the complex neural networks required for phonetic tone tuning mastery and develop into the operatic polyglot.

---

[45] This ability of the learner to produce the behaviours encoded in the engram is thought to be possible through the characteristic of ecphory.

[46] “Repeated multi-sensory exposure enhances the responsiveness of neurons to multi-sensory inputs, which in turn shapes their ability to integrate multi-sensory information” (Schirmer-Mokwa et al., 2015, p.9), which is possibly what accounts for the dormant characteristic of a motor engram once the skills are integrated.

[47] Here, the notion of expertise as defined by Dreyfus (2002) where the expert is immersed in the world of their skilful activity…sees what needs to be done and knows how to do it” (Dreyfus, 2002, p. 4). Dreyfus outlines the progression of expertise from beginner through to expert where 1) the beginner relies on a fixed set of rules to undertake a new task or master a new skill, 2) the advanced learner increases their agility in accessing the rules that need to be applied to master the skill through increased experience in the situations where they have practiced the skills, 3) the expert operates independent of the rules, as the rules are encoded in their performance subconsciously (sub cortically) due to the accumulative extent of engagement in scenarios where the explicit skill was needed. This accounts for why less cortical activity is observed in experts versus amateurs.

The Ten Principles of Neuroplasticity and the Daily Regime of the Western Classical Singer

Neuroplasticity, defined as “the mechanism by which your brain encodes experience and learns new behaviours” (Kleim, 2008, p.225) is embedded in the daily regime of the classical singer, as much as in their longitudinal development through which:

> singing experience enhances the integration of somatosensory information within the speech motor system, perhaps by strengthening salient associations of bodily signals with conscious and non-conscious aspects of expressive language production within a musical framework (Zamorano et al., 2020, p. 1)

The process by which this unfolds is contingent upon ten principles that drive neuroplasticity. These principles will be explored with specific reference to the motor learning requirements of phonetic mastery for the operatic polyglot.

1. Principle One: Use it or Lose it

The brain thrives on loyal learning. Research identifies that if neural circuits are not regularly engaged in a specific task, at length, the skill will as Kleim et al. (2008) postulate, degrade (p. 226). Salient research points to the importance of the sensory modalities to strengthen and retain skills. Deprivation of the visual, tactile, auditory, kinaesthetic or proprioceptive modalities have been shown to result in functional degradation of skills.

The process of singing, either overt or covert (more will be discussed about this in the chapter on deliberate practice) potentially results in the formation of multimodal sensory associations that link back to the complex movements explored by Ladda (2020) required to achieve mastery (p. 11). The working memory of the singer will always be a limiting factor, hence the assimilation of cortical connections with regular practice assists the singer to integrate the complex motor operations to the extent that the expert is able to sing with reduced processing demands in achieving the required behaviours due to the retrieval of a motor engram (p. 10). Possibly, it is in the formation of sensory associations that the singer cements and makes possible the complex demands of retrieving the information required to perform at an elite level. The frequent reproduction of a sung action that links to an outcome and feedback, results in "action feedback associations with very low predictive error" (Ladda, 2020, p. 10)[48] over time and may indeed contribute to storage of the movement by a sensorimotor loop[49] to overcome the working memory burden of the information such that the expert singer can perform with fully integrated and accurate phonetic tone tuning.

- An example of this process could be the act of the singer manoeuvring the vocal tract, muscles, and articulators to sing a top C (C6) on an /a:/ vowel in pianissimo, after years of practice where there is likely to be a low predictive error, with high reproducibility due to the automatisation of complex learned motor patterns and the singer's development of a possible preset as a result of repetitive practice.
- Another example might be the singer's command of Russian diction and ability to phonetically tune their Russian repertoire due to extensive practice and performance of the complex mechanical manoeuvres needed for proficient application of the Russian phonetic inventory such that it is embedded with precision when singing all Russian works.
- Another example might be the successful integration of a novel sound absent in mother tongue that was challenging for the singer to initially achieve across the repertoire that required it. For example, an English native singer with the tendency to aspirate a "t" in place of the required Italian /t̪/ in its laminal-denti alveolar location consistently in all repertoire with increased practice and use of the target.

Based on this principle, if the singer is to progress their expertise and phonetic tone tuning competency, this skill needs to be trained loyally and embedded strategically into the daily singing regime.

2. Use it and improve it

It's been shown that "training that drives a specific brain function can lead to an enhancement of that function" (Kleim, et al., 2008, p. 227). The neural correlates for singing

---

[48] Or high reproducibility, where the singer's attempt is likely to be secure and replicable at a high accuracy rate.
[49] In fact, the more singers practice, the more activity found in the somatosensory association cortex (Kleber, et al., 2013).

are not yet totalised however there is evidence of heightened cortical activity in various regions of the brain, unique to expert singers coupled with enhanced skill[50] comparative to amateur singers. Kleber et al. 2010 found that:

> vocal skills training correlates with increased activity of a cortical network for enhanced kinaesthetic motor control and sensorimotor guidance together with increased involvement of implicit motor memory areas at the subcortical and cerebellar level (Kleber et al., 2010 p. 1144).

If this is the case, it is fruitful to consider practice techniques that are informed by motor learning that specifically relate to the mastery of phonetic proficiency as much as other aspects of creative cognition required in expert level singers.

3. Specificity

Training in a specific modality is thought to increase the neural activity in the region that correlates to that modality, such that the neural circuitry of a professional singer will be vastly different from an amateur, untrained singer. It's considered that each modality will align to a specific cortical network activation, such that over generalisation is unlikely. Evidence of this is found in brain lesion studies that show rehabilitation of skills relates directly to the target trained. For example, if a participant swallow mechanism is impaired, specific therapy measures for swallow enhancement when deployed will not result in improvement to voice production (Huang, Carr, & Can as cited in Kleim et al., 2008, p. 227) since neurogenesis is specific to the skill.

This justifies the due diligence needed in the practice studio and singing pedagogy towards explicit training and deliberate practice of the skills needed for phonetic tone tuning and the operatic polyglot and suggests scope for future research into methods that enhance these proficiencies with correlation to the neuromotor pathway enhancements. Kleber et al. (2010) commented on this "use-dependent plasticity of the vocal system (Kleber, et al., 2010

[50] Musicians have been found to tap synchronised rhythms at faster rates than non-musicians (Repp, 2003); singers have been found to be more attune to their heart beats than string musicians, possibly since singers use "more body-core centred and visceral nature of music production involving organs and muscles of vital importance" (Schwirmer-Mokwa et al., 2015, p. 2).

p. 1144) and found evidence of "increased functional activation of the bilateral somatosensory cortex, representing articulators and the larynx" (Kleber, et al., 2010 p. 1144) when conducting a neuroimaging experiment on opera singers.

Consideration of the areas showing increased functional activation may be a clue to methods in the practice studio that accelerate vocal development. The Kleber et al. (2010) study revealed that classical singing involves increased firing of the neural regions associated with "kinaesthetic information processing from the larynx and articulators" as well as "the cortical regions related to the somatosensory guidance of motor activity and subcortical memory areas" (Kleber et al., 2010, pp. 1147-48). If this is the case and given that singers do not seem to benefit from auditory input so much as somatosensory input as observed in other studies training a phonetic model for pronunciation accuracy that is informed by kinesthetics is supported. The virtue of a kinesthetic model is that it could alert the singer to the physical architecture of the vocal tract as well as sensory profile information. Singers might do well to tap into cognitive processing measures (in their practice regime) that amplify awareness of body-sense feedback overtly when it comes to phonetic tone tuning.

Indeed Kleber et al. (2010) proposed at the end of their research paper that "increased attention on kinaesthetic perception may not only be relevant for the development of fine motor skills in general, but could be particularly beneficial for the optimisation of implicitly learned motor programs" (Kleber et al., p. 1151), suggestive of experience-dependent changes which will be discussed further on the chapter on deliberate practice.

4. Repetition matters

Repeating newly learned behaviour is likely to consolidate lasting neural adaption[51], a principle known too well to singers and performers. Guillot & Collet (2005), propose that the repetitive training of movement patterns increases their precision specifically with reference

[51] This theory was proposed first by Donald Hebb in 1949 in the publication *The Organisation of Human Behaviour* where he proposed that when the brain is exposed to learn learning, neurone start to form a neural network that strengthens with repeated stimulus (via repetition of the activity) creating stronger connections and resulting in more intuitive actions (Hebb, 1949).

to the timing needed to achieve the movement sequence and that over time, the individual can anticipate the timing with high accuracy when producing the overt movement or simply imagining it. Ladda et al. (2020) discuss how the coordination of rhythm and sequencing is thought to be instated and automated in childhood development through the spinal and brainstem processes however the coarticulatory and sequential nature of singing depends on a complex sequencing system that is built around somatosensory integration which is believed to be trained by repeated coupling of motor output and sensory input (p. 3). This repetition of sensory input is not solely auditory as one might assume, but seems to be enhanced by tactile, kinaesthetic, proprioceptive, visual and vestibular input alongside cognitions. More will be discussed about how the practice space can be informed with increased sensory richness to build neural networks particularly with reference to repetitive training strategies for enhanced phonetic accuracy in the chapter dedicated to deliberate practice.

5. Intensity matters

The concentration and volume of training and novel skill acquisition impacts on the neural firing of the skills and overtraining of a skill is thought to reduce progress, particularly at the early acquisition of the skill. This is supported by research discussed by Kleim & Jones (2008) around rehabilitation for individuals who have loss of language (aphasia) or motor movement due to brain damage (p. 227). Given that singing lyrics/ libretto involves an overlap between complex motor manoeuvres and language processing, more research into practice intensity measures that ameliorate or deteriorate skills is needed especially with reference to the neurological and motor controls for phonetic and linguistic processing in opera singers.

6. Time matters

Reference has already been made to the time-based impact of latency in consolidating learning in the previous chapter and while the development of expert musicianship and artistry is longitudinal[52]. Ericsson et al. (1993) review showed the in their seminal article, *The role of deliberate practice in the acquisition of expert performance*, the competitive advantage of increased practice over time on elite violinists noting a separation in practice duration both longituditionally and accumulatively, where those that spent more time practicing had competitive edge. Interestingly it appeared that the time of practice and duration of practice mattered with the best group of violinists practicing before lunch and engaging in longer practice sessions than the so-called good group (Ericsson et al., 1993, p. 375). More research is needed into the practice regime of classical singers, particularly with how much time is dedicated across modalities needed for skills acquisition (assimilating new learning, reviewing and rehearsing consolidated repertoire, intonation tuning, memorisation of lyrics/libretti). Of particular note is the resource restraint around time; although the vocal folds are "designed for fast and variable contraction as well as fatigue resistance (Kleber et al., 2010, p. 1144), the muscle will incur fatigue in the form of inflammation with poor technique or overuse which opens discussion for more insight into strategies for the singer to consolidate their learning that can be incorporated into their daily practice routine when their ergonomic load has been met. Not a lot is known about what singers do in their music related activities outside of overt singing and this is an excellent space of time to expand practice scope particularly with reference to the acquisition of improved phonetic and linguistic skills through deliberate practice methods informed by motor learning and study approaches informed by research into second language acquisition and training for elite performance, more of which will be discussed in the chapter on deliberate practice.

7. Salience matters

It's thought that factors around sufficient motivation and attention to a meaningful outcome are key requirements to the acquisition and refinement of skills. "The ability to perceive and integrate salient (intero- and exteroceptive) sensory information therefore plays an indispensable role in sensorimotor control, emotions and cognition" (Schirmer-

[52] After Ericsson's (1993) paper, many suggest the 10-year rule as the key factor underpinning domain-specific expertise and superior performance (p. 363).

Mokwa et al., 2015, p.10). Given the variance between the degrees of temporal precision required for singing versus speech, it is important to consider drilling pronunciation goals within the sung context, preferably at tempi to ensure the parameters of both specificity and salience are met. Integrating phonetic information alongside pitch, rhythm, melodic and semantic information holistically in the practice studio is more likely to promote the acquisition of the phonetic goals for the singer than working the text in isolation at speech level. It's been suggested by Schirmer-Mokwa (2015) that heightened attention to the body can be achieved by integrating self-relevant external cues such as visual and or acoustic cues (p. 2).

Aspects to boost the salience of sung targets with reference to phonetic tone tuning could include:

1. Producing the phonetic target accurately alongside temporal precision.
2. Producing the phonetic target accurately alongside tonal precision.
3. Producing the phonetic target accurately alongside artistic intent (character building, stylistic factors).
4. Producing the phonetic target accurately with communicative intent (semantics, prosody, non-verbal cues).
5. Integrating all the above.

