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## The PEA Model for Dramatic Mezzo-Soprano Pedagogy: Integrating Pharyngeal, Expressive, And Adaptive Dimensions in Giuseppe Verdi's O Don Fatale

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**Abstract:** *The dramatic mezzo-soprano repertoire demands exceptional vocal power, nuance, and endurance, as exemplified in Giuseppe Verdi's Don Carlo and the aria "O don fatale," with its wide tessitura, emotional contrasts, and dense orchestration. Traditional pedagogy emphasizes breath management, registration, and vowel modification, yet often overlooks the precise vocal-tract adjustments required for rapid timbral shifts and sustained projection. This article introduces the PEA Model (Pharyngeal, Expressive, Adaptive) which integrates three interrelated dimensions of dramatic mezzo-soprano technique. The pharyngeal dimension focuses on controlled shaping of the hypopharyngeal and epilaryngeal spaces to promote singers' formant clustering and reduce phonation thresholds, building on source-filter theory and its later refinements. The expressive dimension highlights how these same adjustments enable timbral modulation that conveys emotional depth, drawing on perceptual and cognitive studies of vocal timbre and affect. The adaptive dimension emphasizes individualized, health-conscious pedagogy that tailors technical development to each singer's anatomy and career path. By mapping these dimensions onto "O don fatale", the article offers testable frameworks and pedagogical applications that integrate acoustic efficiency, expressive intent, and sustainable artistry.*

**Keywords:** *Dramatic mezzo-soprano; Don Carlo; O don fatale; pharyngeal resonance; source-filter theory; vocal pedagogy; timbre and emotion*

## 1. Introduction

The dramatic mezzo-soprano voice has long been celebrated for its unique combination of power and lyricism. Roles such as Amneris in *Aida* and Azucena in *Il trovatore* require a singer to project over a full orchestra while sustaining expressive subtlety. Among these roles, Princess Eboli in Giuseppe Verdi's *Don Carlo* presents a special challenge. Her aria "*O don fatale*" compresses a striking psychological journey into a single scene: it begins with vehement declamation, moves into penitential lyricism, and ends in heroic resolve. Performing this aria convincingly calls for far more than vocal stamina. It demands finely controlled shifts of timbre, rapid dynamic contrasts, and clear articulation of text.

Traditional training for dramatic mezzos focuses on breath management, register balancing, and vowel modification. These foundations remain indispensable, yet they do not always address the subtle vocal-tract adjustments that enable rapid timbral variation and effortless projection across a wide tessitura. Without a systematic understanding of these adjustments, singers may struggle to produce the dramatic color changes required by Verdi and other late-Romantic composers.

A growing body of voice science points to the importance of pharyngeal voice, defined here as coordinated shaping of an expanded hypopharyngeal cavity and a narrowed epilaryngeal tube (the epilarynx). This approach moves beyond metaphorical notions of "darkening" or "opening" the throat by providing an acoustically and physiologically interpretable account of how singers achieve projection with flexibility. Classic acoustic theory supplies the foundation. Sundberg (1974) identified the singers' formant, a clustering of spectral energy around 2.5–3.5 kHz that supports orchestral audibility. Titze (1988) demonstrated that favourable supraglottal inertance can lower phonation threshold pressure, thereby reducing respiratory effort while maintaining loudness. Story and Titze (1995) further clarified how tract shape interacts with source oscillation to support efficient sound production across vowels and registers..

Modern imaging and computational methods have refined these early theories. Magnetic resonance imaging indicates that professional opera singers commonly coordinate a lowered larynx, an enlarged hypopharyngeal cavity, and calibrated epilaryngeal narrowing during high-intensity singing (Ikävalko et al., 2022). Titze and Talkin (1979) explored laryngeal configurations through numerical simulation, showing how intensity and efficiency can be supported through appropriate tissue-layer tensioning within a body–cover framework. Related studies further specify acoustic outcomes: Lee et al. (2008) examined the relationship between the singers' formant and the speaker's ring region using long-term average spectral analyses, while Zhang (2021) described interactions between laryngeal and epilaryngeal adjustments that influence vocal-fold contact pressure under increased intensity. Additional work on modal locking and airflow turbulence suggests that small tract constrictions can have disproportionate effects on acoustic stability and energy loss (Grandchamp et al., 2008; Murtola et al., 2018).

Importantly, pedagogical studies indicate that singers can learn these adjustments more reliably when guided by **real-time acoustic feedback**, operationalised as immediate visual or numerical displays such as spectrograms, long-term average spectra (LTAS), SPL tracking, and band-energy cues in the 2–4 kHz region, rather than relying solely on metaphorical imagery (Mürbe et al., 2002).az

Alongside these physiological and acoustic insights, perceptual and cognitive studies confirm that timbre is a primary vehicle of emotional meaning. Tursunov et al. (2019) found that listeners rely heavily on timbre, beyond fundamental frequency, to recognize vocal emotions. Laukka and Effenbein (2020) demonstrated that associations between timbral brightness and emotional intensity are consistent across cultures. Neuroimaging studies show that professional opera singers activate default-mode network regions when processing operatic vibrato and timbre, suggesting a deep link between vocal color and embodied emotional response (Bihari et al., 2024). Pedagogical research reinforces these findings by showing that singers can learn to adjust resonance deliberately when guided by real-time acoustic feedback rather than metaphorical imagery (Mürbe et al., 2002).

Despite converging evidence across acoustics, imaging, and perception research, studio pedagogy rarely integrates biomechanical efficiency, expressive timbral targets, and individualised training decisions into a single operational workflow for dramatic mezzo-soprano demands. Existing discussions often prioritise one layer of the system, such as breath management and projection heuristics, descriptive accounts of tract postures in imaging studies, or listener-based findings on timbre and affect, without specifying construct boundaries, feedback loops, and decision criteria that can be applied consistently in instruction and evaluated empirically. What remains underdeveloped is a model that (a) defines tract-based efficiency mechanisms, (b) links those mechanisms to expressive timbral contrasts, and (c) articulates adaptive decision rules that protect sustainability under repertoire-specific workload.

