Kinesiology and Voice:

PART II—EXPLORING THE BRIDGES AND GAPS BETWEEN THEORY AND PRACTICAL APPLICATION

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Journal of Singing, November/December 2025
Volume 82, No. 2, pp. 171–185
https://doi.org/10.53830/sing.00167

Voice training is a complex process with numerous variables impacting outcomes. Overtraining and underrecovery are key factors to consider, but our knowledge of managing these is still evolving. Research on the role of exercise physiology principles in training athletes has informed our field; however, generalizability in voice training is still not fully clarified. This follow-up article consolidates the research discussed in part I of this series, providing a conceptual exercise physiology framework for some of our existing voice training paradigms to optimize voice training. This framework helps to build risk resilience and fatigue tolerance in singers.

Part I of this two-part series provided an overview of five exercise physiology principles and highlighted how kinesiology research has investigated the impact of applying these principles to skeletal–limb muscles when training athletes.[1] Similar to their athlete and dancer counterparts, the heightened risk of injury for singers is well documented; the physical demands of singers can be high regardless of professional status or vocal genre.[2] One of the primary desired outcomes of voice training is to build an efficient voice production technique that allows for singing in a desired style or genre in a manner that is reproducible and sustainable without increasing the risk of vocal injury. Part I of this series highlighted science-informed writings and research investigating the benefits of these principles in voice habilitative and rehabilitative arenas.

In athletic training, physical fatigue is often an anticipated outcome of an intense training session; however, this expectation does not typically carry over into the voice-training realm. Many variables can impact vocal health and voice training, and vocal fatigue can be an indication of an emerging problem. This is a scenario all singers and voice trainers must learn to navigate. Monitoring for overtraining and/or underrecovery is key to successfully managing vocal workload and minimizing the risk of vocal fatigue, strain, or injury.

Some of the exercise physiology principles introduced in part I—*workload*, *workload management*, and *acute-to-chronic workload*—are revisited in part II. An exploration of these terms within a voice training paradigm helps singers acquire better resilience from vocal injury and increase resistance to vocal fatigue.

Exercise physiology concepts and practices are not novel in voice training arenas; however, most pedagogy programs do not have structured guidelines for best practices on incorporating preventive measures and risk mitigation strategies into voice training paradigms. As a result, singers and voice trainers in habilitative settings often find themselves left to navigate these complaints on their own. Hoch and Sandage describe how exercise physiology principles might inform our voice training protocols.[3] In their study, they evaluated well-regarded voice pedagogy texts and exercises, categorizing published exercises/vocalizes into skill acquisition, overload, and reversibility.[4] Most exercises targeted skill acquisition (*specificity*) and *overload principles* but did not appear to directly target vocal fatigue in a preventive manner.[5] The authors emphasize the benefits of incorporating vocal exercises that target developing and maintaining a high level of vocal fitness (*reversibility principle*).[6] Conceptually, this aligns with the *acute-to-chronic workload* concept described in part I and later in this paper. Ideally, this approach would help develop better fatigue tolerance of higher voice workload demand, potentially minimizing the risk of vocal strain or injury. If singers maintain a robust baseline level of vocal fitness, they may inherently develop increased resilience to injury risk even if vocal workload and demand increase.[7]

Singers and teachers who are well-informed have likely benefited from existing literature to guide this process. Still, this information is not always formally imparted to pedagogy students or singers during their preprofessional training. Establishing best practices in a more structured manner will provide better foundational knowledge of the potential benefits of these principles, encouraging a more proactive approach to workload management and fatigue tolerance rather than a reactive approach that is implemented only if a problem emerges. Part I of this series described the five exercise physiology training principles in kinesiology and dance research, highlighting some of the parallels between these three disciplines. Part II consolidates these concepts with a focus on the practical application of these principles, highlighting how we may use them in habilitative and rehabilitative voice training paradigms to facilitate the development of fatigue resistance and risk mitigation (resilience) using a proactive, singer-centered approach.

WORKLOAD MANAGEMENT AND VOICE FATIGUE

In part I of this series, the concept of *workload* was defined as the degree of weight or resistance imposed upon a muscle during physical training. *Workload management* refers to how training is implemented.[8] In voice training, *chronic workload* refers to the typical demands on the voice that are sustainable and reproducible for the singer, providing a general idea of the baseline level of vocal fitness. *Acute workload* refers to an abrupt increase in vocal load. How a singer responds to and adjusts to the increased vocal demand could indicate the level of voice fatigability (fatigue resistance). Several variables could impact vocal workload, including vocal demands on range, volume, duration, and novel performance settings. Vocal workload management refers to the strategies employed to accommodate these demands in a healthy, sustainable manner. Some examples may include implementing vocal cooldown (active recovery), utilizing vocal naps (short periods of vocal rest), eliminating extraneous voice demands, optimizing the performance environment (amplification), and altering the key of a song.