Further if singers see the equal importance of text accuracy alongside the musical and rhythmic intention of the notation, this goal for phonetic integrity is likely to be more salient (refer to Figure 2) and thus fulfil the key principle of the *Florentine Camerata* who were thought to be primarily "interested in communicating more 'effectively'" (Katz, 1984, p. 363)[53] If the act of singing is emphasised as a means of communication, the singer is also more likely to activate salience and cortical regions that animate the emotions. Studies show that "emotions modulate the strength of memory consolidation" (Kleim, et al., 2008, p. 231)

53 Where the Camerata sought to "discover the ideal combination of words and music such that text and music, each in its own way and in juxtaposition to the other, could be maximally effective in communicating not just sensory pleasure, vaguely defined, but the specific meanings and emotions appropriate to the text" (Katz, 1984, p. 367).

and possibly this is a key reason for why singers show increased connectivity of the right anterior insula, a region known to be responsible for emotions and but also thought to be the only area in the brain that integrates what is heard and felt (Kleber, 2013) when professional singers sing. Strigo and Craig (2016) discusses how this particular region is thought to be responsible for emotional regulation and Zamorano et al. (2020) explore how it is also plausible to be the location site where:

> singing experience enhances the integration of somatosensory information within the speech motor system, perhaps by strengthening salient associations of bodily signals with conscious and non-conscious aspects of expressive language production within a musical framework (Zamorano, et al., 2020, p. 1}.[54]

8. Age matters

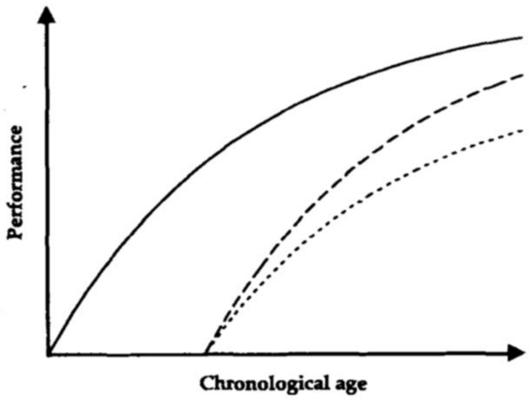
Early commencement of musical training in musicians[55] has been shown to correlate to increased adaptive changes in the brain as well as enhanced performance prowess (see Figure 10).

[54] Research into the communicative process of singing that contrasts meaningful sung text against text that the singer sees as sound segments without meaning would be interesting to see whether there are different neural correlates or indeed performance enhancements when a singer sings with emphasis on sound over meaning, a situation that is likely to occur if the singer does not understand the language sung and has not made an effort to translate the lyrics or libretto.

[55] Commencement of musical training before the age of 7 years correlated with improved success, see Ericsson et al. (1993).

Figure 10:

Performance Skill against Chronological Age



Three schematic relations between chronological age and performance. The solid line shows the performance associate with an early starting age and a high level of practice. The line with long dashes shows performance for an equally high level of practice but with a later starting age. Finally, the dotted line shows the performance associated with the same late starting age and a lower level of practice. (Ericsson et al., 1993, p. 387).

Western classical singers tend to come late to their field comparative to classical instrumentalists and while they build specific skills which optimise an already developed speech motor system, they have not had early access in most cases to the phonological systems of the languages they are required to perform in. More research is needed into the aspects which enhance the linguistic development of the western classical singer[56].

[56] It would be interesting to learn whether there are performance gains in singer's that start their training as multi-linguals versus monolingual singers and whether polyglot singers show enhanced skill in acoustic features of classical singing beyond the phonetic accuracy (such as singer's formant, technical skill) and neurological variance (is there reduced activation of certain cortical areas due to the automatisation of more language systems). Studies that contrast native singers singing in their first language against non-native singers would also be revealing in terms of whether factors like increased cognitive effort as reported by study participants as well as physiological correlates for increased vocal effort can be observed between singers in L1 versus L2.

9. Transference

One of the largest challenges for the Western Classical singer is potentially the ability to transfer the learned skills of singing from the practice studio to real-life performance settings with high level accuracy. Transference capacity is likely to be informed by the degree of specificity, salience and intensity of the musician's deliberate practice, but is also subject to other variables such as singer mindset on stage and possible musical performance anxiety. The singer needs to be able to find the balance between the conscious, problem solving nature of deliberate practice and the expressive and communicative nature of musical performance where it is vital that the "psychological vulnerability to experience negative emotions and a shift toward a self-evaluative focus" (Schirmer-Mokwa et al., 2015, p. 2) is avoided.[57]

10. Interference

The principle of interference is always a risk factor in the acquisition of new skills. Kleim et al. (2008) reference how this makes way for the capacity of other plasticity within the same neural circuit impeding the acquisition of the new target (p. 233). An example of interference reducing the integrity and accuracy of phonetic tone tuning in a performance on stage could be where a singer has integrated maladaptive practice techniques to support pronunciation accuracy at the expense of vocal quality or indeed vocal health. This might be any aspect that accounts for why some singers anecdotally can cite preference for one language over another and may report vocal discomfort with reference to one language against another. More studies are needed on deleterious factors which could impede singing comfort, performance success and creative cognition on stage with reference to the principle of interference globally on the singer.

[57] More research is needed into how singers self-rate and view their performance skill with reference to integrity of text, expression and pronunciation accuracy to see whether there are aspects that are impacting transference of the skill from the studio to the stage. Research in this area could provide further support to deliberate practice methods to build creative cognition in the practice studio that supports the transference of linguistic skills to the stage.

Given the visceral, full body enactment of the act of singing, it seems vital that any consideration of how the singer can refine their command of mechanical manoeuvres that inform the phonetic tone tuning of their creative expression considers the principles of how complex motor movements occur and what fuels the neuroplastic habitat for singer development. More qualitative and quantitative research is needed into the creative cognition of Western classical singers however the research that exists to date from neuropsychology and neuroscience is enlightening and has many implications on the parameters of deliberate practice. The next chapter will explore methods and approaches that could be trialled in the classical singer's studio that are informed by theories of motor learning and the principles of neuroplasticity.

Chapter 4: Deliberate Practice and Practice Studio Resources to boost Creative Cognition in the Operatic Polyglot

The role of Deliberate practice in developing creative cognition for the operatic polyglot

Ericsson et al. (1993), in their seminal work "The role of deliberate practice in the acquisition of expert performance," outlined the importance of practice hour accumulation in skills mastery and expert performance, suggesting the ten-year rule as a defining feature in most masters of their art form in which "deliberate effort" (Ericsson et al., 1993 p. 266) over time is paramount to attaining exceptional performance. Ericsson et al. allude to the principle of salience in the pursuit of neuroplastic advancement. If the target of deliberate practice is enhanced performance skill, "detailed analyses of the musician's activities during practice sessions in music reveal careful monitoring and problem solving by musicians to attain the desired improvements (p. 369).

Since deliberate practise has good outcomes for an expert's superior performance over an amateur, the classical singer must understand that highly structured activities with specific tasks invented to overcome weaknesses are incorporated early to achieve the incremental build-up of skill. Therefore, deliberate practice should not just focus on voice building and learning the repertoire musically, but careful and effortful attention to monitor and problem solve aspects of the phonetic proficiency required for the operatic polyglot.

If the goal of deliberate practice is not “doing more of the same” (Ericsson, 1993, pp. 390- 391), singers must have an arsenal of variable approaches to enable them to fully concentrate on targeted activities to improve their performance within the domain of phonetics as much as other modalities required for their creative cognition. Practice is made deliberate when it is grounded in the ten principles of neuroplasticity.

Since:

> expert pianists prepare a piece for public performance, they spend considerable time determining how to hit the keys with different fingers and thereby minimise such constraints on movement (Ericsson et al., 1993, p. 397)

why should singers not do the same given that the phonetic shaping of the sounds sung will have different movement parameters? What follows are some suggestions on how singers can practice motor precision and sharpen their creative cognition, specifically in the domain of pronunciation, using research-informed practice theories that enhance neuroplasticity, sensorimotor processing, and skill development.

Body Matrix Theory, Flow and Multimodal processing benefits for eminent performance

Most singers in the act of deliberate practice aim to achieve Csikszentmihayli's notion of flow as best as possible. Although flow may sometimes allude them, since "the pursuit of a creative problem is rarely easy” (Csikszentmihalyi, 1996, p. 117). Csikszentmihayli identified that:

> the creative person needs to have a great many personality traits that are conducive to discovery and hard work, including the ability to internalise the rules of the domain and the judgements of the field (Csikszentmihalyi, 1996, pp. 117-118)

Flow is achieved when the "challenges are just right, and the creative process begins to hum, and all other concerns are temporarily shelved in the deep involvement with the activity”

(Csikszentmihalyi, 1996 pp. 117-118.) Csikszentmihayli (1996) references the creative act for the creator as often having an autotelic nature (p. 121), where the process of creation is the purpose in and not apart from itself, which can be described as the pursuit of the art form itself, a process that many singers no doubt report in the practice studio where the act of creative problem solving is undertaken in absence of an audience but may still, be no doubt, highly engaging and enjoyable when the singer experiences smooth integration of the body matrix.

The conceptualisation of the body matrix mode[58] contributes to the sense of flow, accounting for how creative cognition processes (both cortical and subcortical) allow the singer to "model and predict incoming sensory input to minimise the average of surprise[59] across the different body representations" (Riva, 2018, p 251). During early development in infancy, most spinal and brainstem processes that regulate homeostasis are entirely automated- resulting in the narrative of the sentient body described by the body matrix, a subcortical representation. In contrast, other skills relating to "movement coordination and sensorimotor interaction are tracked by repetitive training" (Ladda et al., 2020, p. 3. It is in this repetitive training of motor patterns that precision, accuracy and speed are enhanced. Motor expertise is potentially grounded in the number of body representations evoked during the simulated action, which in turn "strengthens the neural pathways and creates tighter integration between actions and their associated feedback and outcomes" (Ladda et al., 2020, p. 9) known as predictive error. Research points to the benefits of multi-modal learning for neuroplasticity, particularly regarding musicians. Since Schwirmer- Mokwa et al. (2015) conclude that:

[58] Although still a hypothetical model requiring more research, the body matrix appears to be the most apt approach to conceptualise and reconcile the cognitive, affective and sensory processes that fire neurologically to achieve elite level classical singing.

[59] The element of surprise could be seen as error risk, where an anticipated or desired artistic outcome was not achieved. Friston & Stephan (2007) explore how error causes higher free energy, a state that all biological systems are thought to evade, since lower free energy states are important for survival in which systems "minimise free-energy by changing its [sic] configuration to change the way it samples the environment, or to change its expectations" (Friston & Stephan, 2007, p. 417).

> repeated multisensory exposure enhances the responsiveness of neurons to multisensory inputs, which in turn shapes their ability to integrate multisensory information (Schirmer-Mokwa et al., 2015, p. 9),

it is fruitful to consider practice studio methods that expand the singer's engagement with multisensory information. Such considerations might enhance the singer's command of phonetic tone tuning as well as other artistic skill development. This approach is pedagogically sound in that the singing of classical music, in contrast to instrumental music:

> requires more body-core centred motor and anatomic activity involving muscles and internal organs of vital bodily performance such as respiration, salivation, ingestion, speech and social communication, while string instruments and piano playing, investigated in most brain imaging experiments involves fine control of peripheral muscle groups (Kleber et al., 2007, p. 890).

Such notions support the body matrix model as a suitable framework for considering enhanced multi-modal systems in the practice studio.

Given the findings that singers and musicians demonstrate higher levels of interoceptive firing than non-musicians alongside the rising field of interoceptive feedback through "sonoception, i.e., the use of sound and vibration to modify inner body signals- and body illusion techniques" (Riva, 2018, p. 352) there is potentially scope for a massive expansion of practice tools for the singer's studio as well as the application of more technology like augmented reality.

Auditory feedback and phonetic tone tuning

Mürbe et al. (2004) found that masked noise while singing leads to intonation accuracy gains which may suggest that a reliance on auditory input for phonetic tone tuning accuracy may not be strongly indicated. Professional singers in the Muerbe et al (2004) study were found to elicit accurate pitch targets during slow and fast singing targets, and even showed minimal changes in vocal accuracy with masked auditory feedback. Since this study suggests the likelihood of pitch memory being encoded at a neuromuscular level, it's likely that other sound based information relating to phonetic tone tuning for singers takes a similar route. Masking auditory input may create advanced phonetic tone tuning gains for the singer on stage if applied in their practice studio since the Western classical singer will at times need to perform on stage and may not always hear themselves. Zarate (2013), expands on this notion and asserts that:

> auditory training alone (at least in an experimental setting) is not sufficient to improve vocal performance or recruit the experience-dependent network for auditory-motor control of singing; perhaps only simultaneous enhancements in both auditory and vocal motor skills via extensive training would bring forth improvements in vocal performance and engage this particular network (Zarate et al., 2013, p. 5).

Simultanous enhancements would need to be arranged so that singer practices their repertoire with explicit consideration of phonetic tone tuning criteria using devices that don't rely on receiving the sound signal as feedback to allow communication with the neural pathways that result in higher levels of sound accuracy. Sound signal feedback could be replaced with potentially advantageous devices contingent on visual, tactile, kinaesthetic and proprioceptive cues, as mentioned in this chapter so far. Given that the articulatory muscles are integrated into fulfilment of complex motor manoeuvres through an extensive network of somatosensory receptors shaping the vocal tract postures that determine consonant, vowel and formant properties (see also Sundberg, 1975; Sundberg, 1975; Kleber et al., 2007; Kleber et al., 2010 and Kleber et al., 2013) the auditory feedback pathway may not need to take centre stage as the moderator of error correction and fine tuning. It may seem ironic that what follows is suggestions of techniques that don't pivot around auditory input for the singer to enhance their sound accuracy in the process of the phonetic tone tuning required to become an operatic polyglot, but rather follow the significant research-based indicators for the need to pay attention to details in addition from auditory cues and feedback loops due to the neural correlates of singing.