The present article addresses this gap by proposing the PEA Model: Pharyngeal, Expressive, Adaptive. This framework situates pharyngeal adjustments within a dynamic system where technical efficiency, expressive intent, and individualized pedagogy interact continuously. The pharyngeal dimension focuses on precise hypopharyngeal and epilaryngeal management for projection and stamina. The expressive dimension highlights how these same adjustments create timbral contrasts that convey dramatic emotion. The adaptive dimension ensures that training remains tailored to each singer's anatomy and career path, promoting long-term vocal health.

The remainder of this article develops the PEA Model in detail. Section 2 reviews the relevant literature, from classical voice science to contemporary imaging and cognitive studies. Section 3 presents the conceptual framework and its three interdependent dimensions. Section 4 applies the model to Verdi's "O don fatale," demonstrating how physiological and expressive factors align in performance. Sections 5 and 6 discuss pedagogical implications, theoretical contributions, and avenues for future research. The conclusion summarizes how the PEA

Model offers a comprehensive and evidence-based approach to achieving both dramatic power and emotional immediacy in operatic performance.

## **2. Literature Review**

The purpose of this review is to position the proposed PEA Model within current scholarship on operatic voice science. Three strands of research are especially relevant: classical theories of operatic voice production, contemporary imaging and computational modeling of vocal-tract configuration, and perceptual and cognitive studies of vocal timbre and emotion. Together these strands clarify how pharyngeal and epilaryngeal shaping can integrate technical efficiency with expressive meaning

### **2.1 Classical Voice Science: Source–Filter Theory and the Singers’ Formant**

The scientific study of operatic voice production began with acoustic research that established the vocal tract as an active resonance filter. A landmark was Sundberg’s (1974) explanation of the singers’ formant, a concentration of spectral energy around 2.5–3.5 kHz that allows an operatic voice to project over a full orchestra. Sundberg demonstrated that this acoustic advantage results from clustering of the third, fourth, and fifth formants, supported by a widened lower pharynx and the creation of a distinct epilaryngeal tube.

Titze (1988) introduced a complementary physical perspective by describing how supraglottal inertance lowers the phonation threshold pressure required for sustained vibration. This work highlighted that precise control of pharyngeal and epilaryngeal geometry enables powerful sound with reduced respiratory effort. Story and Titze (1995) further modeled the time-varying interactions between harmonics and formants, offering a dynamic account of resonance tuning. Lee et al. (2008) added insight into the so-called speaker’s ring resonance, showing parallels between operatic projection and strategies used in powerful speech.

Other physical investigations deepen understanding of these mechanisms. Murtola et al. (2018) examined modal locking between the vocal folds and the vocal tract, while Grandchamp et al. (2008) analyzed how free-jet turbulence within the tract affects acoustic stability. Together, these classical studies establish three enduring principles: vocal projection depends on tract tuning as much as on lung pressure and glottal closure; clustering of formants reduces phonation thresholds and conserves energy; and small tract adjustments can yield major acoustic and perceptual effects.

### **2.2 Contemporary Imaging and Modeling: Pharyngeal and Epilaryngeal Dynamics**

Advances in imaging and computation have extended these classic theories. Magnetic resonance imaging (MRI) provides direct visualization of vocal-tract shapes during singing. Ikävalko et al. (2022) compared operatic, kulning, and edge qualities in professional singers and found that operatic loud singing consistently involves a lowered laryngeal position, enlarged hypopharyngeal space, and controlled epilaryngeal narrowing. Titze (2006) combined

experimental sound signals with three-dimensional tract models to show that calibrated epilaryngeal constriction increases output power without elevating phonation threshold pressure.

Other studies offer complementary perspectives. Mainka et al. (2015) demonstrated that widening of the hypopharynx lowers the spectral centroid and increases perceived vocal warmth. Zhang (2021) explored how epilaryngeal and laryngeal adjustments interact to regulate vocal-fold contact pressure, providing a biomechanical explanation for how singers manage intensity without strain. Lyubarskaya et al. (2024) reported that female classical singers employ differentiated resonatory strategies depending on pitch and intensity, reinforcing the importance of flexible tract control.

Comparative style studies also enrich pedagogy by clarifying where tract strategies overlap and where constructs diverge across genres. Perta et al. (2021) used MRI to show that “twang,” a bright, forward quality common in contemporary commercial singing, involves a configuration that differs systematically from classical operatic production. Although both operatic projection and “twang” may involve epilaryngeal narrowing, they should not be treated as interchangeable constructs. In this article, “pharyngeal voice” refers to tract-shaping strategies used to support operatic efficiency and controllable colour modulation under classical repertoire constraints, whereas “twang” is primarily a style-labelled perceptual outcome typical of commercial contexts. Clarifying this boundary prevents conceptual conflation when transferring terminology between repertoire systems and aligns pedagogical goals with context-appropriate timbral targets.

Computational and biomechanical modeling adds explanatory depth. Murtola et al. (2018) investigated how interactions between vocal-fold oscillations and tract resonances produce modal locking. Grandchamp et al. (2008) validated simplified free-jet turbulence models applied to the vocal tract, showing how small constrictions influence acoustic energy loss. Together these studies confirm that the pharynx and epilarynx are not passive resonators but dynamic, trainable structures essential to sustained operatic projection and tonal variety.

### **2.3 Vocal Timbre and Emotion Perception**

While the first two strands focus on physiology and acoustics, a third highlights timbre as a central carrier of emotional meaning. Tursunov et al. (2019) demonstrated that listeners rely on timbral cues, often more than on pitch, when decoding vocal emotions. Laukka and Elfenbein (2020) found that timbre–emotion associations, such as the link between brightness and heightened arousal, are consistent across cultures, suggesting a universal perceptual basis for timbral expressivity. Bihari et al. (2024) reported that professional opera singers show heightened default-mode network activity when exposed to operatic vibrato and timbre, pointing to an embodied link between vocal color and affective self-processing.