Athletic trainers manage workload by balancing progressive overload (incremental increase in workload) during intensive training in conjunction with adequate time for posttraining recovery.[9] In essence, rest and recovery are an integral part of a serious athlete's training regimen. In a voice training setting, vocal rest is most commonly initiated in response to a vocal event or emerging problem rather than being considered a standard part of an active voice training regimen. Further, the more traditional version of full vocal rest over an extended period of time (more than two weeks) without any vocal maintenance may lead to a detraining effect (i.e., the reversibility principle).[10] However, incorporating short periods of vocal recovery time during active voice training may help reduce the assumption that voice rest and recovery are only indicated if there is a problem, normalizing use of vocal pacing (judicious distribution of vocal effort over time) as an integral part of active voice training. This paradigm shift could be beneficial not only when actively training, but also during extended periods of high voice demand when "marking" is not always considered a standard practice. Progressive overload in voice training would refer to "training up" to an anticipated voice demand incrementally and systematically. In a single-subject design, Sandage and Hoch described a recital preparation training process over six months.[11] The progressive training protocol included distributed practice, recovery days, and mental practice.[12] These authors describe the importance of balancing building vocal endurance with vocal pacing and judicious distribution of effort, advocating for a proactive approach to facilitate vocal workload management, minimize a detraining effect, and promote a rapid return to baseline after active singing.[13]

Part I in this series defined the *training-injury prevention paradox*, which posits that workload management is the predominant factor impacting the risk of injury (as opposed to the physical demand imposed by the workload itself).[14] Gabbett further described that athletes with a strong baseline level of physical fitness have built-in risk resilience, making them less susceptible to musculoskeletal injury when there is an abrupt increase in workload demand compared to athletes with lower levels of physical fitness.[15] Gabbett's theory requires more robust research to fully quantify the training-injury prevention paradox as directly impacting injury risk for athletes. However, his ideas may provide some useful conceptual guidelines when translating into a voice training model. Within this conceptual framework, it is not the increased vocal workload that increases the risk but rather how that workload is managed and progressively implemented over time to meet the new voice demands that increases the risk level for vocal strain or injury. Therefore, adequate management of an increased vocal workload involves finding the optimal balance between acute-to-chronic vocal workload levels and allowing for adequate recovery time during active training. While the training-injury prevention paradox requires more scientific evidence in kinesiology literature, the documented injury rates of dancers during times of abrupt increased workload—such as transitioning from preprofessional training into a professional company—do align with these concepts.[16] If there is overlap in the voice arena, students in preprofessional settings may benefit from careful monitoring and training as they enter into programs where vocal workload will significantly increase.

Managing vocal workload and overload when training the voice is inherently complex and a deliberate but tailored approach is warranted to minimize voice fatigue. Voice fatigue can be described as a perceived increase in effort after a period of voice use. It can occur either without or with a measurable decline in vocal quality. Like athletes and dancers, many variables, such as reduced sleep, individual biology, general health, and medications, can contribute to perceived fatigue having a negative impact on physical performance. Vocal fatigue is challenging to measure objectively; the degree and duration of vocal fatigue can vary significantly for speakers and singers.[17] Further, the presence of vocal fold mucosal tissue introduces another complex variable that must be considered (more discussion to follow).

The *dose–response* paradigm described by Hunter and colleagues attributes the voice user's *response* to a new *vocal dose* (voice demand) as the reason for the decline in performance. If the physical response does not adequately satisfy the new dose/demand, there will likely be perceived vocal effort, putting the voice user at increased risk for voice strain and possible injury.[18] For example, if an inexperienced singer is cast in a role with heavy voice demands (abrupt increase in acute workload demand) with inadequate training or ability to meet these demands, they may experience the onset of voice strain either with or without a decline in vocal quality. In this scenario, the singer's chronic workload (typical vocal load and demand) was inadequate to tolerate the increased vocal load and demands of the new role (acute workload). This paradigm dovetails nicely with the acute-to-chronic workload paradigm described earlier and in part I of this series. It also echoes some of the kinesiology research in athletes and dancers, which report a heightened risk of injury during times of increased workload without adequate preparation.[19]

Within the context of technical skill, voice training ideally aims to create adequate baseline vocal fitness so that a response to increased workload demand is adequate and efficient; however, how to implement this will vary depending on the singer. Voice fatigue is not necessarily directly related to the demand; only some singers will experience perceived fatigue in the same setting with the same vocal demands. Like an athlete, many variables can impact performance. As mentioned previously, sleep, hydration, individual biology, general health, psychological state, and medications are all variables that can affect perceived fatigue and physiologic performance. The degree of vocal fatigue will vary in terms of both duration and recovery of symptoms, making differentiating the primary cause challenging. The reasons behind these variations in how a singer is impacted are not entirely known, but the singer's level of baseline vocal fitness could be a significant contributing factor.

Similar to athletic training, a deliberate vocal training approach can target specific vocal skills, which aim to develop strength, stamina, and efficiency.[20] Establishing a stable level of baseline vocal fitness may help prevent vocal fatigue and facilitate risk resilience if vocal demands abruptly increase (acute vocal workload). Adequate time for active vocal recovery and vocal rest can be essential, even if vocal fatigue is absent. Given the unique nature of voice training, balancing voice workload and overload during training must be monitored for fatigue and/or decline; this must be addressed if vocal fatigue or decline in capabilities emerges. Strategies to address this are discussed below.