Intensity and Process

In solving phonetic tone tuning and integrating sensorimotor-based learning in the practice studio, the singer might do well to consider the intensity and goal of the practice procedure. Hamano et al. (2020) propose that the inclusion of speed pressure versus an emphasis on accuracy will result in different practice effects in their fMRI study of participants engaged in sequential finger-tapping tasks using their non-dominant hands. They found that "speed pressure can enhance the learning process" (Hamano et al., 2020 p. 27) and once removed, the learner will then start to refine their learning of a sequence which tends to emphasise accuracy with different neural correlates for both outcomes.[60] Measuring the neural correlates for skilled singing is difficult due to the principle of dormancy once a complex motor system is trained. Therefore, more studies are needed that consider aspects of neurogenesis and new learning engrams for untrained skills similar to persistent skills in musicians to gain more insight into the creative cognition of elite singers.

Autoethnomethodology and Practice Related Research

One approach that can enrich multi-model practice and reinforcement of new learning is for the singer to consider integrating practice related research.

> We create art to connect with others, to connect with ourselves, and often just for the sake of it. We experiment with our art to push boundaries, ask questions and learn more about our art form and our role within it. This is nothing new. What emerges, then, from this methodology is the exegesis that accompanies the creative work: that knowledge that has remained implicitly within the artist, made explicit and seated within the context of the scholarly field (Skains, 2018, p.86).

Music is confined to a temporal moment and vocal motor activity in particular is "routinely performed at a faster discrete rate than any other human behaviour" (Kleber, et

[60] Hamano et al. (2020) hypothesised that speed execution engrams appeared to be represented through increased activation in the left anterior intraparietal sulcus and sequential movement engrams with increased firing noted in the bilateral premotor cortex and right primary motor cortex during the learning of tapping task with fingers of the non-dominant hand.

al., 2010, p. 1145), such that deep exegesis after the act of over singing particularly with reference to phonetic tone tuning, can be challenging due to the working memory limitations and dual processing demands of singing. The method of autoethnomethodology in which the artist pursues art as research is a salient learning approach for the operatic polyglot, given the temporal nature of singing practice and performance. Autoethnomethodology is a research process that involves self-directed ethnomethodology, a term first coined by American anthropologist, Harold Garfinkel in his work Studies in Ethnomethodology (1967). Garfinkel defined the term as "the investigation of the rational properties of indexical expressions and other practical actions as contingent ongoing accomplishments of organised artful practices of everyday life" (Garfinkel, 1967, p.11). The approach of autoethnomethodology could be used in the singer's practice studio while in situ or reflectively while planning and evaluating concepts of phonetic tone tuning and delivers learning scope by enabling "insights into art and the practice of art as it occurs, but can throw new and unexpected light onto a range of topics including cognition, discourse, psychology, history, culture, and sociology" (Skains, 2018, p. 84).

One method of conceptual analysis that reduces the risk of memory accuracy on the temporality of art is the use of creative analytical processes (CAP). CAP is a term first introduced by Skains (2018) where the artistic process and analysis is fused.[61] This process can be undertaken through a variety of tools resulting in a methodology that can ensure that the singer maintains attention to the vital components necessary of their art while reinforcing the multi-modal representation of their instrument, their body, considering aspects of the body matrix. The following provides some ideas of means by which the singer could activate the process of autoethnomethodology to harness their creative cognition while working on their repertoire.

---

[61] Skains introduces a Practitioner Model for creative cognition to provide a framework for developing research questions relating to the practice of the art form in question. His interest:

> lies in the interior landscape for the creative mind: where do ideas emerge, how does the imagined work translate into the final artefact, how do the artist's thoughts and experiences shape the creative work and more? (Skains, 2018, pp. 88-89}.

Using a research log to scale as an operatic polyglot

The singer can integrate a research log into their daily practice regime to note insights, processes and difficulties with reference to phonetic tone tuning, thus taking an autoethnomethodological approach. This log might serve as a tight measure of deliberate practice and could assist the singer to problem solve and reduce error prediction in enhancing their phonetic tone tuning using a variety of activities and devices. This log could consider aspects of the multi-prismic properties of the singer's syllable, accuracy drill tracking and notes for the observation and self-evaluation of singing targets. What follows is a set of suggested tasks that can be completed in situ through the singer's research log or reflectively outside of the overt singing session.

Enhancing Visual Processing in the Practice Studio

Mirror Work and Video evaluation of Phonetic Tone Tuning

Various phonemes have aspects that can be observed visually on the face which allows the singer to analyse the visual features of the singing process and phonetic tone tuning. While not all sounds can be seen (glottal sounds, retroflex sounds and certain vowels may be hard to differentiate through observing the face and lip and jaw positioning), the singer can activate the modality of visual processing by online feedback (checking mouth positions and postures in the mirror while in the act of singing) or post singing appraisal (examining facial cues and posture in video recordings after the act of singing).

Aspects such as lip rounding, spreading, opening and frontal articulator contact (tongue, front teeth, lip sealing, lip obstruction) can all be observed through this process. The singer can also contrast their visual placement against recordings of singers of their fach who are native speakers or seen as proficient in the phonetic accuracy of the sung language to observe contrasts and differences. Facial structures are individual, and no singer will valve in the same manner but various general observations can be made regarding the mouth positions used. Further, observing the visual cues made could be enhanced by screen captures of video footage or drawing the shaping of the visible articulation process to heighten sensory cues of a visual nature with reference to the singer's sound targets particularly on vowel opening and tongue position. Once the singer compiles some visual references of what their mouth, jaw and lips actually do across their range, they can start to correlate other aspects of phonetic tone tuning according to the multi-prismic properties of the singer's syllable and test hypotheses and make some deductions about what benefits their artistry (timbre, tone, semantic expression, articulatory integrity and other factors can be considered).

Visual cues

Visual cues may be facilitative for error correction where a phoneme is visible via the movement sequences required to articulate the sound (for example, monitoring lip shaping on a close-mid back vowel /o/ to prevent it opening too far into an open /ɒ/). The use of visual cues is an established approach in the pedagogy of classical singing with many gold standard manuals including diagrams and descriptions of the vocal tract spaces (see Vennard, 1968, Garcia), however in this suggested process the singer will use their own visual feedback to develop improved visual cues.

Undertaking visual analysis by watching a video or use of mirror may assist with the development of individualised visual cues that are personally relevant for the singer, as well as enable to singer to monitor overcompensations of the articulators (for example, chin displacement to the left or right suggestive of asymmetry +/- tension at the jaw in the singer's attempt to correct a native vowel to move closer to a non-native target or due to vowel tuning adjustments in different pitch regions).

Through this studio practice approach, the singer may begin to create hypotheses and test their outcomes by correlating facially visible factors like jaw opening, lip shaping and tongue placement with desired or ill-matched outcomes.

Visual cues may also be fruitful to examine aspects of increased facial effort due to increased concentration on phonetic correction (brow furrowing, stern gaze), which may work counter to artistic intent and the effective communication of the lyrics, text and/or character's emotional considerations.

Visual imitation approaches

Visual imitation may be an option to further reinforce further the development and differentiation of the phonetic placement features of the visible features of unique sounds and placement features of the target operatic languages through careful observation of native language singers. In this instance, the singer may observe video footage of a proficient singer performing their repertoire in the target language. By focusing visual observation deliberately on the mouth cavity shapes of the singer they are observing (either live or by video footage) with the key intent to monitor valving of the visible aspects of vowels and consonants, the singer may potentially prime their own performance and reap some motoric enhancements.[62] This capacity might be put down to the process of mirror neurons which are thought to function with a relationship between visual and motor properties and suggests that visual imagery strategies as much as motor strategies may be equally complementary and vital to learning methods that have an imitative basis for the classical singer. Mirror neurons are thought to assist the viewer to mediate imitation and appear to be the "system that transforms visual information into knowledge" (Rizzolatti & Craighero, 2004, p. 172), and are thus responsible for action understanding. In psychology studies, it has been suggested that:

> when observers see a motor event that shares features with a similar motor event present in their motor repertoire, they are primed to repeat it. The greater the similarity between the observed event and the motor event, the stronger the priming is (Rizzolatti and Craighero, 2004, p. 180.

Hence observational activity may increase and enhance the singer's accuracy in a practice trial thereafter, however more research on the efficacy of action observation and visual

---

[62] In trialling this approach, the singer should be mindful of the biological variations of their own instrument as well as their singing each and stylistic individuality, so critical for artistry.

imitation methods as a device for singing artistry and in particular, phonetic tone tuning, is required.

Paced timing drills for speed enhancement versus sequential drills to strengthen coarticulation of phonetic targets

Given that researchers found the development of alternate motor engrams in speed pressure tasks versus accuracy focused tasks, the phonetic tone tuning would benefit from the implementation of both approaches to strengthen the motor circuit and reduce predictive error. Along with Zatorre et al (2007), this thesis has established that timing precision is vital in music in situ and, unlike speech (which has no beat to adhere to) so the singer needs to align their phonetic tone tuning parameters across a time based system in order to have the necessary error correction mechanisms at their disposal online in performance (p. 551).

Paced Timing Drills

Paced timing drills can be used whereby the singer adapts the speeds by which they drill phonetic phrases in overt singing using a metronome to accelerate the tempo of the phrase inducing time pressure while ensuring that all correlates of phonetic tone tuning are achieved. If there is a noted breakdown or disconnect between the planned outcome and the target, the singer can step down the difficulty level by reducing the drill back to the syllable level or short syllable set level or alternative reduce the speed of the drill in increments until accuracy is achieved. In this process the singer needs to consider the metric principles of phonetic tone tuning paying particular attention to achieving the multi-prismic properties of the singer's syllable with correct onset timing, sustained duration and offset timing which could be mapped prior by the singer in mental practice and then overtly sung and modified using speed pacing.

Graded timed drills could also be used to induce time-based pressure in order to enhance the phonetic tone tuning skill and learning in order to emphasise a higher level of predictive timing vital for agile performance accuracy.

Sequential drills

Sequential drills to strengthen coarticulation should also be considered where the singer adapts their overt singing into tracking the sequences in the motor movements and phonetic placement targets at the varying syllable levels. This approach may be best informed by mental planning of the sequential movements using the multi-prismic properties of the singer's syllable alongside detailed mapping of the syllable properties building up to phrase level. Such drills can slow the tempo of the extract that is rehearsed for phonetic tone tuning but should still maintain the integrity of the rhythmic properties of each syllable's components to benefit transfer accuracy once the singer sings the extract at the required tempo.

Soundwave analysis and computer assisted pronunciation devices

Visual processing and sound accuracy can also be stimulated by analysing the visual features of the waveform using computer assisted pronunciation devices and recording software. Such a method at present would be best suited to spoken rehearsal of text and libretto passages since accompaniments and sung phonation will alter the waveform properties making it challenging to view necessary segmental information. While the ability to read a spectrogram or analyse a soundwave form for its vibrational properties is an acquired skill, the capacity of the singer to examine concrete insights from a sound wave can be facilitative in building their knowledge of the phonetic properties required for target sound segments at phoneme, syllable and phrase level. Computer assisted pronunciation to evaluate the segmental and suprasegmental features of sound is a growing practice in pronunciation instruction for non-native speakers. Many interfaces. such as *Audacity* and the *Mouton Interactive Introduction to Phonetics and Phonology Softwar*e, can be used in this process and may be effective in improving pronunciation accuracy. A study conducted by Benitez-Correa et al (2020) investigated whether non-native students of English improved their pronunciation of simple past tense English verbs (a skill that is very challenging for most non-native Spanish speakers due to the phonetic requirements of voicing of /d/ in word final position and aspiration of /t/ in word final position as well as syllable additions paired with the non-phonetic nature of the English spelling system). The study found that gains were made when students appraised their pronunciation attempts using sound wave analysis.

Use of such software in the music practice context could enables the classical singer to reference a visual representation of the physical properties of the soundwave in terms of sound pressure levels, voicing onset and offset and peak prominence to differentiate between their native speech patterns and attempts to produce the phonemes of non-native languages (example of /t/ English vs /t/ Italian). This approach would benefit from visual input and comparison from a native speaker of the target language so that the singer can view a reference point and the desired waveform properties of their pronunciation targets.