Pedagogical research underscores that such expressive control can be trained. Mürbe et al. (2004) and Mürbe et al. (2002) describe how real-time acoustic feedback and kinesthetic voice pedagogy help singers adjust resonance deliberately, replacing metaphorical imagery with measurable strategies. These insights support the view that pharyngeal shaping is not only an acoustic technique but also a means of conveying psychological depth.

## 2.4 Synthesis

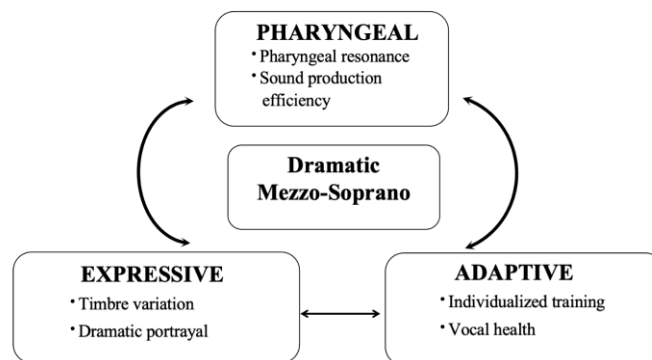
Taken together, these studies converge on three key insights. First, filter control is central: pharyngeal and epilaryngeal adjustments directly determine projection, efficiency, and timbral character. Second, expressive meaning depends strongly on spectral shaping, making pharyngeal control essential for dramatic roles that require rapid emotional shifts. Third, effective training must be individualized, since singers differ in anatomy and perceptual habits. Yet few existing approaches combine these insights into a single pedagogical model. By uniting them in the Pharyngeal–Expressive–Adaptive framework, the present study offers a conceptual bridge from foundational acoustics through modern imaging to the cognitive and emotional realities of operatic performance.

## 3. Conceptual Framework: The PEA Model

This section presents the PEA Model, which stands for Pharyngeal, Expressive, and Adaptive. The model offers a new framework for understanding and teaching dramatic mezzo-soprano technique. Drawing on classic source–filter theory and recent imaging, modeling, and cognitive research, it treats dramatic singing as a dynamic system in which biomechanical filter control, expressive timbral shaping, and adaptive pedagogy interact continuously. Rather than reporting new experimental data, this conceptual framework synthesizes established knowledge into a structure that can guide both empirical studies and practical instruction. The three dimensions of the model are described in the following subsections.

### Figure 1

*The Pharyngeal–Expressive–Adaptive (PEA) Model*



*Note.* Conceptual framework showing how tract-based efficiency mechanisms (Pharyngeal) interact with timbre-based dramatic communication (Expressive) and with individualised training decisions and sustainability safeguards (Adaptive). Suggested indicators include LTAS energy concentration in the 2–4 kHz region (singers' formant/speaker's ring), spectral centroid shifts (brightness–warmth), SPL targets for projection, perceived exertion or fatigue self-report, and, where feasible, laryngeal or epilaryngeal observations. Arrows represent feedback loops: technical efficiency enables expressive nuance (P → E), expressive targets guide adaptive practice choices (E → A), and adaptive diagnostics and safeguards refine pharyngeal settings over time (A → P). Adaptive decisions are made by matching passage demands to observable indicators while maintaining recovery and injury-risk safeguards.

### **3.1 Pharyngeal Dimension: Biomechanical and Acoustic Control**

The pharyngeal dimension provides the technical foundation of the PEA Model. Early voice science showed how deliberate shaping of the vocal tract supports operatic projection. Sundberg (1974) explained that the singers' formant, an energy cluster around 2.5 to 3.5 kHz, results from the combined effect of a widened lower pharynx and a well-defined epilaryngeal tube. Titze (1988) demonstrated that such tract configurations create favorable inertive reactance, lowering the subglottal pressure required to start and sustain vocal-fold vibration. Story and Titze (1995) modeled how time-varying tract shapes reinforce harmonic–formant interactions, strengthening resonance and carrying power.

Modern imaging and computational studies refine these principles. Magnetic resonance imaging has revealed that professional opera singers commonly use a lowered larynx, an expanded hypopharyngeal cavity, and calibrated epilaryngeal narrowing when singing at high intensity (Ikävalko et al., 2022). Titze (2006) further reported that balanced epilaryngeal constriction can increase acoustic output without raising phonation threshold pressure. Mainka et al. (2015) added that controlled widening of the hypopharynx can lower the spectral centroid and enrich timbre when a warmer colour is required.

These findings identify three interrelated mechanisms that define the pharyngeal dimension. First, stable hypopharyngeal expansion supports formant clustering and prevents energy loss. Second, precise epilaryngeal narrowing strengthens the singers' formant and increases carrying power. Third, vowel-specific tuning of the first and second formants maintains clarity and projection across registers. Together these mechanisms create an acoustically efficient and timbrally flexible filter that serves as the technical core of the PEA Model.

### **3.2 Expressive Dimension: Timbral and Dramatic Shaping**

The expressive dimension links the biomechanical control of the pharyngeal dimension to the dramatic and emotional meaning of operatic singing. Contemporary research shows that timbre plays a primary role in how listeners perceive vocal emotion. Tursunov et al. (2019)

demonstrated that listeners depend strongly on timbral cues, sometimes more than on pitch, when identifying emotions in the human voice. Laukka and Elfenbein (2020) confirmed that associations between timbral brightness and heightened arousal or urgency are consistent across cultures, indicating that the expressive function of timbre has a universal perceptual basis. Bihari et al. (2024) reported that operatic vibrato and timbre activate default-mode network areas in professional singers, suggesting a deep embodied link between timbral color and emotional engagement.