CROSS-TRAINING AND COUNTERTRAINING

Cross-training refers to a voice training paradigm that addresses the student's entire voice range regardless of genre. This could include chest-dominant training for a coloratura soprano. That is not to say that a coloratura must train in a rock/belt style; instead, it refers to strengthening and coordinating opposing registers even if that singer does not access it in a performance setting. A cross-training paradigm is often used by speech pathologists who are clinical singing voice specialists to address biomechanical imbalances that can lead to muscle tension dysphonia (MTD).[21]

In addition to registration, cross-training can also refer to training in varied vocal styles and genres. This is often required for musical theater performers, who are frequently required to shift vocal gears for a specific show, role, or audition requirement. Some operas can also call for vocal flexibility that is atypical for a given voice type. Described by Gershwin as a folk opera, *Porgy and Bess* is an example of bridging classical singing with other vocal styles.[22] A more recent contemporary opera departing from traditional operatic vocal production is *Fire Shut Up in My Bones* by Terence Blanchard (b. 1962). Making its debut at the Metropolitan Opera during the 2021–2022 season, this work required opera singers to have a facility with jazz and gospel vocal styles.[23] Regardless of genre or voice type, many voice trainers in both habilitative and rehabilitative settings incorporate some degree of cross-training and register balance into their teaching model, even if it is not viewed within the context of exercise physiology principles.[24]

Muscle and Muscle Fiber Adaptation

Voice pedagogues have used physiologic approaches that have shown great empirical utility. However, the underlying mechanisms relative to laryngeal musculature have yet to be fully vetted scientifically. In the study mentioned previously, Hoch and Sandage surveyed a collection of vocalises from respected voice pedagogy resources.[25] They highlighted that skill acquisition (specificity) and overload principles were among the most common training regimens.[26] In kinesiology, these principles relate specifically to training muscles. Although the generalizability to the laryngeal muscles is not fully clarified, some parallels warrant consideration.

As highlighted in part I of this series, voice science literature has documented that laryngeal muscles share some similarities to skeletal–limb muscles in terms of fiber type and density. Laryngeal muscles are comprised primarily of type II "fast-twitch" fibers (80 percent) that allow for rapid movements but expend muscular fuel more quickly (more easily fatigable). Most of the remaining muscle fibers are type I "slow-twitch" fibers (20 percent), which are more fatigue resistant. The posterior cricoarytenoid is an exception, consisting primarily of type I "fatigue-resistant" fibers. This is logical, given its critical role in opening the airway for breathing.[27] Kinesiology research has documented that some type II fibers may adapt to mirror the more fatigue-resistant fibers with targeted training.[28] Voice scientists have also documented adaptations with stimulation of thyroarytenoid (TA) and ultrasonic vocalization in rats.[29] These adaptations are primarily at the neuromuscular junction rather than changing muscle fiber size.[30] Although these studies have documented muscle fiber changes of the TA in rats with electronic stimulation of the TA over an extended time period, the degree to which laryngeal muscle fibers in humans are able to adapt to targeted training is not fully known. One of the earlier studies on laryngeal muscle morphology documented variation in laryngeal muscle fiber distribution across normal cadavers.[31] This prompts the question of whether these variations were genetic or adaptive based on the voice demands of that person during their lifetime. If these muscle fiber changes were adaptive based on voice demands over the lifetime of the person, the potential implications for voice training and muscle adaptation warrant serious consideration.

Reciprocal Inhibition

Each muscle in the body has a unidirectional action and a partner that engages in an opposite activity. These are referred to as agonist/antagonist pairs. The bicep extends the arm out and straight, and the tricep flexes the arm. This is a clear example of an agonist/antagonist pair. When the bicep is the predominating actor (agonist), the tricep is inhibited from engaging in its full capability and vice versa. *Reciprocal inhibition* (RI) is an involuntary spinal reflex that serves as a built-in protective mechanism.[32] During this neurological phenomenon, the nervous system inhibits the movement of the antagonist muscle when the agonist muscle is active. As an example, consider the bicep and tricep agonist/antagonist pairs. If one touches a hot stove burner, their arm will involuntarily and abruptly flex (bicep/agonist), moving the hand swiftly away to avoid injury. While the nervous system is signaling this involuntary, protective action (bicep), it simultaneously inhibits the antagonist muscle (tricep) so that its action does not conflict with the action of the bicep. In this setting, reciprocal inhibition functions primarily as a reflexive and involuntary safety mechanism, allowing for swift, unopposed movement in one direction. If both agonist and antagonist (bicep/tricep) muscles simultaneously contract to their full extent, the arm would not be able to move quickly because the actions of these muscles oppose each other. Contracting an agonist and antagonist muscle at high levels would be functionally akin to putting one foot on the brake and one foot on the gas pedal of a car.

A related phenomenon to RI is *coactivation,* which refers to the simultaneous contraction of agonist/antagonist muscle pairs. When both agonist and antagonist are contracted, they partially inhibit the action of the partner muscle. This results in a reduced amount of force generated by the agonist muscle. Consider how challenging it would be to walk with your hamstrings and quadriceps equally contracted. It is easy to imagine the gross inefficiency of both agonist and antagonist entirely opposing one another, and efficient movement encompasses a balance of these actions. Kinesiology literature has reported inconsistent findings regarding whether coactivation is wholly maladaptive or has potential stabilizing benefits in the appropriate setting. Latash speculated that the coactivation response is not always generated by the objective performance demands placed on the actor (agonist) but rather by the actor's subjective and subconscious perception of the physical demand (how the nervous system thinks the muscle should react in that setting). The unpredictability of a novel and challenging motor task can trigger "corrective action." This excessive coactivation is a "strategy of desperation," leading to overinvestment and excessive muscular contraction.[33]

Singing involves numerous actors, which can be both productive and counterproductive. Corrective actions that are counterproductive can reduce inefficiency, leading to vocal strain and/or fatigue. The role of reciprocal inhibition and coactivation in voice production has not been investigated, and how these mechanisms manifest biomechanically during singing is unknown. Still, the reciprocal relationship of agonist/antagonist muscle pairs and complementary coactivation can be viewed conceptually as part of a voice training paradigm. It is interesting to consider the role of coactive contraction in singing. The thyroarytenoid (TA) and cricothyroid (CT) are agonist/antagonist pairs. Grossly simplified, "TA-dominant" singing is conventionally associated with chest register, and "CT-dominant" singing is associated with head register. Given the TA and CT are both very active during most singing, the role of reciprocal inhibition as an involuntary, inhibitory, and reflexive response is not applicable in this context. Still, we can conceptualize the reciprocal relationship of muscle partners (agonist/antagonist) within a voice training paradigm, as voice production requires coordinated and efficient movement of the agonist-antagonist muscle pairs in the larynx, facilitating precise control over vocal fold function and pitch modulation during speech and singing.