Figure 11:

Audacity Sample of English versus an Italian Pronunciation Attempt attempt in a passage from Caro Nome from Guiseppe Verdi's opera Rigoletto (Verdi, 1851)

Figure 12*:*

Audacity Sample of English Versus an Italian Pronunciation Attempt in a Passage from Caro Nome from Giuseppe Verdi's Opera Rigoletto (Verdi, 1851)

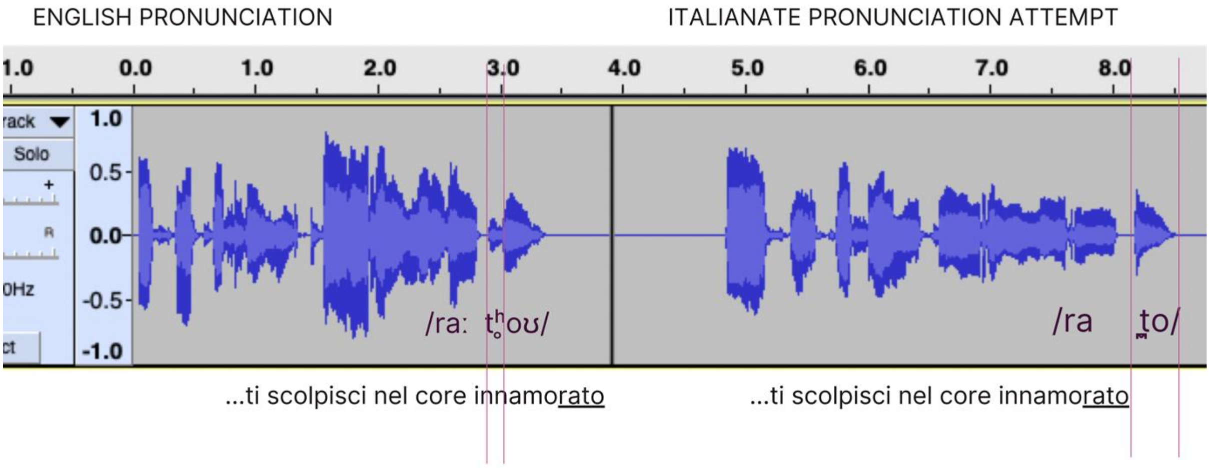


Figure 11 shows the variation in the phoneme segment and the differentiation between English pronunciation of two syllables versus the pronunciation of two syllables with an Italian attempt in speaking a short excerpt from *Caro Nome* from Guiseppe Verdi's Rigoletto (Verdi, 1851). Diacritic transcription is included. From this visual the singer can observe that pronouncing the English /t/ sound on the segments "-rato" will result in increased peak prominence on an English /t/ against the vowel in contrast to the Italianate target "t" which contains voicing, a dental contact (rather than alveolar contact which merges with the vowel and shows no prominence. There is also a visual difference between the incorrect use of English diphthong /oʊ/ against the cardinal /o/ required for Italian.

The singer can make various observations regarding the following concrete properties of the singer's syllable with this method including:

- peak prominence of consonants against vowels (reduced peak prominence will facilitate closer linking of the consonant with the vowel resulting in reduced bandwidth contrast across the segment)

- voicing onset and offset
- devoicing
- segment features relative to the phoneme segment, and,
- effectively create a baseline to test against alternate attempts in refining their target

Singers can also deploy a large arsenal of tools and interfaces to measure and evaluate their output through the use of spectrograms and soundwave recording feedback. This paper does not intend to elaborate on the devices and software available to receive bio-feedback and visual feedback on features like sound pressure level, vowel formants and other acoustic parameters however interested readers can find a significant body of exploration on the use of software in acoustic vocal pedagogy and psychoacoustics as found in the work of Ian Howell (Howell, 2016) and Kenneth Wood Bozeman (Bozeman, 2021).

Likewise visual prosody and suprasegmental features can also be tracked through waveform data that reveals peaks sound pressure levels, voicing onset and offset and rhythmic properties such that the singer can receive online feedback of various vocal and notational requirements like staccato, declamation, sprechstimme and legato line phrasing, each of which will show differing properties in the soundwave data in terms of their form but possibly also varying features relative to the phonetic requirements of the language of the song text or libretto. More acoustic, physiological and neural based research is needed into the soundwave properties of these vocal artistry features according to the languages (and possibly even vocal facts) that they are rendered in.

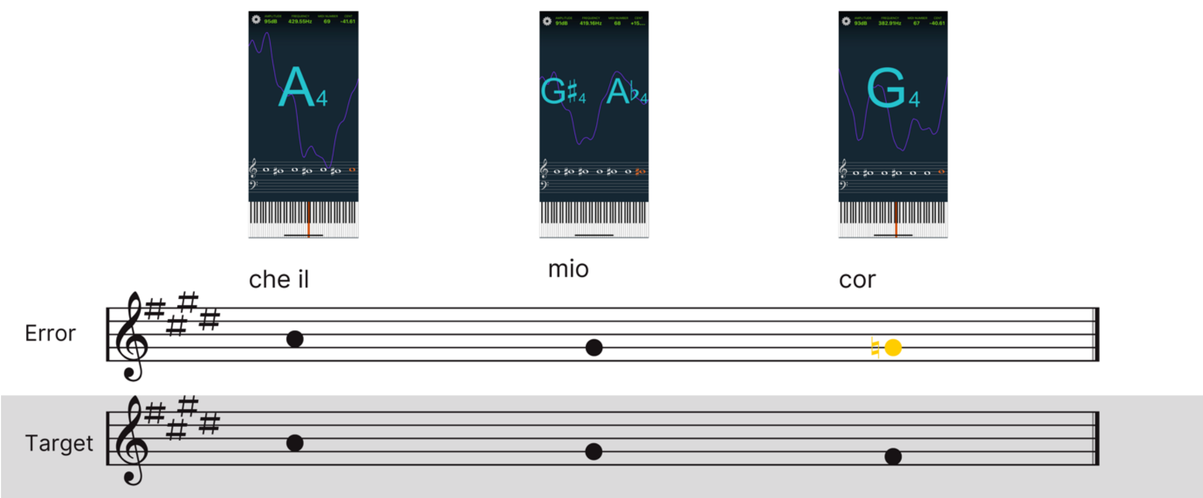
Pitch tracking measures

Pitch trackers and tuners can be downloaded as mobile apps and can provide in situ feedback with reference to the pitch accuracy of sung tones. The singer might wish to use slow practice to ensure the accurate integration of the multi-prismic properties of the singer's syllable with particular focus on the pitch value correlates required per segment. Most pitch trackers give the note name as well as Hertz value so absolute precision can be achieved. This approach can be used to tune pitch values in terms of onset tuning, sostenuto tuning and offset tuning. The singer may choose to monitor their targets while looking at the pitch tracker on their device in situ or screen capture while the device is tracking their pitch for post phrase analysis.

In figure 13 the singer has experiences an onset tuning error on the final syllable at the opening of *Caro nome* which the pitch tuner app has identified. Here the singer under stepped the pitch placement, resulting in a tuning error that is out by 1 semitone. Examining the phonetic tone tuning of the text indicates that at pitch tuning error occurred that aligned with both the onset tuning (devoicing of the first phoneme segment /k/ could account for this error at onset) as well as sostenuto (if the singer observed continued error while sustaining the tone in situ or in evaluating the live feedback during the sustained duration) and offset tuning (if the pitch aberration continues on the ensuing tone). This method can be logged while using a score, piano and pitch analyser during deliberate practice tasks (see Figure 12). Depending on the app and interface used (mobile phone, tablet or desktop) and microphone sensitivity, the singer can adjust the sensitivity of the analyser to ensure clear measurement.

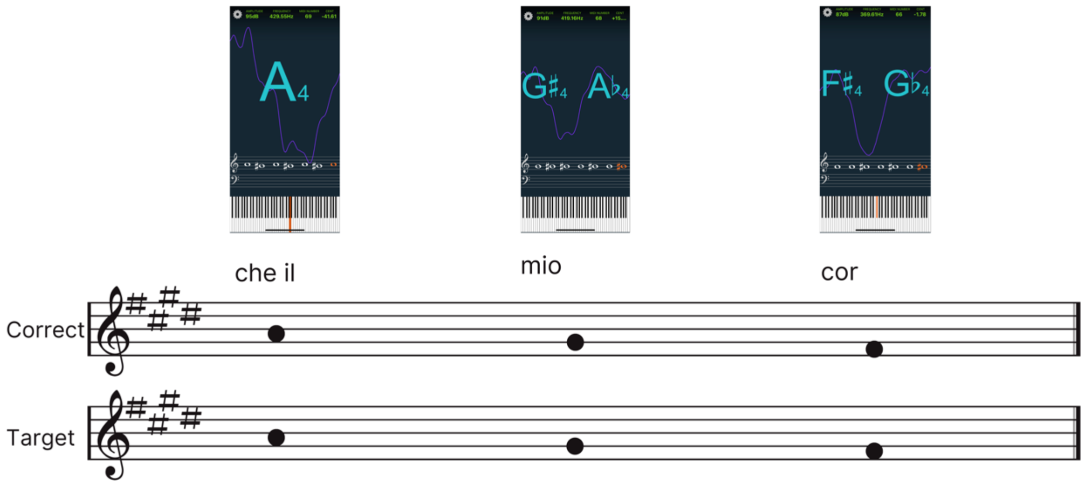
Figure 13:

Pitch Tuning Error during Phonetic Tuning as Observed with a Pitch tracker.



In the figure 14 the singer has reached their target accurately as represented by the pitch analyser's feedback. This approach is easier undertaken through slow practice (reduced tempo) and it's recommended that the rhythmic value of each tone is considered even if sung at a slower tempo.

Figure 14:
Pitch Tuning Correction During Phonetic Tuning as Observed with a Pitch Tracker



Pitch analysis can be done through biofeedback cues from mobile phone apps or a pitch tuner but may also be supported through the singer's own perceptual feedback by close work at the piano.

Phonetic transcription

The use of systematic phonetic transcription has been shown to enhance pronunciation accuracy for target accents in non-native speakers (see Lyster, 2013; Lord, 2005 and Miller and Kornelis, 2012), but does it have practical use for the singer? Phonetic transcription involves the transcriber recoding written or spoken word with the phonetic alphabet in an attempt to capture and delineate its sound-based properties at the segmental and suprasegmental level. Systematic phonetic transcription aims to show "all the phonetic details that are part of the language and can be stated in terms of phonological rules" (Ladefoged, 2015, p. 318).

Kurt Adler was an early adopter of the International Phonetic Alphabet and flouted its capacity to inform increased sound accuracy for singers approaching non-native languages stating that "the adjustment of phonetics to the vocal phrase is the real problem for any accompanist and coach and the solution constitutes a very important part of this art" (Adler, 1967 p. 5). While Adler refers to the accompanist and coach's role in this process, the singer needs to take into account how the acoustic properties and phonological requirements of song and aria texts vary significantly from spoken text, when transcribing lyrics and libretto.

Transcribing IPA information onto the score can serve as a visual reminder to focus on the correct phonology of the language in question. For this to be effective, the singer needs to inform themselves in detail of the phonological requirements of the sung language and may need more specific insights from a diction coach proficient in the language or to refer to various gold standard manuals and textbooks for singing pronunciation[63].

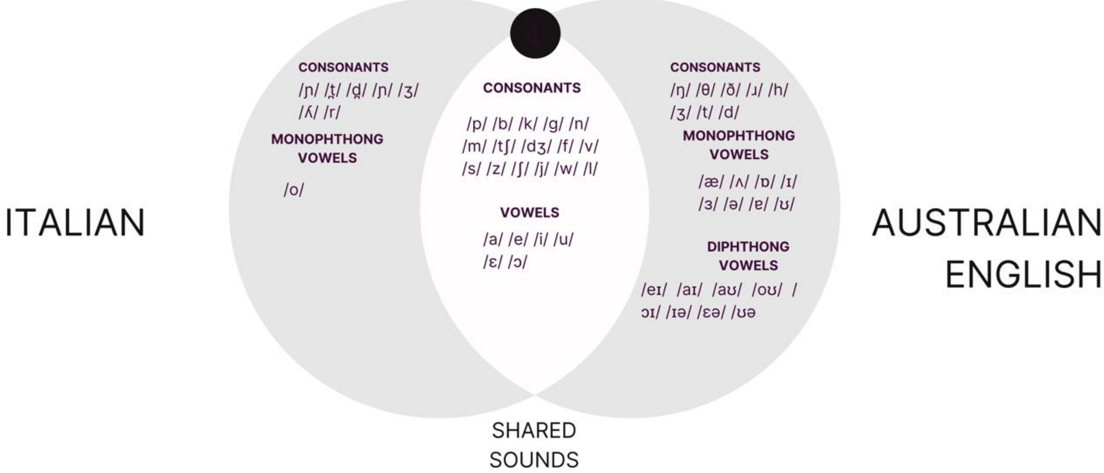
A considerable amount of work in the active practice studio can involve research and mapping of phoneme targets required outside of the score for the singer's languages. In this process the singer must have a detailed understanding of the vocal tract tuning features of their first language and contrast it with the vocal tract tuning features of their target language using diacritic details to increase precision. This is best approached with a growth mindset as the singer may feel overwhelmed at what appears to be a possibly never-ending process at the beginnings of reaching more insight into a language, in particular languages that have limited reference points to their first language. The benefit of this approach is that it provides the singer with a personalised and subjective reference point, which is necessary for them to gain more detailed insight into the manoeuvres required by their anatomy. It can also consider other phonetic tone tuning and adjustment nuances they need to be mindful of

[63] Renowned texts that provide extensive information on the phonetics and phonology of Western classical singing include books such as Nico Castel's extensive opera libretti series, Timothy Cheek's definitive guide, "Singing in Czech: A Guide to Czech Lyric Diction and Vocal Repertoire" (Cheek, 2001) and Pierre Bernac's "The Interpretation of French Song" (Bernac, 1970) to mention a few.

relating to their understanding of what constitutes optimal resonance for their own unique voice.