For the dramatic mezzo-soprano, controlled pharyngeal adjustments become powerful expressive tools. Subtle narrowing or release of the epilaryngeal tube can shift spectral energy to create vocal colours that convey anger, sorrow, or supplication. Likewise, minor modifications of the lateral pharyngeal walls and tongue position can darken or brighten the tone, enabling quick transitions between emotional states. Such abilities are essential for a role like Princess Eboli in Verdi's *Don Carlo*, whose aria "O don fatale" demands an immediate move from fierce self-reproach to humble prayer and back to passionate resolve.

Pedagogical studies support the trainability of these expressive skills. Mürbe et al. (2004) and Mürbe et al. (2002) describe how real-time acoustic feedback, such as spectrogram/LTAS visualisation, SPL monitoring, and 2–4 kHz band-energy cues, can help singers shape the spectral envelope deliberately and link tract sensations to observable outcomes. These approaches suggest that timbral manipulation is not an accidental by-product of technique but a learnable component of artistic communication. Within the PEA Model, the expressive dimension therefore emphasises purposeful use of pharyngeal and epilaryngeal configurations to communicate emotional content with clarity and immediacy.

### **3.3 Adaptive Dimension: Individualized Pedagogy and Vocal Sustainability**

The adaptive dimension ensures that pharyngeal and expressive techniques are applied in a way that suits each singer's anatomy, learning style, and long-term health. No two singers have identical vocal tracts or identical artistic goals. An approach that is safe and effective for one voice may cause tension or fatigue in another. The adaptive dimension of the PEA Model therefore emphasizes diagnosis, progressive skill building, and continual monitoring.

Diagnostic assessment can include non-invasive acoustic analysis, real-time spectrographic feedback, and, where available, magnetic resonance imaging to visualize the singer's default laryngeal height, pharyngeal width, and vowel tuning (Ikävalko et al., 2022; Perta et al., 2021). These tools allow teachers to identify individual tendencies and to design training exercises that target specific needs. Pedagogical research supports this individualized approach. Mürbe et al. (2004) show that customized acoustic and kinesthetic feedback accelerate the development of resonant strategies, while Mürbe et al. (2002) highlights the benefits of incremental, goal-focused lessons that adapt to each student's progress.

Progressive training can begin with semi-occluded vocal-tract (SOVT) exercises that stabilise source–filter interaction and enhance proprioceptive awareness, for example straw phonation (in air or water), lip trills, tongue trills, and voiced fricatives such as /v/ and /z/. Progression criteria can include stable SPL at reduced perceived effort, consistent 2–4 kHz band-energy cues across vowels, and the ability to reproduce a target timbre without excessive throat constriction. The sequence can then move to vowel-anchored tasks across pitch and intensity to stabilise formant alignment, before integrating these behaviours into aria-level rehearsal with rapid dynamic and timbral contrasts. Throughout this process, teachers encourage planned recovery periods, adequate hydration, and balanced alternation of narrowing and controlled release to avoid chronic constriction (Titze, 2006).

By embedding health and efficiency safeguards into daily practice, the adaptive dimension supports vocal longevity. It ensures that the technical gains of pharyngeal and expressive training contribute to sustainable artistry rather than short-term effects. Within the PEA Model, adaptation is therefore not an optional afterthought but a structural principle that links scientific insight with individual vocal welfare.

### **3.4 Dynamic Interactions**

The three dimensions of the PEA Model (pharyngeal, expressive, and adaptive) work together as a unified system rather than as separate steps. Each dimension influences the others in a continuous feedback process that mirrors the realities of operatic performance and training. Pharyngeal control supports expressive variety. Stabilizing the hypopharynx and adjusting the epilaryngeal tube create the acoustic flexibility needed to move between brilliant and warm timbres (Sundberg, 1974; Titze, 1988; Titze, 2006). These timbral changes enhance dramatic interpretation and align with the psychological transformations conveyed by music and text (Tursunov et al., 2019; Laukka & Elfenbein, 2020). Expressive objectives also shape adaptive decisions. When a singer aims to portray sudden rage or tenderness, the teacher can select exercises that strengthen or release specific pharyngeal or epilaryngeal actions that influence timbre (Ikävalko et al., 2022; Mainka et al., 2015).

The adaptive dimension further refines technical development. Ongoing monitoring with acoustic analysis or, when available, imaging allows singers and teachers to observe how the voice responds to different tract settings and to improve efficiency and expressivity over time (Mürbe et al., 2004; Perta et al., 2021). Planned recovery periods, adequate hydration, and balanced alternation of narrowing and release protect vocal health and support long careers (Titze, 2006; Zhang, 2021).

Through this dynamic interaction, the PEA Model presents technical efficiency, expressive depth, and individual adaptation as mutually reinforcing processes that develop together in daily practice and on stage.

### 3.5 Propositions for Future Empirical Testing

Although this article is conceptual, the PEA Model leads to several precise hypotheses that can guide future interdisciplinary research. Each proposition is grounded in established findings in vocal acoustics, physiology, and music perception.

**Efficiency proposition.** Training that combines hypopharyngeal stabilisation with carefully calibrated epilaryngeal narrowing is expected to reduce the subglottal pressure required to reach high SPL targets, consistent with evidence that favourable supraglottal inertance can lower phonation threshold pressure (Titze, 1988; Titze, 2006). Candidate measures include SPL-to-perceived-effort ratios, airflow estimates, and non-invasive proxies of phonation threshold pressure, complemented by LTAS-based efficiency indicators.

**Projection proposition.** Sustained clustering of spectral energy in the 2.5–3.5 kHz region is expected to correlate with stronger perceived orchestral penetration than can be achieved through glottal adduction alone (Sundberg, 1974; Ikävalko et al., 2022). Suggested metrics include LTAS band ratios in the 2–4 kHz region, spectral slope or centroid measures, and blinded listener ratings of “carry” under orchestra-masked listening conditions.