A muscle in a constantly contracted state can become chronically foreshortened, which in turn forces the antagonist into a chronically lengthened position. If this unbalanced relationship is maintained, eventually, the antagonist will become weaker, further reinforcing the imbalance. If we apply this concept to voice training, when targeting the TA for strengthening chest register, it follows that training should also incorporate exercises targeting CT-dominant training to maintain balance. Theoretically, this cross-training allows the targeted active muscle to return to a more neutral position, helping to maintain a good length/tension relationship between the agonist/antagonist pairs (TA and CT) when training.

In addition to cross-training, we may further view the agonist/antagonist relationship of muscle pairs within the context of countertraining. This author defines countertraining as an immediate active recovery strategy employed to maintain a dynamic equilibrium after a vocal event. While some overlap exists, this author distinguishes countertraining from cross-training. Cross-training describes a longer-term, overarching voice training paradigm that fosters a general degree of vocal flexibility and balance, whereas countertraining can be viewed as a task-specific, active recovery strategy to help maintain balance and flexibility.

Active Recovery and Vocal Cooldown

Active recovery refers to engaging in lower-intensity activity after more rigorous exercise. In contrast, passive recovery refers to inactivity after extensive exercise. The voice training that correlates to the active recovery is the vocal *cooldown*. The vocal cooldown is a well-established concept used by many voice trainers and singers.[34] The positive impact of vocal cooldown exercises has been documented; however, they are less frequently incorporated into a singer's vocal fitness regimen than vocal warm-ups.[35] Within a countertraining framework, a vocal cooldown routine is more nuanced and targeted. It serves as an active recovery routine that considers agonist/antagonist muscle pairs and registration. It employs task specificity by countering the vocal "gear" that was highly active (rehearsal or performance). For example, a countertraining cooldown for a singer playing a role requiring a chest dominant, high pop/rock belt would include voice exercises that target the partner muscle or opposing "gear." This might include a light or "hooty" CT-dominant production of gentle sighs and descending scales. Using the concept of how agonist/antagonist muscle partners interact, the goal of this cooldown is to facilitate equilibrium by increasing CT activation, which helps to neutralize TA. Conversely, a high soprano cooling down after singing extensively in a CT-dominant production in the upper range might still incorporate gentle descending head register sounds, but would also elicit gentle vocalizations in a chest-dominant, TA voice production below the first passaggio to help counter the extensive activity of the CT. Both cooldown scenarios could be characterized as an active recovery strategy aiming to reestablish vocal dynamic equilibrium. We see similar strategies in the physical therapy realm when the opposing muscle group is targeted to facilitate stretch tolerance and physiologic balance between muscle groups.[36] Research investigating the applicability of these concepts specifically to laryngeal musculature is lacking and would be challenging to measure objectively. Still, it can be beneficial for the singer and the teacher to think about agonist/antagonist muscle pairs when targeting active recovery after extensive voice training or performance.

For more experienced teachers and singers, these concepts may be very straightforward; however, others may not consider the potential benefits of this training paradigm. Using a countertraining/active recovery strategy can extend beyond singing. Teachers using their speaking voice all day typically benefit from a vocal cooldown countermeasure at the end of the day. If the speaking voice is chest dominant, a lighter CT-dominant countermeasure could be incorporated into a vocal cooldown routine to help neutralize the vocal "gear" from a full day of teaching. Even if the teacher's speaking voice is chest-dominant, SOVT exercises in an easy chest-dominant production can be useful to help reset the voice, but targeting the partner muscle (CT-dominant lip trills or sighs) should also contribute to a more productive, active recovery after a full day of teaching. In addition to habilitative training paradigms, this countertraining strategy can be used in rehabilitative scenarios as a voice recalibration and active recovery strategy for patients who struggle with vocal fatigue.

Objectively measuring the efficacy of vocal warm-up, cooldown, and active recovery faces similar challenges to other voice science research, making broad generalizability across singers difficult. Some of the studies discussed in part I distinguished between traditional vocalizations and physiologically based protocols such as straw phonation and water resistance therapy (WRT), suggesting that more traditional vocalizations may contribute to early vocal fatigue rather than a vocal warm-up. Other studies reported a dose response (between 5–10 minutes) as a "sweet spot" for vocal calibration with the potential for generating early vocal fatigue if using traditional warm-ups not specifically targeted toward voice calibration.[37] This speaks to the importance of differentiating vocal calibration exercises from exercises targeting skill-building or muscle strengthening.