Figure 15:

A Cross-Sectional Phonetic Inventory for Italian and Australian English



Cross-sectional inventories

The cross-sectional inventory highlights for the singer, the sounds needed for the target language that they do not possess in the languages they speak at native proficiency or with which they are incredibly familiar with singing in (see Figure 15). By locating the phonemes absent from their personally calibrated phonetic inventory, the singer can start to incorporate these targets into their daily practice to build agility and accuracy in rendering the targets according to the principles of the multi-prismic properties of the singer's segment. Phonemes can then be produced in short phrase drills from repertoire as part of warm up across the range or at varying tempi or alternatively incorporated into runs and vocalises to build muscle memory and encourage increased motoric proficiency by virtue of the principles of neuroplasticity. Singers should also be mindful of the sounds that are not needed in their target language comparative to their dominant language, this is particularly important with reference to languages like English, which tend to contain more vowels than Romance languages. If the singer is mindful of their dominant language's phonetic inventory they can be mindful of subtle placement adjustments to the vowel positions needed in their target language and even consider incorporating specific phonetic segments into daily technical drills, scales and vocalises to increase their agility to achieve the target across a variety of context to enhance the motoric integration of complex or distant phonemes (to L1), predicting increased performance readiness and agility for phonetic accuracy.

Phonetic placement manipulation

Liaising between phonetic targets that are neighbouring while overtly singing to increase valving ability as well as sensory and auditory insight into variations of manoeuvres and their impacts on tone. Vowel drills already do this in some standard warm up and technical drills but the same could be done for grading tongue position, jaw opening etc. Phonetic placement manipulation is already an established process in singing pedagogy, we see evidence of it where the singer undertakes technical exercises that alternate between front and back, open and closed vowels, very common in isometric drills and vocal warmups. However, this process could be specifically used to integrate phonetic tone tuning agility and accuracy through using a target language's phonemes solely for a technical drill. For example, an English native singer may engage in scalic runs elicited on a Czech voiced nasal /ɲ/ with alternating the core monophthongs of Czech (/a, ɛ, e, ɪ, i, o, u/) to integrate them more effectively while working on Czech repertoire or completing an arpeggio drill on the palletised Russian “” /lʲ/ while alternating some distinct Russian monophthongs (/ ɨ ʉ ɵ /).

Phonetic placement exercises may also be used in an attempt to enhance the singer's ability to contrast the varying postures of consonant segments through coarticulating neighbouring sounds in technical exercises by moving through the alternate positions of place, manner and voicing in the supra-laryngeal space. For example, a singer may use one pitch and alternate between the following chart to tune differences perceptually, kinaesthetically and mechanically between neighbouring sounds while vocalising. Minimal pairs could also be used in this process to create differentiation and potentially benefit intelligibility measures at the consonant and vowel level.

An example of how to plan out such exercises relative to target languages appears below in Figure 15. This could be used to make more distinction between place, manner and voicing of sounds for the singer's dominant and non-dominant languages (for example, contrasting the sounds of Spanish L1 versus English L2 when singing) or against sounds in the target language (contrasting consonants or vowels of Russian) that they are working on while being mindful of the phonological rules.

Figure 16:

Phonetic tuning According to Place, Manner and the Voicing of Alveolar sounds in two West Germanic Languages (English, German)

PLACE	MANNER	+ VOICING	- VOICING	Kinaesthetic observation Questions for the singer
Alveolar	plosive	/d/	/t/	• Where do you feel vibration? • What are the key points of contact (*eg. the tongue tip touches the alveolar ridge so the contact points are tongue tip and alveolar ridge)* • What shape are the lips? (eg. the English /tʃ/ tends to be rounder at the lips resulting in more air stream pressure) • Are the teeth apart or closed? • What movements happen to release the sound? • Do you feel vibration on the neck (indicated voicing) with gentle palpation of fingers? • Does the sound sustain for a duration or release immediately. What achieves this with the movement patterns and what do you feel engaging during this process? • Do you feel strong, light or no air pressure release at the mouth against yor hand when you release the sound (important for plosive properties)?
	fricative	/z/	/s/	
	affricate	/dʒ/	/tʃ/	
	nasal	/n/	-	
	tap	/ɾ/	-	
	approximant	/ɹ/	-	
	lateral	/l/	-	
Minimal pair drills	Keep like parts but adjust manner *eg.* /dain/ ≠ /zain/ (German *Dein* vs. *Sein*)	• Keep like parts but adjust voicing *eg.* /bʌd/ ≠ /bʌt/ (English *Bud* vs. *But*)		
Coarticulation chaining	Move between minimum one sound or more in one breath cycle with or without vocalising.	• Sustain /n/ - /l/ on one tone • Release /t/ /d/ by alternating voicing at high repetition for one breath cycle with or without a vowel while maintaining pitch accuracy "ta-da-ta-da-ta-da" on the same tone or scale passages"		

Verbal phonetic placement instruction in singing lessons

Various experiments suggest that "an echo-neuron system exists in humans: when an individual listens to verbal stimuli, there is an activation of the speech-related motor centres" (Rizzolatti and Craighero, 2004 p. 186), but beyond that, a study by Tettamanti et al. indicated that when an individual listens to sentences outlining physical actions performed but the mouth, hand/arm or leg, compared to sentences of a similar syntax structure that did not refer to actions of the mouth, hand/ arm or leg; the actions of the cortical area were as active as those in observing the action (as cited in Rizzolatti and

Craighero, 2004, p. 187). In the instruction of the required pronunciation features of a language or the phonetic targets, it is potentially fruitful for singing teachers to provide explicit information about the shaping and articulatory actions needed to create or possibly even sequence and coarticulate the target phonemes accurately while coaching a student. Interestingly enough, according to Rizzolatti and Craighero (2004), increased activation was explicitly observed concerning mouth-based actions compared to the movement of the limbs (p. 187), so this approach is potentially even more suited to singers than instrumentalists.

Tapping tasks

Singer's may benefit from engaging in tapping tasks to improve their rhythmic accuracy and understanding of their target language's prosody features. Research into non-native speakers who were asked to tap the rhythms of short phrases found that the "frequency and inter-tap variability" of an individual's tapping patterns was influenced by the listener's "native language and language-specific acoustics" (Rathcke et al., 2021, pp. 3-4). The mechanical and rhythmic properties of any spoken text (as well as possibly sung lyrics and libretti) required on stage and in concert are therefore likely to be affected by the first language features of the singer and is possibly an area that can be overtly trained and practiced in the singer's studio. This could have some implications on the singer's notion of the required lexical stress and emphasis in sung phrases, despite rhythmic notation informing the singer on aspects of this, it does not necessarily delineate the prosodic stress requirements that the text requires. Training linguistic rhythm through tapping is seen as a sensory-motor approach that has been found to be "well suited for the study of subtle rhythmic differences in the spoken signal" (Rathcke et al., 2014, p. 3) and is likely useful for singers to consider to bolster their suprasegmental proficiency when practicing words in their non dominant language(s). Rathcke et al. (2021) also go postulate that synchronous sensory-motor sequencing research points to the presence of "movement-based paradigms [that] tap into language-specific properties of speech" (Rathcke et al., 2021, p. 5" and this method reaches effectiveness when study participants tapped synchronously with looped speech. More more research is needed to identify if asynchronous tapping (after perceiving speech) is also effective. Further the method that seemed to work the best was where the participants listened to the looped speech and tapped on the second and third repetition of the phrase where it was thought they could focus more on the rhythm properties of the phrase once receiving the semantic info in the first two repetitions. The repetition process was thought to reduce cognitive load on the speaker so that they could tune into the rhythmic properties of the phrase. Tapping tasks are viable approaches that could be enriched by further research into implementation by singers with repetiteurs or singing teachers with native proficiency in the target language on hand to mediate.

Motor Imagery Tasks and Silent Practice

Interest in using motor imagery as a concept to improve performance first arose in the first half of the twentieth century, and up until the 1990s, research was primarily dedicated to motor imagery activities to enhance sporting performance in athletes.

However, after that, growing attention to this approach has spread into alternate disciplines that require command of complex motor movements such as music and surgery (see Rienzo et al. 2016, p. 1). Initial motor imagery approaches revolved around imagining isometric contractions to bolster strength, but with time, more interest has extended into the application of motor imagery to enhance movement kinematics.

Rehearsing mentally without moving (silent rehearsal) is thought to stabilise “the representation of movements particularly concerning the order of movement sequences” (Ladda et al., 2020, p. 10) which is precisely what is required to achieve both phonetic, melodic and metric accuracy.

Consideration of multi-modal imagery tasks is justifiable since they may assist the performer in the act of performance to switch attentional focus more rapidly when required. Imagery tasks may also "[free] us from the chains of external perceptual cues” (Kleber et al., 2007, p. 899), and possibly increase the integrity of the neural connections, allowing the singer to focus on the invisible cues needed to master improved creative cognition and motor planning for complex problem solving when singing. Furthermore, imagined singing appears to increase activation in the interior parietal cortex [64] bilaterally to the same degree as overt singing.

There are several means by which the singer can build their practice resources using imagery. Each variant might support creative cognition and mastery to boost the motor engram for daily practice activities as much as in the performance context performance.

Imagined Singing- Auditory Imagery

Imagined singing involves the singer imagining the sounds of their melody or aria and is likely to activate the auditory processing pathways in the brain explicitly while drawing on memory routes. In their fMRI imagined singing study exploring the neural correlates for imagery related tasks in professional classical singers, Kleber et al. (2007) found that an "auditory association area in the left hemisphere … reported to be responsible for the control of spoken and listened words" (Kleber, et al. 2007, p. 898) was active suggesting stimulation of regions vital to speech and song processing.

The classical singers in this study were required to focus on auditory imagery while they imagined singing an Italian aria. Furthermore, the study found that singers experienced increased activity in the primary and secondary sensorimotor areas as well as the limbic area, a region involved heavily in the processing of emotions during the imagined singing task and the superior parietal lobe (an area suspected of being responsible for imagined movements, particularly complex movements[65]).

Mental Singing - Multi-modal imagery

Mental singing deals with the cognitive consideration of the multiple modalities that represent the act of singing, including and not limited to the somatosensory, kinaesthetic,

---

[64] The storage of phonetic and intonational acoustic information, which contributes to the working memory system is attributed to this region (see Kleber et al., 2007, p. 898 for more discussion on this process).

[65] This area seems to show increased activation during imagined singing, where lesions to this region result in patients struggling to complete tasks that require imagined movements according to research undertaken by Gerardin et al. (1996).

proprioceptive, motor aspects as much as the internal artists' psyche and conscious interpretation and expression of the work or artistic act.

Several researchers have explored this area in more detail, looking at fMRI studies to establish the neural correlates of both the live and motor imagery process of singing; however, most of these studies fail to include the role of phonetic accuracy, instead of considering metre, rhythm, vocal tract configurations and laryngeal valving for pitch and voice quality. Models for mental singing / motor imagery-based tasks for classical singers are still quite preliminary (see those provided by the research of Kleber et al., 2007; Kleber et al., 2010; Ladda et al., 2020; Peretz and Coltheart, 2003, and Reed and McPherson, 2020) and there is scope to speculate how existing models could include the interaction of the former aspects with the complex motor differentiation needed by singers to duly and accurately produce the acoustic requirements of the language they are singing with minimal error. This topic is noteworthy, particularly since many singers will encounter libretti and lyrics in languages, they have not achieved total proficiency across their careers. Additionally, many singers will receive late exposure to some of their operatic languages, thus breaching the ability to acquire native-like speech pattern awareness and capacity prior to working professionally or indeed before the critical period hypothesis.[66]

With some studies such as Reed and McPherson (2020) suggesting that "imagining and executing an activity will result in similar neural activation… mental rehearsal of a vocal exercise will excite parts of the brain necessary to perform that exercise” (Reed and McPherson, 2020, p.1235), it is likely fruitful to bolster phonetic and linguistic/phonological accuracy for singers singing in languages other than their mother tongue to build creative cognition for this vital element in the classical singer's skill set.

[66] The critical period hypothesis proposes that native speaker proficiency with reference to accent and pronunciation cannot be acquired after a certain age and some researchers even go on to argue that young learners will still “end up speaking the L2 with a non-native accent” (Dekeyser et al., 2010, p. 3). Whether adult language learners are disadvantaged in second language acquisition, in particular phonetic accuracy, is a topic that has received heated debate in the literature with certain studies disputing the age - related debate and the notion that acquisition must start at an earlier age.