**Expressive proposition.** Controlled adjustments of hypopharyngeal and epilaryngeal shaping are expected to correlate with listener ratings of emotional intensity and dramatic authenticity, consistent with evidence that timbre is central to vocal-emotion decoding (Tursunov et al., 2019; Laukka & Efenbein, 2020) and that operatic timbre engages affective neural networks in trained singers (Bihari et al., 2024). Test protocols may combine controlled timbre-contrast tasks with acoustic feature extraction and blinded perceptual panels for emotion intensity and dramatic authenticity ratings.

**Health proposition.** Adaptive training that alternates narrowing with controlled release and includes planned recovery is expected to reduce fatigue risk relative to approaches that rely mainly on forceful glottal closure (Titze, 2006; Zhang, 2021). Monitoring can include fatigue and recovery self-reports, session-load tracking, and, where available, clinician-supported screening or laryngeal observation to contextualise risk.

These propositions can be tested through combined acoustic, physiological, and perceptual studies. For example, real-time subglottal pressure measurements could verify reductions in phonation threshold, while blinded listening panels could evaluate the effect of targeted pharyngeal adjustments on perceived emotional intensity. Longitudinal studies could examine how PEA-based training influences vocal health and career longevity.

### 3.6 Conceptual Contribution

The PEA Model provides a comprehensive framework that unites technical efficiency, expressive artistry, and adaptive pedagogy in a single conceptual structure. Earlier studies often treated these aspects separately, focusing either on the physics of source–filter interaction

(Sundberg, 1974; Titze, 1988), on imaging and modeling of vocal-tract shapes (Ikävalko et al., 2022; Titze, 2006), or on the perceptual decoding of vocal timbre (Tursunov et al., 2019; Laukka & Efenbein, 2020). By integrating these strands, the PEA Model shows that the same pharyngeal and epilaryngeal adjustments that optimize resonance also shape emotional communication and can be trained safely through individualized methods.

This conceptual integration carries several pedagogical and research implications. For teachers, it reframes pharyngeal control as a primary and trainable skill, complementing traditional emphases on breath management and registration. For researchers, it provides a system of testable propositions that connect measurable acoustic and physiological variables with perceptual outcomes and long-term vocal health (Titze, 2006; Zhang, 2021). For performers, it offers a holistic understanding of how physical configuration, expressive intent, and adaptive practice interact during demanding repertoire such as Verdi's *O don fatale*.

By bringing together biomechanical, cognitive, and educational perspectives, the PEA Model moves beyond descriptive accounts of operatic voice. It presents pharyngeal voice training as an essential component of dramatic mezzo-soprano technique and lays a foundation for future empirical studies that will refine and expand the model. In doing so, it contributes both a theoretical advance and a practical resource for singers and teachers seeking to unite technical mastery with dramatic immediacy.

#### **4. Application of the PEA Model to Verdi's *O don fatale***

To make the application score-anchored without reproducing copyrighted excerpts, the analysis uses text cues and formal-function labels to segment "*O don fatale*" and to operationalise the PEA dimensions at the segment level. The application is implemented as a cyclical workflow: (a) identify the segment demand and the intended timbre direction, (b) select an initial pharyngeal strategy to meet baseline efficiency/projection targets, (c) run brief practice trials with immediate acoustic and perceptual checks, and (d) make adaptive decisions by adjusting intensity, exercise choice, and recovery dosing when targets are not met without undue effort or accumulating fatigue. Operational indicators include spectrogram/LTAS cues (2–4 kHz energy), spectral centroid shifts (brightness–warmth), SPL–effort matching, and fatigue self-report. The segment-based mapping below is intended as a compact rehearsal guide and as a template for future segment-based acoustic sampling and blinded perceptual ratings.

Princess Eboli's aria *O don fatale* from Verdi's *Don Carlo* exemplifies the vocal and dramatic challenges faced by the dramatic mezzo-soprano. The music demands both orchestral penetration and finely shaded emotional contrast. The PEA Model—Pharyngeal, Expressive, Adaptive—provides a framework for analyzing these requirements and for guiding singers toward sustainable solutions.

#### **Segment mapping (text-anchored, without score excerpts).**

**Opening exclamation (“O don fatale”; dramatic declamation).** The primary demand is immediate orchestral audibility and a stable high-intensity onset without pressed phonation. PEA emphasis is Pharyngeal + Adaptive, prioritising calibrated epilaryngeal narrowing with hypopharyngeal stability while controlling intensity ramping and recovery. Quick “call” trials and brief SOVT resets can stabilise the onset, with checks for stable 2–4 kHz energy and SPL targets achieved at reduced perceived effort.

**High-arousal self-reproach lines (rapid text delivery).** The primary demand is clarity and rapid dynamic contrast without losing ring. PEA emphasis is Pharyngeal → Expressive, maintaining efficiency while shaping a brighter, urgent timbre. Rhythm-first drills followed by pitched repetition and intentional contrast pairs (brighter vs warmer) can establish controllable timbral contrasts. Diagnostics include listener checks for urgency without shouting and acoustic stability across repetitions.

**Lyrical prayer (“O mia regina”; sustained legato).** The primary demand is warmth, legato continuity, and resonance stability across long phrases. PEA emphasis is Expressive supported by Pharyngeal, allowing warmth without dullness. Vowel-anchored legato work with mapped breath points and micro-resets supports consistent timbre, monitored by centroid shifts toward warmth without SPL collapse and stable fatigue ratings across takes.

**Final resolve / climactic closing (sustained load).** The primary demand is authority and sustained projection under cumulative fatigue. PEA emphasis is Adaptive integrating Pharyngeal + Expressive, with pacing and recovery dosing to preserve ring while sustaining dramatic colour. Segment chaining limited full-run blocks, and post-run cooldown routines support reproducibility, monitored by stable spectral features and fatigue–recovery patterns over time.