Overtraining versus Underrecovery

Elite athletes include recovery strategies and rest as part of their training regimen. Although studies investigating active recovery have had varied results, athletic trainers consider this to be an integral part of training, as this is when tissue repair, restoration of muscle fuel, and adaptations occur.[38] Further research is needed to investigate whether the mechanisms of active recovery in athletes and dancers also apply to vocal athletes. Still, in most cases, a vocal cooldown routine tailored within a countertraining framework (i.e., targeting agonist/antagonist muscles or opposing registrations) can be incorporated as a general part of a vocal fitness and wellness routine, regardless of the presence or absence of vocal fatigue or pathology.

A "vocal nap" is a common term used to describe a period of relative or complete voice rest after active and extensive use. Voice science has not provided objective information on how much voice rest is needed after various voice tasks. However, studies have investigated vocal recovery time after periods of increased vocal demand. Carroll and his colleagues used vocal dosimetry to objectively measure vocal fatigue in seven classical choral singers over a two-week period.[39] These authors reported that subjects subjectively reported recovery from increased vocal load after forty-eight hours; however, the degree of recovery varied across subjects.[40] Although this study was small, it speaks to the complex nature of vocal fatigue and the importance of self-monitoring and vocal pacing. Katherine Verdolini Abbot and her colleagues investigated the impact of voice exercises on vocal fold inflammation. These authors reported that after a heavy vocal loading task (reading aloud at high volumes for an extended period), an active recovery strategy followed by a period of vocal rest resulted in a faster reduction of vocal fold inflammatory markers compared to voice rest alone without a vocal cooldown. In contrast, returning to typical voice use after a voice loading task without a vocal cooldown or vocal nap increased inflammatory markers up to twenty-four hours after the task.

The results from this study demonstrated the benefit of active recovery (vocal cooldown group) compared to the complete voice rest group.[41] While this study looked at vocally healthy nonsinger volunteers, these findings help affirm that a cooldown routine can be an effective active recovery strategy after higher levels of singing or voice use. Targeting the opposing muscle as a countertrain might further encourage the restoration of muscular balance, enhancing the benefit of the cooldown routine. Further, this study speaks to the importance of building in adequate recovery time after active voice training to minimize overtraining and underrecovery. Although research in this area continues to evolve, mental practice is commonly used and can be a helpful strategy to enhance vocal motor learning while allowing for a vocal nap.[42]

Unfortunately, many singers in the professional realm do not have control over the imposed vocal workload, and many struggle with vocal fatigue and even pathologies as a result. Part I discussed the pitching guidelines published on the Major League Baseball website that stipulate the recommended number of rest days in between games if pitching exceeds a certain pitch count based on age.[43] These kinds of guardrails do not exist in most performance settings. While some singers can have an understudy perform in their place, these measures are more likely because a vocal event or illness has already occurred. In contrast, the pitching guidelines are designed to be proactive and preventive. Studies defining the benefits of vocal recovery—including the efficacy of active versus passive recovery—are needed to help us better understand how to tailor the appropriate load management needs of singers. Still, voice training paradigms that proactively incorporate tailored recovery and rest strategies will help build risk resilience and fatigue resistance in this high-risk population.

Vocal Fatigue: Distinguishing Train versus Strain

This article has discussed building risk resilience and fatigue resistance as a standard part of our voice training paradigms. In athletic training, muscular fatigue is sometimes a goal to ensure overload is being targeted. However, in voice training, we never target vocal fatigue as a goal during exercise and typically view it as undesirable. Vocal fatigue is challenging to quantify, as it is subjective, nonspecific, and not clearly understood within vocology disciplines. Performance fatigue can be defined as the neuromuscular system not meeting the performance demands due to a lack of bioenergetic (muscle-fuel) support. It can be described as an unpleasant sensation of strain, tenderness, and increased effort, either with or without perceptual change in vocal quality.[44] Numerous factors can impact vocal fatigue, and its degree and duration can vary. This makes vocal fatigue challenging to describe and quantify, and novice singers may have difficulty recognizing vocal fatigue when it emerges, especially if they are training new skills.

When implementing the overload principle to develop strength and stamina, singers must be able to distinguish between training and straining. An inexperienced singer may initially have difficulty discerning a strength-building vocal workout with exercises that employ the overload principle (training zone) from voice training or self-guided practice that exceeds a comfortable overload threshold (straining zone). One easy indicator is any sensation of soreness or pain during or after a training session. This likely indicates that a singer has migrated outside of their training zone. A decline in vocal quality or reduced capability during or after a practice session is another likely indicator that the singer has surpassed the training zone threshold. Another strategy is establishing a rating of perceived exertion. The Borg CR-10 is a simple self-rating visual analog scale used in athletic training to rate perceived physical exertion from no exertion to extreme exertion. This scale has also been used to rate perceived vocal effort.[45]

Vocal Fold Mucosal Tissue

While neuromuscular fatigue has been the target of much of the voice research, we must also account for the role of vocal fold mucosal tissue in perceived vocal fatigue. While outside of the focus of this article, it is important to briefly highlight the importance of vocal fold mucosal tissue, which plays a vital role during phonation. Any inefficiency that impacts the integrity of vocal fold mucosal tissue will likely impact the vibratory mechanics of the vocal folds, heightening the risk of increasing laryngeal load. As mentioned previously, the pitch count guidelines published by the Major League Baseball organization were discussed to illustrate the proactive protocols put in place to protect young athletes from injury related to repetitive use.[46] Perhaps this is a reasonable corollary to the increased risk for phonotrauma to vocal fold mucosal tissue due to excessive collisional and impact forces, yet proactive protocols are not common in the habilitative voice training arena.[47]

