Voice, Nervous System, and Trauma: What Are Potential Implications for Singing?

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This article discusses the interconnection between voice, singing, the nervous system, and psychological trauma. The engagement of the nervous system in voice, particularly singing, is still being investigated in the field. Evidence is gradually emerging on what nervous system structures may be involved in voice and singing. At the same time, literature on the nervous system and trauma discusses the impact of past experiences on structure and function. In this article, the potential interconnections and implications of the presented information are discussed.

The complexity of singing is closely related to the complexity of the nervous system. The beautiful and intricate act of singing calls upon a variety of mechanisms that have to do with both perception and production of sound. Additionally, these mechanisms involve all layers of the nervous system, from central to peripheral.

When singing, one engages physiology, language, emotion, intention, and precision.[1] As one produces sound, they also engage as attentive listeners in a continuous auditory feedback loop that helps them keep on course.[2] What internal structures help a singer do all this?

What forces can influence these structures aside from the ongoing task being performed? If the nervous system can be influenced by one's past experiences, can these experiences have an influence on the nervous system's engagement when singing? In this article, information from different kinds of literature will be presented to reflect on these questions. Answers to these questions cannot be provided at this time, but reflections on potential implications for singers will be discussed.

THE NERVOUS SYSTEM, VOICE, AND SINGING

When it comes to vocalization, it is not surprising that numerous structures of the nervous system are involved. These structures collaborate in a highly coordinated manner to produce vocalizations.[3] In this article, a few of the structures involved in voice and singing will be mentioned. To those who are voice neuroscientists, the following descriptions may seem simplistic; for our purposes, the hope is that they will suffice when it comes to the questions this article poses.

When picturing the act of phonation, the vocal folds immediately come to mind. Their movements are directly influenced by intrinsic and extrinsic laryngeal muscles. The reflexogenic systems kinetic with intrinsic laryngeal

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muscles help stabilize vocalization. The support of the other muscles is fundamental for phonation to occur—particularly, the diaphragm and intercostal muscles provide the power for phonation and articulatory muscles of the jaw, lips, and tongue help with the vocal output.[4] An important role is that of the *vagus nerve* (cranial nerve X), which innervates the intrinsic laryngeal musculature via its two branches: the *recurrent laryngeal nerve* and the *superior laryngeal nerve*. The recurrent laryngeal nerve connects to the thyroarytenoid, lateral and posterior cricoarytenoids, and interarytenoids. The cricothyroid is innervated via the superior laryngeal nerve.[5]

Another important force that helps stabilize vocalization is auditory feedback. As one produces sound, their ability to hear what they are producing creates quick adjustments that maintain stability. The *auditory cortex* certainly serves an important role in this mechanism,[6] and is particularly important for control of pitch.

Two neural structures that are connected to phonation muscles are the *pons* and *medulla*, which are also connected to the *periaqueductal gray* (PAG) and *anterior cingulate cortex* (ACC).[7] Additional structures involved are the *primary motor cortex* and subcortical structures such as the *putamen*, *globus pallidus*, *pontine gray*, and *cerebellum*. These structures modulate commands from the primary motor cortex and send modified motor signals back to the primary motor cortex via the ventrolateral thalamus. Then the ventral part of the primary motor cortex stimulates articulatory and phonation muscles.[8]

The higher the structure in the brain, the more complex its function seems to be in relation to vocalization. It is at the level of the primary motor cortex that learned vocalization occurs, including speech and singing. This becomes apparent because lesions of the primary motor cortex can affect the ability to speak or sing.[9]

The complex task of singing requires work from the primary motor cortex as well as integration with the auditory cortex and *Broca's area*.[10] This occurs via the arcuate fasciculus, a white matter track connecting the temporal and the frontal lobes. Other structures involved include the *dorsal premotor cortex*, the ACC, the *anterior insula*, and the *inferior parietal lobes*.[11] The mentioned structures are involved in the complex task of singing as well as speech. Compared to speaking, singing exclusively utilizes bilateral networks more lateralized to the right hemisphere.[12]

Additional regions that can potentially be involved in singing, particularly when it comes to audio-vocal integration, are the *superior temporal sulcus* (pSTS), *inferior parietal cortex*, ACC, *inferior frontal gyrus* (IFG), and the anterior insulae.[13] Of note, the primary motor cortex has been associated with diaphragmatic volitional inspiration, fundamental for singing.[14] The frontal lobe also plays a fundamental role in singing because of its involvement with executive function and planning. It contains the previously mentioned primary motor cortex. The parietal lobes are fundamental for integrating information from different senses, from auditory to tactile to kinesthetic, which is fundamental for singing.[15] The temporal lobes are fundamental for auditory feedback. The right temporal lobe is particularly specialized in the processing of frequency relations.[16]

THE NERVOUS SYSTEM AND TRAUMA

The trauma literature suggests that past events can have a long-lasting impact on an individual's nervous system.[17] Recently, the definition of trauma has evolved to not center simply on the nature of the event the person has lived through, but particularly emphasizing how one's nervous system has reacted to such an event (or series of events).[18] "Trauma responses" are adaptations that occur in the nervous system to prepare to face future events in the way one's current nervous system knows how.[19]

Traumatic events, from acute to chronic, are linked to physiological and structural differences in the nervous system.[20] Peripherally, the reactions in the autonomic nervous system become modified to be more responsive in the face of potential danger. Centrally, brain regions can appear different in size, function, and connectivity.[21] This happens because the totality of the nervous system becomes invested in survival; therefore, the structures and systems specialized in survival become more active. These changes heavily affect an individual's quality of life. Physiologically, it is hard for many traumatized individuals to find homeostasis; they tend to live more in a hyper- or hypo-aroused state. They can face difficulties with cognition, attention, concentration, and connecting with others.[22]

Much more can be discussed about the effects of trauma on the nervous system. For the purposes of this article, the focus will shift to key regions that are also involved in voice and singing. The literature presented will be only a small portion of the vast body of evidence about the effects of trauma on the nervous system, but it will be sufficient to suggest that a potential interplay of trauma and singing voice via the nervous system is to be taken into consideration.