#### **4.1 Pharyngeal Dimension: Acoustic and Physiological Strategies**

The opening exclamation “O don fatale” requires immediate brilliance capable of cutting through Verdi’s dense orchestration. According to the singers’ formant principle, clustering of upper formants around 2.5 to 3.5 kHz enables such projection (Sundberg, 1974). Source–filter theory adds that when the epilaryngeal tube is shaped to create favorable inertive reactance, the subglottal pressure needed for loud phonation decreases (Titze, 1988; Titze, 2006). MRI studies confirm that professional opera singers typically achieve this effect with a lowered larynx, an expanded hypopharynx, and targeted epilaryngeal narrowing (Ikävalko et al., 2022).

In practice, the singer can begin the aria by narrowing the epilaryngeal tube while maintaining lateral pharyngeal openness. This combination reinforces the singers’ formant and maintains vowel clarity. As the aria moves to the central lyrical section “O mia regina,” a controlled release of the epilaryngeal constriction together with slight widening of the oropharyngeal space can lower the spectral centroid and add warmth (Mainka et al., 2015). The reprise of the opening theme calls for a return to brilliance without vocal strain, achieved through reactivation

of epilaryngeal narrowing combined with precise vowel tuning (Story & Titze, 1995). These sequential adjustments illustrate the core mechanisms of the pharyngeal dimension in a live operatic context.

#### **4.2 Expressive Dimension: Dramatic and Affective Mapping**

The expressive dimension of the PEA Model explains how these physical maneuvers translate into dramatic meaning. The first section's metallic brightness communicates Eboli's self-reproach and despair. Studies of vocal emotion show that listeners consistently associate high spectral energy and timbral brightness with anger or urgency (Tursunov et al., 2019; Laukka & Elfenbein, 2020). During the middle section, timbral darkening conveys humility and penitence, drawing on cultural and cross-cultural associations of lower spectral centroid with warmth and sorrow (Laukka & Elfenbein, 2020). The climactic return integrates brilliance with the earlier lyric warmth, symbolizing the character's synthesis of guilt and courage.

Neuroscientific evidence supports this interpretation. Operatic vibrato and rich timbre activate affective and self-referential networks in trained singers, highlighting a deep embodied connection between vocal color and emotional processing (Bihari et al., 2024). The expressive dimension therefore treats timbre not as a by-product but as a central element of dramatic storytelling. Through conscious pharyngeal and epilaryngeal control, the singer can match vocal color to evolving psychological states and musical form.

#### **4.3 Adaptive Dimension: Pedagogical and Health Considerations**

The adaptive dimension ensures that these strategies are tailored to each singer's unique anatomy and artistic profile. Initial assessment can include acoustic spectrography to identify default laryngeal position, habitual vowel tuning, and preferred resonance strategies (Mürbe et al., 2004; Perta et al., 2021; Peterson & Barney, 1952). With this information, teachers can build a progressive regimen. The first stage focuses on awareness through semi-occluded vocal-tract exercises that heighten proprioceptive sensitivity to the pharyngeal and epilaryngeal spaces. The second stage uses isolated vowel exercises across a wide tessitura to stabilize formant alignment, supported by real-time spectral feedback (Titze, 2006). The third stage integrates these skills into full-aria rehearsals that include sudden dynamic contrasts and sustained high tessitura passages.

Throughout the process, careful pacing and recovery are essential. Adequate hydration, scheduled vocal rest, and balanced alternation between narrowing and release help prevent excessive muscular tension and reduce the risk of phonotrauma (Titze, 2006). This individualized approach ensures that dramatic expressivity is achieved without sacrificing long-term vocal health.

## 4.4 Summary

Analyzing *O don fatale* through the PEA Model demonstrates how pharyngeal, expressive, and adaptive factors converge in performance. Pharyngeal shaping secures the acoustic power needed to project over the orchestra. Expressive control of timbre translates physical adjustments into vivid emotional meaning. Adaptive pedagogy aligns these strategies with the singer's unique physiology and career demands. By linking measurable acoustic mechanisms with dramatic interpretation and sustainable training, the PEA Model provides both a theoretical framework and a practical guide for one of the most demanding arias in the dramatic mezzo-soprano repertoire.

## 5. Discussion

The analysis of Verdi's *O don fatale* through the PEA Model clarifies how pharyngeal voice training can unify technical efficiency and expressive artistry in dramatic mezzo-soprano performance. This section discusses theoretical implications, pedagogical applications, relationships to traditional instruction, directions for research, and the conceptual contribution of the model.

### 5.1 Integrating Technical Efficiency and Expressive Artistry

The PEA Model demonstrates that pharyngeal and epilaryngeal adjustments are not peripheral resonance strategies but essential tools for efficient operatic singing. Classical source-filter theory explains how supraglottal inertance lowers phonation threshold pressure (Titze, 1988) and how singers' formant clustering enhances orchestral penetration (Sundberg, 1974). Contemporary imaging and modeling confirm that professional singers typically combine a lowered larynx with precise hypopharyngeal and epilaryngeal shaping to achieve these effects (Ikävalko et al., 2022; Titze & Talkin, 1979; Anikin, 2020).

At the same time, the expressive dimension shows that timbre, more than pitch alone, conveys emotional meaning (Tursunov et al., 2019; Laukka & Elfenbein, 2020). Neuroimaging indicates that operatic vibrato and timbre engage affective neural circuits, strengthening both the performer's and the audience's emotional experience (Bihari et al., 2024). By joining these physiological and cognitive insights, the PEA Model illustrates that technical efficiency and dramatic communication are mutually reinforcing.