This can be achieved by exploring models for mental singing that can be incorporated into the singer's daily routine. Of particular benefit is the impact this can add to the singer's practice capacity. The singing voice is subject to fatigue, and most singers report the practice capacity of real-time singing as amounting to at best, 25 hours per week (get citation), such that adding this form of practice to the daily routine will expand singing development in a structured manner that is supported by motor principles and an evidence base. Furthermore, it has been suggested that "like physical training, mental training enhances motor performance and muscle strength" (Rozand et al., 2014, p. 1981), so this approach could be of merit to reinforcing the muscle integrity and flexibility of the vocal system for singers. However, the strength gains may be lower compared to physical practice. Research by Rozand et al. (2014) concluded that a single session of mental training taken in isolation or alongside physical training did not trigger additional neuromuscular fatigue (p. 1981). The previous study speculated that "motor imagery may be added to physical practice to increase the total workload without exacerbating neuromuscular fatigue" (Rozand et al., 2014 p. 1981), a notion which holds particular merit for professional classical singers who experience a vocal load / ergonomic cap that prevents them from oversinging without structural risk and possible vocal trauma. A study by Reiser, et al., 2011 revealed that alternating "high-intensity voluntary contractions" with "imagined contractions reduces muscle fatigue" (as cited in Rozand et al., 2014, pp. 1981- 1982). Likewise, the scope of this approach for injury prevention in instrumental players who are also at risk of repetitive strain injury is also positive.

Towards a creative cognitive model for motor imagery practice in the classical singer's studio

A singer engaging in motor imagery practice with the goal of finessing phonetic tone tuning could focus on rehearsing mentally without moving in an act of silent rehearsal with the articulators and vocal tract with the attempt to integrate numerous modalities to prime their skill. This could be achieved through evoking aspects of the body matrix model since it integrates the numerous modalities required for singing. That motor imagery practice is believed to stabilise the "representation of movements particularly with regard to the order of movement sequences" (Ladda et al. 2020, p. 10) is vital since stabilisation of movement is precisely what is required to achieve both phonetic, melodic and metric accuracy according to the parameters of the multi-dimensional properties of the singer's syllable. Although the singer lacks the spatial, proprioceptive and velocity based feedback provided through overt singing, this approach may have benefits by building the singer's attentional focus to the variables needed for accuracy such that they can troubleshoot and mitigate error risk in live performance and has been found to improve the speed and smoothness of complex movement patterns and is thought to be just as beneficial to improve both novel and skilled sequential movement trajectories (see Lacourse, 2005). Ladda et al. (2010) propose the tight development of a stepwise approach that integrates attention to the varied feedback modalities (proprioception, kinaesthetic, auditory feedback etc). What follows is a proposed map informed by the multiple modalities that shape a phonetic sequence with reinforcement of motor imagery (see Figure 17).

Figure 17:

A Creative Cognitive Model for Motor Imagery Practice

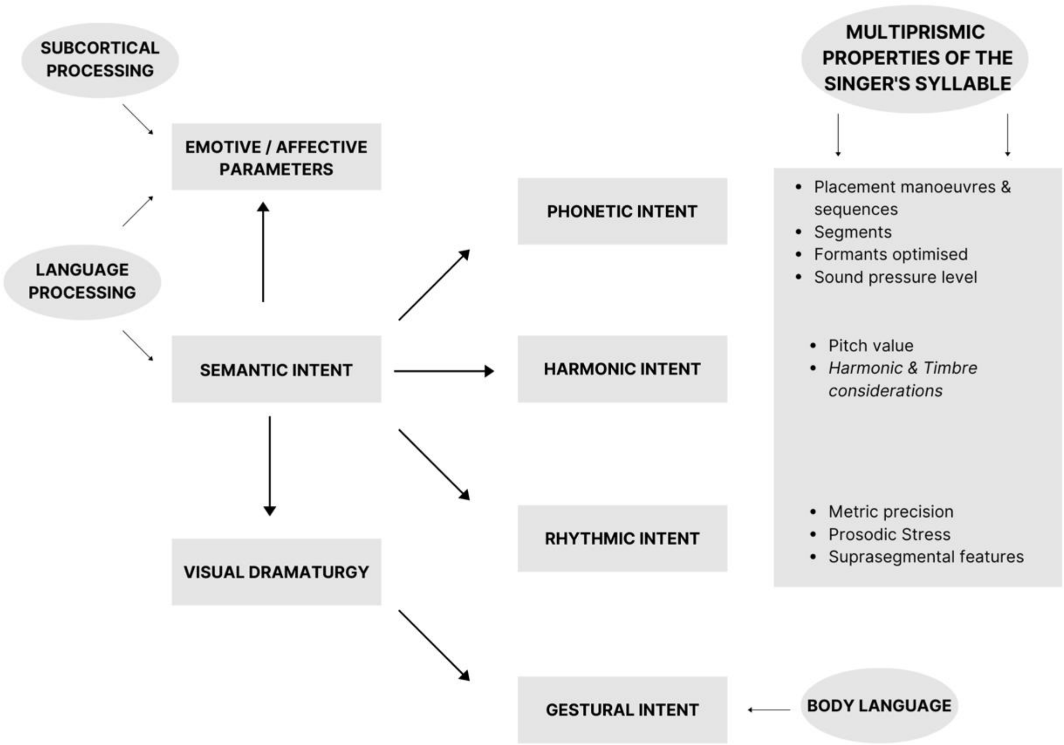


Figure 17 could be viewed as a creative cognition model that can inform motor imagery practice and ensure that task specific goals around phonetic tone tuning are integrated within the parameters of artistry such that the singer embeds gestalt learning while still leveraging their accuracy phonetically. Although a rudimentary conceptual model for creative cognition, this is a proposed starting point specifically with reference to motor imagery practice functioning within a holistic framework (yet to be fully exploited by further research) that takes into account the importance of affective parameters, semantic intent and visual dramaturgy, factors which will have some influence on the multi-prismic properties of the singer’s syllable. For example, if the singer aims to emote a phrase in anger (the affective parameter) with an expression of fury (semantic intent parameter) while running onto stage (visual dramaturgy), these factors can be reinforced through aspects of the multi-prismic properties of the singer’s syllable (the singer may choose to increase the sound pressure level and increase facial expression as well as suprasegmental cues through detaching the phrase syllables to create marcato which will serve their artistic goal but in so doing may disrupt the motoric accuracy of the singer's syllable resulting in an increase in error risk). Through motor imagery practice that activates elements of the multi-prismic properties of the singer's syllable embedded within one or more of the sequences, the singer may increase their ability to strengthen the entire network and heighten both their phonetic tone tuning integrity as much as strengthen their artistic imagination and expression.

Motor imagery practice can be reduced to as little as two elements at a time or increased to all elements as the singer trains.

An example of two elements would be the singer using mental practice to rehearse each phonetic tone tuning manoeuvre of short phrase embedded while actively attending to their semantic intent. This approach may commence with the singer first focusing on one element of the multi-prismic properties of the singer's syllable until they are adept[67] at integrating all elements into the mental rehearsal systematically. Motor imagery of single modalities could also benefit the ability to switch attentional focus to individual planning pathways during the actual performance, thus giving an attentional boost to the performer while singing overtly.

An example of multiple elements in motor imagery practice would be the singer mentally practicing the syllables of a complex melisma passage with respect to the multi-prismic properties of the singer's syllable (each of which relies on complex motor programs) while adding incrementally awareness of the affective parameter, the semantic intent and the visual dramaturgy to their visualisation. while adding incrementally awareness of the affective parameter, the semantic intent and the and the visual dramaturgy to their visualisation.

To achieve the metric precision innately required for phonetic tone tuning (onset, sustained duration and offset duration), it is enlightening to consider that "motor areas can become active to…rhythm, even in the absence of movement" (Levitin et al., 2018 as cited in Ladda et al., 2020, p. 3). As such, mental practice, if directed deliberately to specific timed

[67] With practice, it is likely that imagery training can be undertaken with more than one cue.

properties of the singer's syllable, may enhance the rhythmic components of the singer's syllable.

While motor imagery practice is not a replacement for the motor gains of deliberate overt singing practice, it is likely to strengthen and refine the neural correlates of singing and create deeper creative cognition for the singer.

Mental practice appears to be an effective approach to practice that allows the singer to embed the cognitive rehearsal of their movement sequences (the technical-motor abilities) into strong emotional engagement and is anticipated to allow the singer to enhance both the "dynamics of their motor performance" (Kleber et al., 2007, p. 889) alongside their capacity to express the emotional, semantic and communicative intent of the work. In fact, it may create the capacity to achieve improved creative cognition and motor planning for complex problem solving when singing as it can be seen to emancipate the singer from external perceptual input and allows them instead to focus and develop internal super cues to enhance their master. More research into task specific attempts with reference to phonetic tone tuning and outcomes as result of motor imagery practice as a complement to motor execution in singers is needed.

Kinaesthetic Motor Imagery

There is also an argument for the neurologically enhancing impacts of kinaesthetic motor imagery. In this process, the singer would attempt to perceive the typical sensations they might feel in the "muscle-tendon complexes when executing the movement, rather than visualising the execution" (Kleber et al., 2007, p. 890).

Quite possibly, kinaesthetic motor imagery could be more efficacious for the classical singer than visual imagery strategies. A study but Lebon et al., 2017 found a stronger correlation between high kinaesthetic imagery vividness and high performance after training than the use of visual imagery strategies (p. 1805) where participants were instructed to move the fingers of their right hand overtly in a specific sequence using motor imagery versus visual imagery strategies. Training via kinaesthetic imagery also resulted in the participants being able to sequence the finger movements more rapidly and with a lower error rate for sequencing, suggesting that motor imagery training increased motor performance.

Although some studies point to the advantage of kinaesthetic motor imagery over visual imagery, a study by Fery (2003) suggests the output mode is more predictive in creating differentiation between success, postulating that visual imagery is more facilitative for form-based tasks versus kinaesthetic imagery as more effective for tasks that require timing and coordination of two hands. While no studies appear to examine the impact of kinaesthetic versus visual imagery for the complex motoric proficiency needed in classical singers, both approaches may be salient. Singers count on form for the phonetic shaping of the visual articulatory cues at the mouth (for example, vowel opening, tongue fronting, rounding, cues on spreading, all can be visually determined by observation of the mouth, lips, tongue and jaw). However, by the same measure, the sequential and temporal based nature of singing and the prosodic and metric requirements of the lyrics or libretto against the rhythmic and harmonic composition are also likely to be best supported through kinaesthetic imagery.

Kinaesthetic motor imagery may also have higher performance outcomes than auditory imagery when it comes to phonetic precision. Research by Caldara et al., 2004, has also found that kinaesthetic motor imagery movements involved the primary motor context to the same degree as motor executions, indicating a comparable activation of this brain structure in both conditions. Kinaesthetic motor imagery movements have been found to involve the primary motor context to the same degree as motor execution conditions, indicating a comparable activation of this brain structure in both conditions. In this process the singer attempts to feel the sensations usually perceived in the muscle articulations and movements when executing the movement sequence, rather than visualising the execution. An example for this in terms of phonetic application could be activate kinaesthetic motor imagery drills on target drills for vowel correction in which the singer would intentionally imagine the sensations of tongue placement with a front tongue position as well as the jaw sensations for the /a/ vowel if they tended to back the tongue and darken the vowel unnecessarily.

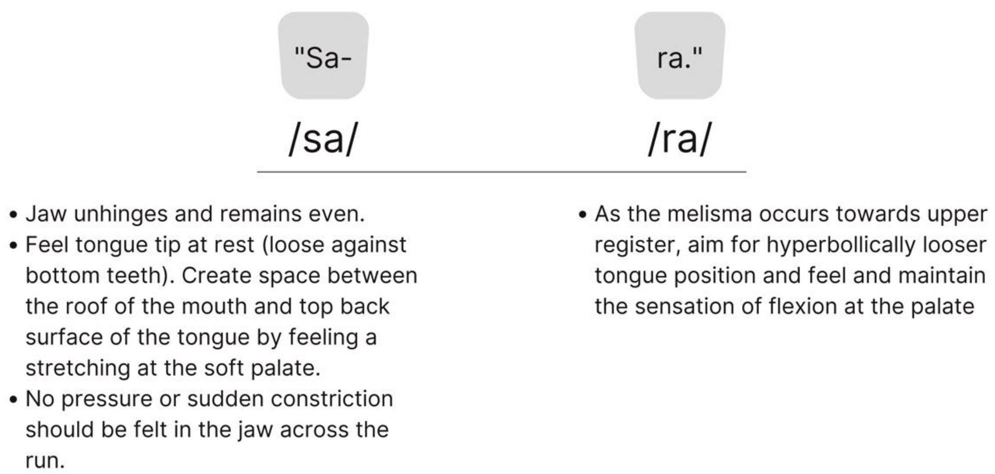
Towards a kinaesthetic motor imagery map for phonetic placement patterns in the classical singer's studio

A singer might find it helpful to create kinaesthetic motor imagery maps for the placement patterns and sensate movements across an entire area or text, considering the impacts of the vocal tract and resonance tuning in addition to the physical sensation of movements that inform the prosody and metre of the text in question against the pitch and harmonic demands of the piece.

Figure 18 provides an example of a possible **kinaesthetic motor imagery map** to enhance vowel placement awareness for the final two syllables of melisma in "Caro nome," from Rigoletto, Guiseppe Verdi (Verdi, 1851).