Further, there is likely daily variability in the status of vocal fold mucosal tissue within one person. A recent study by Allison and her colleagues documented changes in the appearance (size, extent, and symmetry) of vocal fold pathology in a single subject over twenty-eight days. The changes observed on stroboscopic examination over this time period mirrored changes seen in acoustic and perceptual measures.[48] Although this was a single-subject design, the variation in the appearance of vocal fold lesions over the twenty-eight days speaks to the importance of maintaining a proactive vocal fitness and wellness regimen and monitoring for subtle changes in function, such as a reduced mucosal ceiling (discussed below). Hunter and Titze documented vocal fold mucosal tissue changes after a two-hour higher vocal load. Results from their study on healthy, nonsinger subjects revealed about 90 percent recovery from vocal fatigue within 4–6 hours and a complete return to baseline at 12–18 hours.[49] These authors compared this recovery trajectory to that of a dermal wound. They posited that a persistent increase in vocal load could mirror a chronic wound healing trajectory with a likely threshold for the ability of mucosal tissue to repair without a shift to a more acute wound repair scenario. The Verdolini Abbott study described earlier investigated the impact of a vocal loading task on vocal fold mucosal tissue. They reported increased inflammation for up to twenty-four hours after vocal loading in the group who returned to normal speaking without active recovery or vocal rest.[50]

Results from these studies highlight the importance of adequate rest and recovery when actively training or performing not only for muscular recovery but also for mucosal rest and recovery. They also underscore the likely benefit of maintaining a high baseline level of vocal fitness. Although the role of mucosal tissue in vocal fatigue is not well understood, it undoubtedly plays a critical role in efficient voice production. In addition to rest and recovery, surface hydration, reduced or wisely

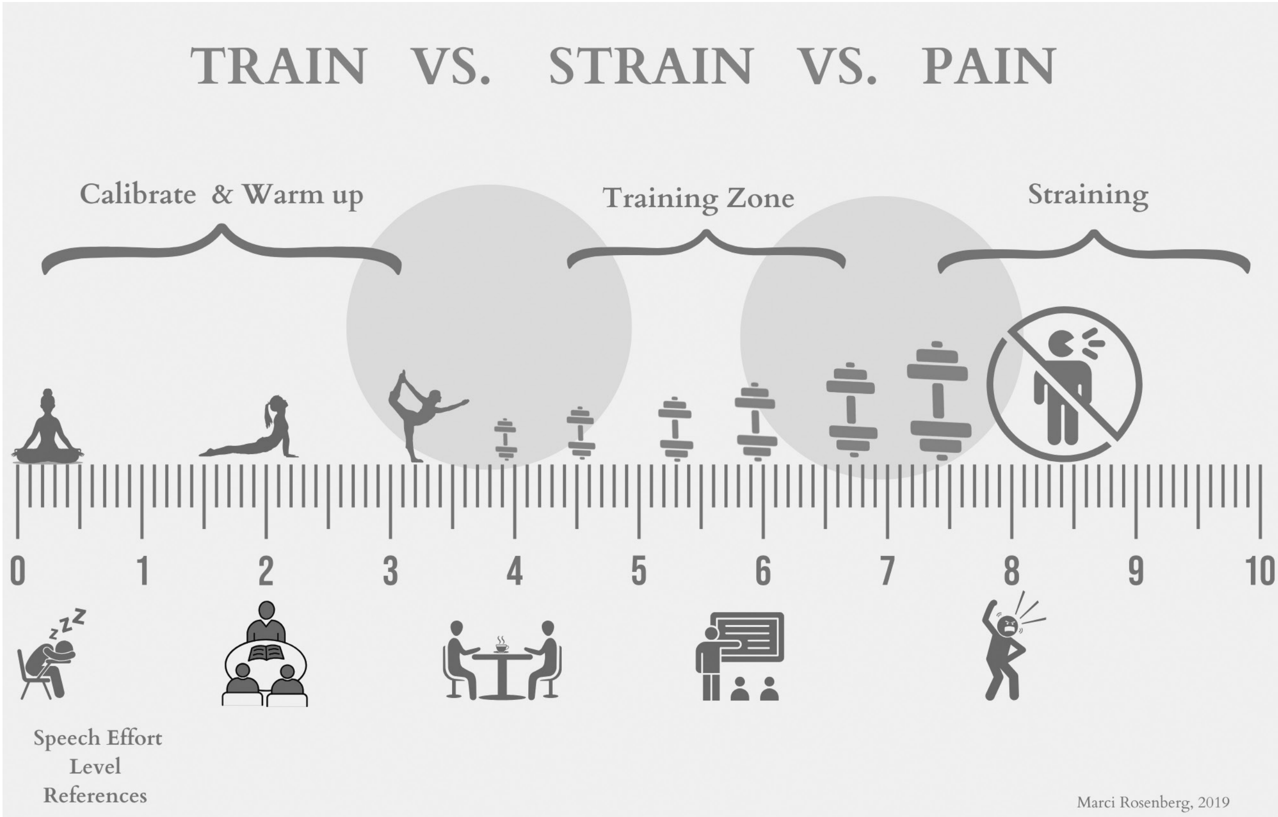

Figure 1. **The Scale of Vocal Effort is an ordinal scale that encourages singers to develop a consistent kinesthetic reference point for the degree of perceived effort for a given vocal task. It encompasses low vocal activity (1–3), moderate vocal activity (4–6), and extensive vocal activity (6+), with schematic examples to help characterize and differentiate between vocal training and vocal straining.**

distributed vocal load, and a targeted active recovery cooldown are viable strategies to help facilitate faster recovery.