### 5.2 Pedagogical Implications

For vocal pedagogy, the model supports diagnostic and adaptive instruction. Teachers can begin with acoustic spectrography or real-time imaging to identify each singer's default pharyngeal and laryngeal settings (Mürbe et al., 2004; Perta et al., 2021). Training then progresses from awareness-building through semi-occluded vocal-tract exercises to controlled epilaryngeal narrowing and hypopharyngeal management, culminating in full-aria integration.

Throughout, balanced alternation between narrowing and release and planned recovery periods guard against fatigue and phonotrauma (Titze, 2006; Zhang, 2021).

This structured, evidence-based pedagogy clarifies common misconceptions that dramatic projection requires heavy glottal pressure or excessive chest dominance. Instead, it positions efficient filter control as the key to producing powerful sound safely and with expressive flexibility.

### **5.3 Relationship to Traditional Approaches**

The PEA Model complements rather than replaces classical operatic training. Breath management, registration balancing, and vowel modification remain indispensable. What the model adds is a targeted understanding of pharyngeal and epilaryngeal resonance as a primary, trainable skill. This perspective parallels developments in other high-intensity vocal styles. For instance, Tuvan overtone singing and commercial “twang” both rely on deliberate tract shaping for projection and color (Bergevin et al., 2020; Perta et al., 2021; Saldías et al., 2021). By situating dramatic mezzo-soprano training within this broader context, the model enriches rather than disrupts established pedagogical traditions.

### **5.4 Directions for Future Research**

The propositions identified earlier provide clear avenues for empirical testing. Controlled experiments could compare singers trained with PEA-based pharyngeal techniques to those following traditional methods, measuring acoustic spectra, subglottal pressure, and listener ratings of dramatic intensity. Longitudinal studies could examine whether systematic pharyngeal training extends career longevity or reduces vocal injury risk. Neuroimaging might reveal how deliberate timbre modulation affects singers’ own affective engagement (Bihari et al., 2024). Cross-style comparisons could explore how the model adapts to dramatic sopranos, baritones, or non-classical performers while preserving its core mechanisms.

### **5.5 Positioning and Limitations**

The model’s core conceptual contribution is articulated in Section 3.6; here the PEA Model is positioned relative to established pedagogical and voice-science approaches, and its limitations are clarified. Compared with frameworks that primarily isolate anatomical movements or training “figures,” the PEA Model foregrounds repertoire-specific workflow integration by linking tract-based efficiency mechanisms to expressive timbral targets and to adaptive decision rules under sustained performance load. At the same time, the PEA Model is a synthesis framework and does not itself establish causal training effects; its propositions require empirical testing across singers, institutions, and repertoire contexts. Terminology overlap across styles (e.g., projection, “ring,” and “twang”) also necessitates careful construct definition when the model is applied beyond dramatic mezzo-soprano repertoire. These boundaries are presented to support transparent interpretation and to guide future validation studies.

## 6. Conclusion

This article has presented the PEA Model—Pharyngeal, Expressive, Adaptive—as a new framework for understanding and teaching dramatic mezzo-soprano technique. The model synthesizes classic source–filter theory (Sundberg, 1974; Titze, 1988) with recent imaging and computational research (Ikävalko et al., 2022; Titze & Talkin, 1979; Anikin, 2020) and with cognitive studies on vocal timbre and emotion (Bihari et al., 2024; Tursunov et al., 2019; Laukka & Elfenbein, 2020). By bringing these strands together, it highlights the central role of pharyngeal and epilaryngeal shaping in producing operatic power, sustaining vocal health, and communicating dramatic meaning.

The pharyngeal dimension shows how controlled hypopharyngeal expansion, precise epilaryngeal narrowing, and vowel-specific formant tuning create an acoustically efficient and timbrally versatile filter. The expressive dimension explains how these same adjustments yield the timbral contrasts that listeners associate with emotional intensity and psychological depth. The adaptive dimension ensures that training is individualized and health conscious, using diagnostic tools and progressive exercises to accommodate anatomical diversity and career demands.

The application of the PEA Model to Verdi’s *O don fatale* illustrates its practical value. By mapping acoustic strategies to key dramatic moments, the model provides both an analytical lens and a procedural guide for performers and teachers. It also generates testable propositions regarding efficiency, projection, expressive impact, and vocal health, opening pathways for future empirical validation.

By positioning pharyngeal voice training as a core component of dramatic mezzo-soprano technique, the PEA Model bridges long-standing gaps between vocal science, pedagogy, and expressive performance. It offers a conceptual foundation for new interdisciplinary studies and a practical resource for singers and teachers seeking to unite technical mastery with dramatic immediacy.

## References

- Anikin, A. (2020). The link between auditory salience and emotion intensity. *Cognition and Emotion*, 34(6), 1246–1259. <https://doi.org/10.1080/02699931.2020.1736992>
- Bergevin, C., Narayan, C., Williams, J., Mhatre, N., Steeves, J. K., Bernstein, J. G., & Story, B. (2020). Overtone focusing in biphonic tuvan throat singing. *ELife*, 9, e50476. <https://doi.org/10.7554/eLife.50476>