A variety of studies have investigated the relationship between traumatic experiences—particularly childhood experiences—and brain structure and function.[23] The gray matter volume of the frontal cortex has been observed to be smaller in survivors of sexual abuse between the ages of 14 and 16 years old.[24] Some preliminary data indicate that survivors of harsh corporal punishment can exhibit a reduction of the volume of the medial *prefrontal cortex* (PFC), dorsolateral PFC, and right dorsal ACC.[25] This type of punishment was also found to be associated with lower activation in the *putamen*, *thalamus*, *nucleus accumbens*, and *substantia nigra*.[26] Survivors of emotional maltreatment (a combination of emotional abuse and emotional neglect) can exhibit a reduction in the volume of the dorsomedial PFC extending to the anterior medial PFC. These individuals can also exhibit hyperactivity of the medial prefrontal cortex during word encoding and recognition tasks.[27] Emotional abuse was found to be associated with lower cortical thickness in the ventral ACC.[28] Smaller ACC volume has been reported in individuals who witnessed domestic violence in childhood.[29]

Childhood neglect has been associated with reduced resting-state connectivity in the cerebellum. The cerebellum appears strongly connected to the somatomotor cortex and appears to be involved in executive control and default mode brain networks. The cerebellum is not only involved in motor control but also in error monitoring, working memory, learning, and behavioral adaptation—all fundamental skills for voice and singing.[30] Neglect is also associated with reduced connectivity in insular regions. Researchers speculate that there may be reduced information exchange in the insula's white matter bundles.[31]

Additionally, connectivity between insular regions and the primary motor cortex has shown differences in relation to physical abuse survivorship and symptom severity.[32] The PAG has been shown to be heavily involved in physiological changes of the autonomic nervous system in relation to threat detection and imminence of danger. These responses can manifest as extreme hyper- or hypo-arousal, depending on the trauma history of the individual.[33] This is linked to differences in "vagal tone," which refers to the vagus nerve's ability to help maintain physiological homeostasis, heavily disrupted in the presence of trauma history.[34] The *ventral medulla* is also involved in defense responses—including tonic immobility—which has been observed in survivors of assault.[35]

Childhood abuse has been found to be associated with reduced volume of the right superior parietal lobe. Childhood trauma has also been associated with abnormalities and connectivity disruption in the frontal lobe, particularly connectivity of the frontal lobe with limbic regions of the brain, having implications for inhibition and interpersonal interaction.[36] Additionally, survivors of severe parental verbal abuse were found to have alterations in gray matter volume in the left auditory cortex and reduced integrity of the left arcuate fasciculus language pathway.[37] A study on stress (not specifically related to trauma, but trauma is related to stress reactivity) found stress reactivity linked to lower laryngeal motor cortex activation.[38] For summarized examples of potential voice/nervous system trauma links, see table 1.

HOW CAN VOICE, NERVOUS SYSTEM, AND TRAUMA INTERACT?

The literature presented above discusses some evidence regarding nervous system regions and structures involved in voice and singing and associated with differences in the presence of trauma. The question this article intends to pose is: If trauma is linked to changes in nervous system regions and structures that are also involved in voice and singing, what are the implications? To what extent can trauma impact voice and singing via the nervous system?[39]

If there is an indirect impact, how can this show up in the voice studio? Can it look like a voice student is taxed in ways one may not associate with trauma unless they are aware of possible connections? What can this "taxing" look like? Cognitively, physiologically, vocally, and affectively one may observe some differences in

TABLE 1. Examples of potential voice / nervous system trauma links

Nervous System Structures Involved in Voice	Specifically Involved in Singing?	Specifics About Trauma
Frontal Lobes	✓	Reduced cortical volume related to sexual trauma, emotional maltreatment, and harsh corporal punishment; reduced connectivity with limbic regions
Temporal Lobes	✓	Alterations in volume of left auditory cortex
Parietal Lobes	✓	Reduced cortical volume related to abuse
Primary Motor Cortex	✓	Reduced connectivity with insulae related to physical abuse; nonspecific stress reactivity linked to lower laryngeal motor cortex activation
Insula/e	✓	Reduced connectivity related to neglect; reduced connectivity with primary motor cortex related to physical abuse
Thalamus/i		Lower activation related to harsh corporal punishment
Periaqueductal Gray (PAG)		Difference in reactivity (related to threat detection) observed in various types of chronic and acute trauma
Anterior Cingulate Cortex (ACC)	✓	Reduced cortical volume related to harsh corporal punishment and emotional abuse; reduced general volume associated with witnessing domestic violence
Cerebellum		Reduced connectivity related to neglect
Putamen		Lower activation related to harsh corporal punishment
Vagus Nerve (Cranial Nerve X)	✓	Disruption in ability to maintain homeostasis observed in various types of chronic and acute trauma

[a] Likely all structures listed have a role in singing, the ones emphasized here are the ones discussed in the literature specifically in relationship to singing.

some students. Can these be associated with structural and functional internal differences due to difficult past experiences?

These questions are not posed for an answer to be provided at this time. These questions are posed because they need to become a priority in the field of voice science and voice pedagogy. If singers are influenced by their past, theoretical questions posed about the potential implications need to flourish into further research investigations, as well as growing trauma-informed awareness in the voice studio.

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