Tools to Promote a Proactive Mindset: Self-Rating and Voice Tracking

As vocal fatigue is a common complaint, monitoring vocal status and the degree of fatigue is a skill all singers should develop. There are many ways to develop a reliable self-rating system. Frequent self-assessments of effort level will help inexperienced singers understand when they are functioning at their baseline and when they are experiencing vocal strain and fatigue. Similar to the Borg CR-10 scale of perceived exertion described earlier, the Scale of Vocal Effort is a basic tool that provides a linear scale of self-perceived effort (figure 1).[51] This scale can be used for a specific vocal task (a -particular note in a song) or it can be used as a general rating. An expanded variation of a rating of perceived vocal effort, this tool provides a visual reference for a singer to rate perceived muscle activation or effort.

The Scale of Vocal Effort can be useful for beginning students, helping them distinguish between training and straining when learning a new skill or during a period of increased vocal load. Students learn to associate varying levels of voice use (i.e., in the library, during a classroom lecture, on stage, or while screaming) with muscle activation versus muscle effort. Training less-experienced singers to attune to their baseline level of function may allow them to identify when they are overexerting more easily. Phyland and her colleagues published the Evaluation of the Ability to Sing Easily (EASE) self-assessment survey.[52] This is another useful tool that increases awareness and helps singers gauge and manage their training load. The Singing Voice Handicap Index (SVHI-10) is another tool modified for singers.[53] These simple surveys draw attention to common red flags that can indicate emerging problems. The Vocal Fatigue Index (VFI) is another validated tool created for normal speakers to identify the presence of vocal fatigue.[54] The tools described above help foster self-reliance and accountability, empowering singers to more easily identify emerging problems before they become more significant.

The training-injury prevention paradox asserts that athletes with a high level of baseline fitness (i.e., higher demand or chronic load) have a degree of risk resilience not achieved by athletes who train at lower chronic loads and are less physically fit. The athletes with lower baseline fitness are more likely to sustain injuries during abrupt changes in acute training loads, thus making transition periods carry a higher risk for injury. In voice disciplines, we see these trends at the beginning of college, when social and voice performance workloads abruptly increase. Students in this preprofessional stage benefit from tools that teach them to gauge their own levels of voice use. The Vocal Fold Responsiveness Log is a self-tracking tool developed to use a modified version of the subjective Bastian protocol to establish a vocal baseline and track a singer's mucosal ceiling over time (figure 2).[55] The mucosal ceiling refers to the highest note a singer can produce in a light head register at soft