- Bihari, A., Nárai, Á., Kleber, B., Zsuga, J., Hermann, P., & Vidnyánszky, Z. (2024). Operatic voices engage the default mode network in professional opera singers. *Scientific Reports*, 14(1). <https://doi.org/10.1038/s41598-024-71458-4>
- Buescher, R., & Sims, S. (2011). The female pharyngeal voice and theories of low vocal fold damping. *Journal of Singing*, 68(1), 23-28.
- Edwin, R. (2008). Cross Training for the Voice. *Journal of Singing*, 65(1), 73.
- Grandchamp, X., Van Hirtum, A., & Pelorson, X. (2008). Experimental validation of simplified free jet turbulence models applied to the vocal tract. *arXiv preprint arXiv:0809.1639*. <https://doi.org/10.48550/arXiv.0809.1639>
- Ikävalko, T., Laukkanen, A.-M., McAllister, A., Eklund, R., Lammentausta, E., Leppävuori, M., & Nieminen, M. T. (2022). Three Professional Singers' Vocal Tract Dimensions in Operatic Singing, Kulning, and Edge—A Multiple Case Study Examining Loud Singing. *Journal of Voice*, 38(5). <https://doi.org/10.1016/j.jvoice.2022.01.024>
- Koufman, J., Radomski, T., Joharji, G., Russell, G., & Pillsbury, D. (1996). Laryngeal biomechanics of the singing voice. *Otolaryngology–Head and Neck Surgery*, 115(6), 527–537. [https://doi.org/10.1016/S0194-5998\(96\)70007-4](https://doi.org/10.1016/S0194-5998(96)70007-4)
- Laukka, P., & Elfenbein, H. A. (2020). Cross-Cultural Emotion Recognition and In-Group Advantage in Vocal Expression: A Meta-Analysis. *Emotion Review*, 13(1), 175407391989729. <https://doi.org/10.1177/1754073919897295>
- Lee, S.-H., Kwon, H.-J., Choi, H.-J., Lee, N.-H., Lee, S.-J., & Jin, S.-M. (2008). The Singer's Formant and Speaker's Ring Resonance: A Long-Term Average Spectrum Analysis. *Clinical and Experimental Otorhinolaryngology*, 1(2), 92. <https://doi.org/10.3342/ceo.2008.1.2.92>
- Lyubarskaya, F., Klimova, A., Fleischer, M., Mürbe, D., & Mainka, A. (2024). Female Classical Singers Apply Different Resonatory Strategies Than Male: Insights from an MRI-Based Analysis. *Journal of Voice*, 0892-1997. <https://doi.org/10.1016/j.jvoice.2024.06.016>
- Mainka, A., Poznyakovskiy, A., Platzek, I., Fleischer, M., Sundberg, J., & Mürbe, D. (2015). Lower Vocal Tract Morphologic Adjustments Are Relevant for Voice Timbre in Singing. *PLOS ONE*, 10(7), e0132241. <https://doi.org/10.1371/journal.pone.0132241>
- Mürbe, D., Pabst, F., Hofmann, G., & Sundberg, J. (2002). Significance of Auditory and Kinesthetic Feedback to Singers' Pitch Control. *Journal of Voice*, 16(1), 44–51. [https://doi.org/10.1016/s0892-1997\(02\)00071-1](https://doi.org/10.1016/s0892-1997(02)00071-1)

- 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*, *18*(2), 236–241. <https://doi.org/10.1016/j.jvoice.2003.05.001>
- Murtola, T., Aalto, A., Malinen, J., Aalto, D., & Vainio, M. (2018). Modal Locking Between Vocal Fold Oscillations and Vocal Tract Acoustics. *Acta Acustica United with Acustica*, *104*(2), 323–337. <https://doi.org/10.3813/aaa.919175>
- Perta, K., Bae, Y., & Obert, K. (2021). A pilot investigation of twang quality using magnetic resonance imaging. *Logopedics Phoniatrics Vocology*, *46*(2), 1–9. <https://doi.org/10.1080/14015439.2020.1757147>
- Peterson, G. E., & Barney, H. L. (1952). Control Methods Used in a Study of the Vowels. *The Journal of the Acoustical Society of America*, *24*(2), 175–184. <https://doi.org/10.1121/1.1906875>
- Saldías, M., Laukkanen, A. M., Guzmán, M., Miranda, G., Stoney, J., Alku, P., & Sundberg, J. (2021). The vocal tract in loud twang-like singing while producing high and low pitches. *Journal of Voice*, *35*(5), 807–e1. <https://doi.org/10.1016/j.jvoice.2020.02.005>
- Sen, R. (2025). The Harmony of Body and Voice: Integrating Vocal Techniques and Sports Physiology in Education. *Retos*, *70*, 1575–1585. <https://doi.org/10.47197/retos.v70.117140>
- Steinhauer, K. M. (2023). The Estill Voice Model: A paradigm for voice training and treatment. *Journal of the Acoustical Society of America*, *154*(4\_supplement), A352–A353. <https://doi.org/10.1121/10.0023770>
- Story, B. H., & Titze, I. R. (1995). Voice simulation with a body-cover model of the vocal folds. *The Journal of the Acoustical Society of America*, *97*(2), 1249–1260. <https://doi.org/10.1121/1.412234>
- Sundberg, J. (1974). Articulatory interpretation of the “singing formant.” *The Journal of the Acoustical Society of America*, *55*(4), 838–844. <https://doi.org/10.1121/1.1914609>
- Titze, I. R. (1988). The physics of small-amplitude oscillation of the vocal folds. *Journal of the Acoustical Society of America*, *83*(4), 1536–1552. <https://doi.org/10.1121/1.395910>
- Titze, I. R. (2006). Voice Training and Therapy With a Semi-Occluded Vocal Tract: Rationale and Scientific Underpinnings. *Journal of Speech, Language, and Hearing Research*, *49*(2), 448–459. [https://doi.org/10.1044/1092-4388\(2006/035\)](https://doi.org/10.1044/1092-4388(2006/035))

- Titze, I. R., & Talkin, D. T. (1979). A theoretical study of the effects of various laryngeal configurations on the acoustics of phonation. *The Journal of the Acoustical Society of America*, 66(1), 60–74. <https://doi.org/10.1121/1.382973>
- Tursunov, A., Kwon, S., & Pang, H.-S. (2019). Discriminating Emotions in the Valence Dimension from Speech Using Timbre Features. *Applied Sciences*, 9(12), 2470. <https://doi.org/10.3390/app9122470>
- Zhang, Z. (2021). Interaction between epilaryngeal and laryngeal adjustments in regulating vocal fold contact pressure. *JASA Express Letters*, 1(2). <https://doi.org/10.1121/10.0003393>