Figure 18:

Kinaesthetic Motor Imagery Map of the Final Two Syllables of Caro Nome from Rigoletto, Guiseppe Verdi (Verdi, 1851)



Kinaesthetic motor imager may be a beneficial approach to not only attaining increased phonetic accuracy but reducing the risk of habitual errors with articulatory adjustments that can affect not only pronunciation integrity of the text being sung but also the singers' formant and resonance cavity tuning (for example, spreading on the /e/ or /i/ vowel. For the English native singer, this technique may provide a more concrete target for vowel correction and minimisation to the core cardinal vowels. Since the ability to perceive vowels accurately is risky when the vowels lie outside of a speaker's dominant language's phonetic inventory (add reference for sound accuracy from imitation versus production of placement in adults), this approach may provide more of a tangible and concrete cue then relying on the memory or even incorrect perception of an auditory cue. This approach may be useful for an English native singer who is inclined to apply English vowels across the Romance languages, which is erroneous stylistically, linguistically and technically. Kinaesthetic bombardment over auditory bombardment in vowel and consonant tuning may be more facilitative, mainly since the vocal tract vibrates according to frequencies at which it is tuned as such, would it not make sense to focus on the cavity sensations for filtering as much as the auditory outcome, since this approach takes into account the principles of physics that govern how the vocal tract vibrates and produces sound due to aerodynamics and cavity shaping?[68]

Further, this approach may be beneficial to reducing the risk of performance anxiety, such that the singer is encoding attention to tangible sensations, which may build habitual attention to structural and technical cues that are fruitful to determining a better artistic outcome than fearing for the anticipatory top C. This approach may be useful for reducing the impacts and occurrence of music performance anxiety since some research exists[69] that connects therapeutic management to kinaesthetic and relaxation-based techniques to split the performer's attention to topics other than the anxiety they face in performing.[70]

[68] See Story et al., 1996 and Ohala, 1983, for more on vocal tract aerodynamics.
[69] See Kenny (2005); Kenny and Mitchell (2006) and Kenny (2016) for singer classical centric studies and resources on performance psychology.
[70] Do classical singers experience music performance anxiety that links to performance shame and fear of inadequacy with reference to their command of the demands of singing in a complex target language in addition to other technical concerns? Not a lot is known about this topic and more research is required in the field.

Many singers may already apply kinaesthetic cues in the context of real-time singing and performing as a means of coaching themselves through the challenging vocal tract tunings of high tessitura or rapid melisma, or even messa di voce and pianissimi on high tones; however, what separates this approach is the reduction of distraction in the process and higher predictive error due to attentional, memory and live spontaneous factors. Such that if the singer has strengthened the numerous modalities (i.e., phonetic, sensorimotor, auditory) to high artistic performance through motor imagery with precision and maybe even after more skilled practice of this approach with a more holistic, global approach (where multiple modalities are worked on with simultaneous and concurrent imagery), their ability to draw on the solutions in moments of unexpected performance risk (for example, loss of breath pressure and subsequent jaw tension as a concomitant may be avoided or corrected more briskly if the singer is alert to the kinaesthetic modality for that moment as much as the auditory and perceptual respiratory cue), may be more agile. With increased awareness to this area of rehearsal through kinaesthetic motor imagery and auto ethnography, singers may devise a framework of kinaesthetic cues for the core vowels and consonants of their target languages or the application of granular phonetic tone tuning within challenging moments of their specific repertoire resulting in a super cue (as outlined in the previous chapter).

Conclusion and Further Considerations

This paper has explored avenues for developing the practice studio of the classical singer to support their independent daily regime with tools and approaches to develop into the operatic polyglot. Topic constraints to hypotheses and considerations around the phonetic integrity of the singer in producing both musically, technically and linguistically expert performance based upon neural correlates for singing and complex motor learning entails gaping questions that are of note for further neurological research. This thesis has been constrained and areas for future research might also include research into “group flow” among singers with reference to phonetic tone tuning since it has been found that performers “simultaneously listen to themselves and each other while playing music” (Ladda et al., 2020, p. 6). No fMRI studies were identified in the literature that investigated the neural correlates between opera singers singing in mother tongue versus second language against native speakers would be helpful to see what areas of the brain are firing the most, especially if singing in a language that has had less experience and more research is needed into the sensorimotor controls for phonetic and linguistic processing in opera singers as much as the communication traits of eminent singers.

After discovering the growing research base into the neural correlates of classical singing, further research into the impact of cognitive processes in classical singers and the unique to neural correlates aligned to elite singing provide scope to considering whether the unique processes and skills acquired by professional singers can be used within a therapeutic space to benefit neurological impairment that is affecting the body-core centred motor and anatomic activities where there is an overlap between singing and daily function (social communication, respiration, phonation, articulation, salivation, ingestion). Likewise there is scope for these concepts in speech clarification training and vocal therapy. If the motor circuits are strengthened through these resources and approaches in the singer, and predictive error is lessened, potentially firing the neural network through mental speaking could be efficacious for a client experiencing acquired motor speech disorders, aphasia or dementia. This would obviously require fMRI studies and could be challenging to determine whether outcomes were aligned neural rebuilding or the activities, so the trial would need to be carefully devised.

The role of motor imagery and motor engrams and their potential impact on rehabilitation and recovery through explicit training of these techniques could potentially have clinical applications, further concepts such as the body matrix might be used in the development of novel therapy methods for individuals affected with dysarthria, dysphonia or dysphagia since the integrity of the speech voice and swallowing systems rely heavily on the laryngeal motor cortex. Further pedagogical research (given the predictors of motor learning neurologically, particularly through the variable outcomes of kinaesthetic imagery tasks are there better approaches to instructional cueing for singing teachers that can be deployed?) would also be beneficial to developing further understanding of the human brain in mastering complex motor learning that could also translate to the clinical and rehabilitative spaces.

List of Contributions

- The physiological mechanics of singing recruits over 100 muscles, and unlike instrumentalists, the singer must not only master the technical, physiological movements required of an instrument but also embody the instrument, navigate affective sensations, process information and exert control over motoric maneuvers to create optimal sound wave properties all the while conjuring up their artistic imagination and musical expression to communicating their artistic intent to the audience. This doctoral thesis examines the **cognitive and mechanical processes** that Western Classical singers can deploy in their practice studio within the niche skill of tuning their voice mechanically to the pronunciation standard valorised by the tradition to be phonetically accurate. The text discusses the cognitive, scholastic and motoric processes that underpin the accuracy of text, declamation, prosody, and phonetics as components of performance mastery. It builds on the definition of creative cognition for opera singers as a term to describe singer sentience and the physiological mastery of their instrument.
- The author proposes a **hypothetical model to represent the multiple intelligences of classical singing**, selecting Guiseppe Riva's Body Matrix as an appropriate tool to explain the singing process and adapting the matrix to create a specific Singer's Body Matrix that attempts to represent the multimodal processing involved in the act of singing. The Singer's Body Matrix can be assistive in mapping the hypothetical body memory processes that constitute elite singing, considering the multimodal nature of the singing process. The model is by no means prescriptive but can be used to consider the variables at play when a singer attempts to tune their

mechanism and develop the elite cognitions required for skilful singing, with particular focus on the purposes of this paper, the development of phonetic tone tuning precision. The Singer's Body Matrix could be used to explore other niche skills required in the training and development of elite-level classical singing, not only at the research level to inform various hypotheses for testing how the brain sings but also in the singer's studio as a framework for understanding the multiple intelligences that allow for artistic master more holistically.

- The author has created a **new term, operatic polyglot, to refer to the elite singer who has acquired the technical mastery of singing adeptly in languages other than their mother tongue** with the expectation that the singer achieves native-like proficiency phonetically, balancing the parameters of spoken language and musical language while vocalising in a domain that is exorbitantly disparate from producing spoken words.
- The author has delineated new parameters for sung pronunciation by defining the **sung syllable's multi-prismic properties, showcasing** the unique features and requisites of sung syllables distinct from spoken syllables. Classical singers need to grasp the multi-prismic properties of sung syllables to reach elite mastery. These new parameters for sung syllables successfully embed sound pronunciation into the acoustic, linguistic, harmonic and metric expectations of elite classical singers.
- The author has developed a new term, **phonetic tone tuning, to capture a uniquely sung skill distinct from diction, pronunciation or speech accuracy**, but instead denoting the vital process by which the elite opera singer produces accurate phoneme targets embedded within the distinct overtones and resonance properties required of Western classical singing, involving vital acoustic properties that are not always present in the speech signals as well as meeting the rhythmic and harmonic parameters of the musical and original language. The process of phonetic tone tuning is unique to opera singing. The term is unlike diction and articulation-related terms, which tend to disregard musical form's necessary sung

soundwave properties. The author has outlined three skills specific to the physical properties of sung sound related to phonetic tone tuning accuracy: mastery of phoneme onset tuning, phoneme sostenuto tuning and phoneme offset tuning.

- The author has developed a classification system for phonetic errors that corresponds to rhythm and intonational aberrations so that artists can articulate their technical goals relating to phonetic tone tuning with clarity and precision and gain awareness of the equal importance of phonetic tone tuning to rhythmic and intonational accuracy. Since singers produce sound waves that communicate, it is alarming to consider that there is no error classification system for phonetic accuracy when phonemes are just as concretely measurable as tones and time and even more critical for transferring linguistic meaning. This **classification system for phonetic tone tuning** breaches that classical singers can face while striving for mastery as an **operatic polyglot** should assist with aiding risk prediction by creating a framework for self-evaluation and a deeper understanding of how phonemes exist within the soundscape of sung music. The key phonetic tone tuning errors can be grouped under three categories: Phoneme Onset Tuning Errors, Phoneme Sostenuto Tuning Errors and Phoneme Offset Tuning Errors. It is hoped this thesis gives singers a vocabulary to define their technical goals and objectives in becoming an operatic polyglot and eminent elite artist with technical and artistic prowess.

References

Adler, K. (1967). *Italian, French, Spanish, German Phonetics and Diction in Singing*. The University of Minnesota Press.

Alexander, A. (1974). *Operanatomy: An Eclectic Introduction to the Art of the Conductor, Instrumentalist, Composer, Producer, and to Score Reading*. Crescendo Publishing Company. https://books.google.com.au/books?id=DPcXAQAAIAAJ

Bellini, V. (1851). Casta diva, [Musical score]. In G. Alary (Ed.), *Les* maîtres italiens: ècole vocale italienne (pp.4 -13). Heugel (Original work published 1831)

Belyk, M., & Brown, S. (2017). The origins of the vocal brain in humans. *Neuroscience & Biobehavioral Reviews*, *77*, 177-193.

Bernac, P. (1970). *The Interpretation of French Songs*. Frederick A. Praeger Publishers.

Blanke, O., Slater, M., & Serino, A. (2015). Behavioral, Neural, and Computational Principles of Bodily Self-Consciousness. *Neuron*, *88*(1), 145-166. https://doi.org/10.1016/j.neuron.2015.09.029

Brown, S., Laird, A., Pfordresher, P., Thelen, S. M., Turkeltaub, P., & Liotti, M. (2009). Author ' s personal copy The somatotopy of speech: Phonation and articulation in the human motor cortex.

Bozeman, K., & McCoy, S. (2021). *Kinesthetic Voice Pedagogy 2: Motivating Acoustic Efficiency*. Inside View Press. https://books.google.com.au/books?id=rzopzgEACAAJ

Cameron, J., Duffy, M., & Glenwright, B. (2014). Singers take center stage! Personality traits and stereotypes of popular musicians. *Psychology of Music*, *43*. https://doi.org/10.1177/0305735614543217

Chausson, E. (1890). La Cigale [The Cicada] [Musical score] *4 Melodiés, Op. 13* (pp. 37 – 41). Hamelle.

Cheek, T. (2001). *Singing in Czech: A guide to Czech lyric diction and vocal repertoire*. Scarecrow Press.

Chrysakis, T. (2010). The Structural and Aesthetic Capacity of Sonic Matter: Remarks on Sonic Dramaturgy.

Corrigall, K., Schellenberg, E. G., & Misura, N. (2013). Music Training, Cognition, and Personality [Original Research]. *Frontiers in Psychology*, *4*(222). https://doi.org/10.3389/fpsyg.2013.00222

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. Harper Collins.

Dekeyser, R., Alfi-Shabtay, I., & Ravid, D. (2010). Cross-linguistic evidence for the nature of age effects in second language acquisition. *Applied Psycholinguistics*, *31*, 413 - 438.

Doyon, J., & Benali, H. (2005). *Reorganization and plasticity in the adult brain during learning of motor skills* (Vol. 15). https://doi.org/10.1109/IJCNN.2005.1556102

Dreyfus, H. L. (2002). Intelligence without representation – Merleau-Ponty's critique of mental representation The relevance of phenomenology to scientific explanation. *Phenomenology and the Cognitive Sciences*, *1*(4), 367-383. https://doi.org/10.1023/A:1021351606209

Ericsson, K. A., Krampe, R., & Tesch-Rˆmer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363-406.