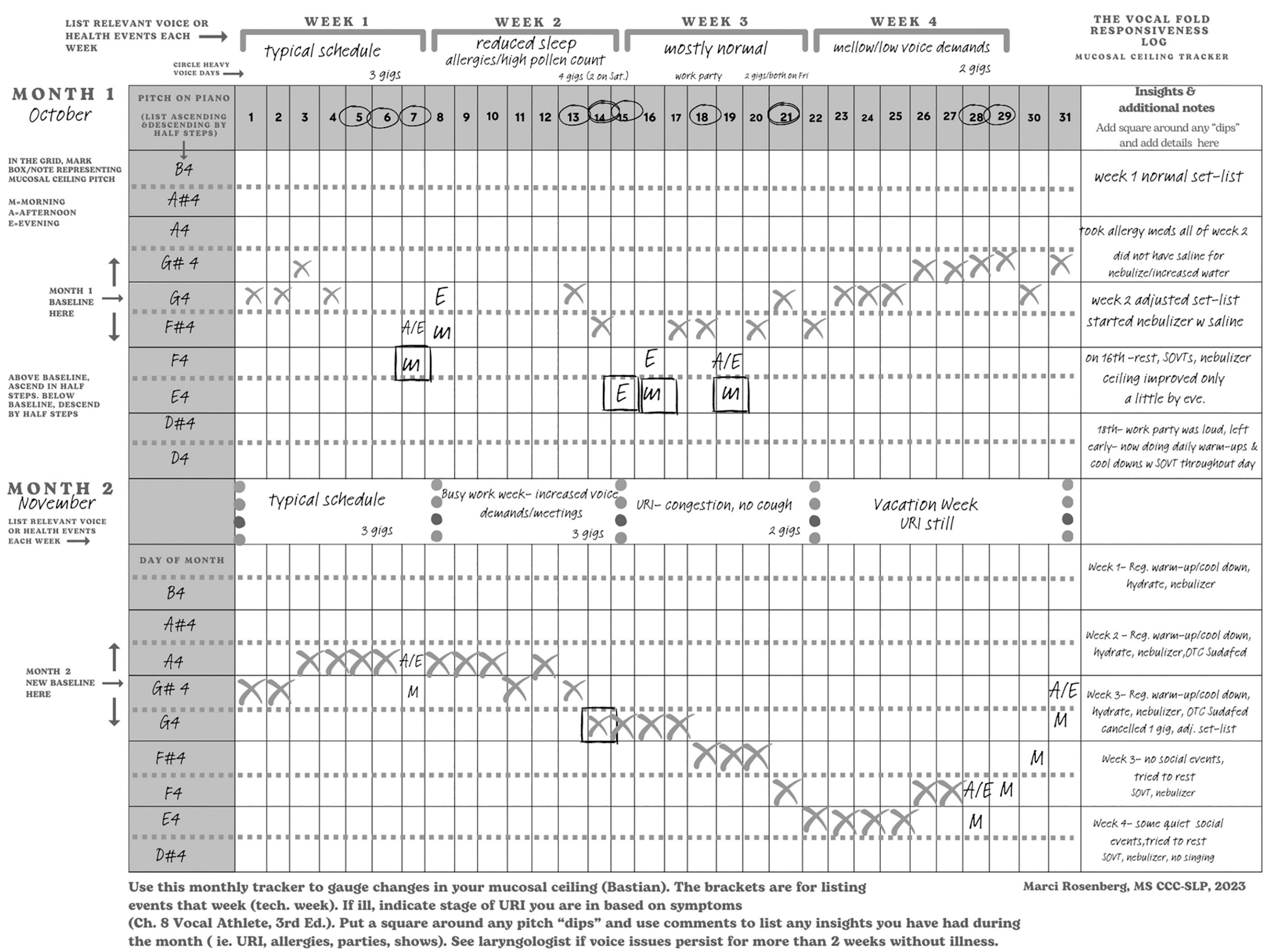

Figure 2. Sample of Vocal Fold Responsiveness Log, a visual tracking log using a modified version of Bastian's mucosal ceiling check to track changes in vocal fold responsiveness over time, relating patterns to other activities and events. Reprinted with permission from Plural Publishing.

volume.[56] This low-tech perceptual tool is a visual grid that allows a singer to identify and learn about patterns in their vocal fold responsiveness over time. Regular tracking allows them to relate their activities and actions that may have contributed to the observed pattern. It also facilitates agency in the young, less-experienced singer who is still learning to balance vocal workload management, allowing them to be proactive about potential emerging voice problems instead of reactive after the situation has progressed.

A Holistic Approach to Voice Training

The concept of overload in voice training should be expanded beyond muscle strengthening. It is not always about increasing muscle power; sometimes, it is about restoring balance within the vocal mechanism. Voice production encompasses the whole body, and efficiency extends beyond the vocal folds and laryngeal musculature. Extrinsic laryngeal musculature, vocal tract shaping, breath management, and alignment with related musculature all play equally important roles in efficient voice production. Although exercise physiology literature tends to be muscle-centric (disproportionately emphasizing skeletal–limb muscles), singing relies on numerous other variables to support efficient voice production. The consistent finding that neural adaptations precede fiber changes in the TA muscles of rats speaks to the importance of viewing voice training as strengthening motor patterns and coordination and the level of the nervous system. Singers relying on muscular activity of the laryngeal muscles as the primary currency for voice production will likely experience vocal strain and fatigue. Rather, good voice training teaches balance and coordination. It also highlights the importance of what Helding has called "the third pillar of voice pedagogy"—the "missing mind."[57] Voice trainers must consider the learning readiness of the student and create a tailored teaching environment that fosters a growth mindset and optimizes how the learner receives training.

While we can draw numerous parallels between the athlete and the singer, voice production contains one prominent variable that is not present in the athlete or dancer. Vocal fold mucosal tissue, while not related to strength or fitness, plays a vital role in healthy voice production and requires careful and specific consideration. A singer may have adequate vocal stamina, coordination, and strength, but if there is mucosal injury, voice production can be significantly impacted. Strategies to facilitate vocal fold mucosal and general vocal health and integrity include distributing the vocal workload of day-to-day use, building in active recovery, regularly using voice resets/calibrations and vocal naps, appropriately managing vocal training, and learning to identify subtle changes in voice capabilities by using low-tech self-rating tools. However, it is too simplistic to attribute vocal strengthening and conditioning solely to the overload principle. Rather, a head-to-toe holistic approach encompassing all of the subsystems with special consideration of vocal fold mucosal integrity and the vital role of the nervous system collectively results in efficient voice training. Other vocal hygiene strategies, such as the use of a personal, handheld ultrasonic nebulizer with sterile saline (.09 percent), if not contraindicated, maintaining general hydration, and getting adequate sleep, should all be part of a singer's standard vocal health and wellness toolkit.[58] Imparting this knowledge to voice pedagogy students and younger singers will empower them to be accountable for their vocal health throughout their vocal journey.

CONCLUSION

Exercise physiology research, especially in the areas of strength and risk resilience in athletes, offers potential parallels for training vocal athletes. Both parts of this series reviewed kinesiology literature and provided some conceptual parallels to consider when training vocal athletes. An example of pedagogy-informed science, many decades of both clinical and studio observations have aligned philosophically with a functional and physiological approach to voice training. The voice science literature has documented the efficacy of this approach. However, the exact mechanisms involved are not fully understood, and the role of mucosal tissue adds an important variable that does not apply to general athletes and dancers. Research on the generalizability of exercise physiology principles—from skeletal musculature in athletes to vocal fold physiology—continues to emerge. Barriers to accessible, noninvasive measurements in humans have limited our ability to objectively translate and differentiate how these principles apply to voice musculature. Further, there is great variability in how a singer coordinates subsystems for sound production and adapts their vocal style according to genre. Our clinical wisdom and empirical knowledge have helped shape how we approach voice training to build strength, coordination, and stamina. As research further clarifies these mechanisms, we will continue to adapt our learner-centered training paradigms to fully optimize vocal performance, reduce the risk of vocal fold injury, and build risk resilience to help the singers with whom we work attain long and sustainable vocal careers.

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