Fery, Y. (2003). Differentiating visual and kinesthetic imagery in mental practice. *Canadian journal of experimental psychology = Revue canadienne de psychologie expérimentale*, *57*, 1-10. https://doi.org/10.1037/h0087408

Friston, K. J., & Stephan, K. E. (2007). Free-energy and the brain. *Synthese*, *159*(3), 417-458. https://doi.org/10.1007/s11229-007-9237-y

Fine, P. A., & Ginsborg, J. (2014). Making myself understood: perceived factors affecting the intelligibility of sung text [Original Research]. *Frontiers in Psychology*, *5*(809). https://doi.org/10.3389/fpsyg.2014.00809

Fox, M. (2015, June 3, 2015). Nico Castel, Tenor and Diction Coach at the Met, dies at 83. *The New York Times*, 18. https://www.nytimes.com/2015/06/04/arts/music/nico-castel-tenor-and-diction-coach-at-the-met-dies-at-83.html

Gatti, R., Tettamanti, A., Gough, P. M., Riboldi, E., Marinoni, L., & Buccino, G. (2013). Action observation versus motor imagery in learning a complex motor task: A short review of literature and a kinematics study. *Neuroscience Letters*, *540*, 37-42. https://doi.org/https://doi.org/10.1016/j.neulet.2012.11.039

Garcia, M. (1800). *Garcia's New Treatise on the Art of Singing*. Oliver Ditson Company.

Garnier, M., Henrich Bernardoni, N., Smith, J., & Wolfe, J. (2010). Vocal tract adjustments in the high soprano range. *The Journal of the Acoustical Society of America*, *127*, 3771-3780. https://doi.org/10.1121/1.3419907

Gerardin, E., Sirigu, A., Lehéricy, S., Poline, J.-B., Gaymard, B., Marsault, C., Agid, Y., & Le Bihan, D. (2000). Partially overlapping neural networks for real and imagined hand movements. *Cerebral Cortex*, *10*, 1093-1104. https://doi.org/10.1093/cercor/10.11.1093

Guillot, A., & Collet, C. (2005). Duration of Mentally Simulated Movement: A Review. *Journal of Motor Behavior*, *37*(1), 10-20. https://doi.org/10.3200/JMBR.37.1.10-20

Hamano, Y. H., Sugawara, S. K., Yoshimoto, T., & Sadato, N. (2020). The motor engram as a dynamic change of the cortical network during early sequence learning: An fMRI study. *Neuroscience Research*, *153*, 27-39. https://doi.org/https://doi.org/10.1016/j.neures.2019.03.004

Hebb, D. O. (1949). *The organization of behavior; a neuropsychological theory*. Wiley.

Howell, I. (2016). Parsing the spectral envelope: Toward a general theory of vocal tone color.

Järvinen, K., & Laukkanen, A.-M. (2015). Vocal Loading in Speaking a Foreign Language. *Folia phoniatrica et logopaedica : official organ of the International Association of Logopedics and Phoniatrics (IALP)*, *67*, 1-7. https://doi.org/10.1159/000381183

Josselyn, S. A., Köhler, S., & Frankland, P. W. (2015). Finding the engram. *Nature Reviews Neuroscience*, *16*(9), 521-534. https://doi.org/10.1038/nrn4000

Jung, R., Mead, B., Carrasco, J., & Flores, R. (2013). The structure of creative cognition in the human brain [Review]. *Frontiers in Human Neuroscience*, *7*(330). https://doi.org/10.3389/fnhum.2013.00330

Katz, R. (1984). Collective "Problem-Solving" in the History of Music: The Case of the Camerata. *Journal of the History of Ideas*, *45*(3), 361-377. https://doi.org/10.2307/2709230

Keller, P., Novembre, G., & Hove, M. (2014). Rhythm in joint action: Psychological and neurophysiological mechanisms for real-time interpersonal coordination. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, *369*. https://doi.org/10.1098/rstb.2013.0394

Kenny, D. (2005). A Systematic Review of Treatments for Music Performance Anxiety. *Anxiety, Stress & Coping: An International Journal*, *18*, 183-208. https://doi.org/10.1080/10615800500167258

Kenny, D., & Mitchell, H. (2006). Acoustic and perceptual analysis of vocal gestures in female classical singers. *Journal of Voice*, *20*, 55-70.

Kenny, D. (2016). *Kenny Music Performance Anxiety Inventory (K-MPAI) and scoring form*.

Kent, M. (2007). *The Oxford Dictionary of Sports Science & Medicine*. Oxford University Press. https://doi.org/10.1093/acref/9780198568506.001.0001

Kleber, B., Birbaumer, N., Veit, R., Trevorrow, T., & Lotze, M. (2007). Overt and imagined singing of an Italian aria. *Neuroimage*, *36*(3), 889-900. https://doi.org/10.1016/j.neuroimage.2007.02.053

Kleber, B., Veit, R., Birbaumer, N., Gruzelier, J., & Lotze, M. (2010). The brain of opera singers: experience-dependent changes in functional activation. *Cereb Cortex*, *20*(5), 1144-1152. https://doi.org/10.1093/cercor/bhp177

Kleber, B., Zeitouni, A. G., Friberg, A., & Zatorre, R. J. (2013). Experience-dependent modulation of feedback integration during singing: role of the right anterior insula. *J Neurosci*, *33*(14), 6070-6080. https://doi.org/10.1523/jneurosci.4418-12.2013

Kleim, J., & Jones, T. (2008). Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res 51:S225-S239. *Journal of speech, language, and hearing research : JSLHR*, *51*, S225-239. https://doi.org/10.1044/1092-4388(2008/018)

Lacourse, M. G., Orr, E. L., Cramer, S. C., & Cohen, M. J. (2005). Brain activation during execution and motor imagery of novel and skilled sequential hand movements. *Neuroimage*, *27*(3), 505-519. https://doi.org/10.1016/j.neuroimage.2005.04.025

Ladda, A., Wallwork, S., & Lotze, M. (2020). Multimodal Sensory-Spatial Integration and Retrieval of Trained Motor Patterns for Body Coordination in Musicians and Dancers. *Frontiers in Psychology*, *11*, 576120. https://doi.org/10.3389/fpsyg.2020.576120

Ladefoged, P., & Johnson, K. (2015). *A Course in Phonetics (Seventh Edition)* (7th edition ed.). Cengage Learning. (2006)

Lametti, D. R., Nasir, S. M., & Ostry, D. (2012). Sensory Preference in Speech Production Revealed by Simultaneous Alteration of Auditory and Somatosensory Feedback. *The Journal of Neuroscience*, *32*, 9351 - 9358.

Lebon, F., Horn, U., Domin, M., & Lotze, M. (2018). Motor imagery training: Kinesthetic imagery strategy and inferior parietal fMRI activation. *Human Brain Mapping*, *39*. https://doi.org/10.1002/hbm.23956

Long, M. (2014). *Architectural Acoustics (Second edition)*. Academic Press. (2014)

Lord, G. (2005). (How) Can We Teach Foreign Language Pronunciation? On the Effects of a Spanish Phonetics Course. *Hispania*, *88*, 557. https://doi.org/10.2307/20063159

Lyster, R., Saito, K., & Sato, M. (2013). Oral corrective feedback in second language classrooms. *Language Teaching*, *46*, 1-40. https://doi.org/10.1017/S0261444812000365

Mendelssohn-Bartholdy. (2015). Letters of Felix Mendelssohn-Bartholdy from 1833 to 1847. Retrieved from https://www.gutenberg.org/ebooks/50473

Mercer-Taylor, P. (2004). *The Cambridge Companion to Mendelssohn* (P. Mercer-Taylor, Ed.). Cambridge University Press. https://doi.org/DOI: 10.1017/CCOL9780521826037

Miller, J. S. (2012). Teaching French pronunciation with phonetics in college-level beginner French course. *NECTFL Rev.*, *69*, 47-68.

Miller, R. a. S., Harm Kornelis. (2019). The effect of tongue position on spectra in singing. *Journal of Singing*, *76*(1), 25-29. (The Nats Bulletin, Volume 37, No. 3, January/ February, 1981)

Mozart, W.A. (1922). Bei Männern, welche Liebe fühlen [Musical score]. *Die Zauberflöte* K.620 Ricordi. (Original work published 1791)

Mürbe, D., Pabst, F., Hofmann, G., & Sundberg, J. (2004). Effects of a professional solo singer education on auditory and kinesthetic feedback--a longitudinal study of singers' pitch control. *Journal of voice : official journal of the Voice Foundation*, *18 2*, 236-241.

Ohala, J. (1983). The Origin of Sound Patterns in Vocal Tract Constraints. https://doi.org/10.1007/978-1-4613-8202-7_9

Peretz, I., & Coltheart, M. (2003). Modularity of music processing. *Nature neuroscience*, *6*, 688-691. https://doi.org/10.1038/nn1083

Price, C. J., & Hooven, C. (2018). Interoceptive Awareness Skills for Emotion Regulation: Theory and Approach of Mindful Awareness in Body-Oriented Therapy (MABT). *Frontiers in Psychology*, *9*, 798-798. https://doi.org/10.3389/fpsyg.2018.00798

Rathcke, T., Lin, C.-Y., Falk, S., & Dalla Bella, S. (2021). *Tapping into linguistic rhythm*.

Repp, B. H. (2003). Rate limits in sensorimotor synchronization with auditory and visual sequences: the synchronization threshold and the benefits and costs of interval subdivision. *J Mot Behav*, *35*(4), 355-370. https://doi.org/10.1080/00222890309603156

Reed, C. N., & McPherson, A. P. (2020). Surface Electromyography for Direct Vocal Control.

Rienzo, F., Debarnot, U., Daligault, S., Saruco, E., Delpuech, C., Doyon, J., Collet, C., & Guillot, A. (2016). Online and Offline Performance Gains Following Motor Imagery Practice: A Comprehensive Review of Behavioral and Neuroimaging Studies. *Frontiers in Human Neuroscience*, *10*. https://doi.org/10.3389/fnhum.2016.00315

Riva, G. (2018). The neuroscience of body memory: From the self through the space to the others. *Cortex*, *104*, 241-260. https://doi.org/https://doi.org/10.1016/j.cortex.2017.07.013

Rizzolatti, G., & Craighero, L. (2004). THE MIRROR-NEURON SYSTEM. *Annual Review of Neuroscience*, *27*(1), 169-192. https://doi.org/10.1146/annurev.neuro.27.070203.144230

Rozand, V., Lebon, F., Papaxanthis, C., & Lepers, R. (2014). Does a Mental-Training Session Induce Neuromuscular Fatigue? *Medicine and science in sports and exercise*, *46*. https://doi.org/10.1249/MSS.0000000000000327

Schirmer-Mokwa, K. L., Fard, P., Zamorano, A. M., Finkel, S., Birbaumer, N., & Kleber, B. (2015). Evidence for Enhanced Interoceptive Accuracy in Professional Musicians. *Frontiers in Behavioral Neuroscience*, *9*.

Strauss, R. (1950). Im Abendrot [Musical score] *4 Letzte Lieder, TrV 296* (pp. 196 - 207). Boosey & Hawkes (Original work published 1950)

Skains, R. L. (2018). Creative Practice as Research: Discourse on Methodology. *Media Practice and Education*, *19*(1), 82-97. https://doi.org/https://doi.org/10.1080/14682753.2017.1362175

Story, B., Titze, I., & Hoffman, E. (1996). Vocal tract area functions from magnetic resonance imaging. *The Journal of the Acoustical Society of America*, *100*, 537-554. https://doi.org/10.1121/1.415960

Strigo, I. A., & Craig, A. D. (2016). Interoception, homeostatic emotions and sympathovagal balance. *Philos Trans R Soc Lond B Biol Sci*, *371*(1708). https://doi.org/10.1098/rstb.2016.0010

Sundberg, J. (1975). Formant technique in a professional female singer. *Acta Acustica united with Acustica*, *32*(2), 89-96.

Timmers, R., MacRitchie, J., Schabrun, S. M., Thapa, T., Varlet, M., & Keller, P. E. (2020). Neural multimodal integration underlying synchronization with a co-performer in music: Influences of motor expertise and visual information. *Neuroscience Letters*, *721*, 134803. https://doi.org/https://doi.org/10.1016/j.neulet.2020.134803

Vennard, W. (1968). Singing : the mechanism and the technic. *Notes*, *25*, 237.

Verdi, Giuseppe. (1851). Caro nome, [Musical score]. In L. Truzzi (Ed.), *Rigoletto* (pp.1 -8). Blanchette

Vos, R., Murphy, D., Howard, D., & Daffern, H. (2017). The Perception of Formant Tuning in Soprano Voices. *Journal of Voice*, *32*. https://doi.org/10.1016/j.jvoice.2017.03.017

Youens, S. (2004). Mendelssohn's Songs. In Mercer-Taylor, P. (2004). *The Cambridge Companion to Mendelssohn* (P. Mercer-Taylor, Ed.). Cambridge University Press. https://doi.org/DOI: 10.1017/CCOL9780521826037

Zamorano, A. M., Zatorre, R., Vuust, P., Friberg, A., Birbaumer, N., & Kleber, B. (2020). Singing training predicts increased insula connectivity with speech and respiratory sensorimotor areas at rest. *bioRxiv*.

Zatorre, R. J., & Baum, S. R. (2012). Musical melody and speech intonation: singing a different tune. *PLoS Biol*, *10*(7), e1001372. https://doi.org/10.1371/journal.pbio.1001372