Guest Contributor:
Stephen W. Porges, PhD

Music Therapy & Trauma: Insights from the Polyvagal Theory

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Music is an important component of the human experience. The use of music in culture has been a documented feature of the history of civilizations. Types of music have been uniquely associated with distinct feelings, experiences, and social interactions. Cultures have incorporated music into the educational process, religious and tribal rituals, and patriotic expressions. Music conveys features of culture both with lyrics and melody. Vocal music has been used both as a contemporary vehicle and an archival mechanism to transmit important cultural, moral, spiritual, and historical events and values. Music has been used to calm, to enable feelings of safety, and to reduce the social distance between people.

Music is intertwined with emotions, affect regulation, and interpersonal social behavior as well as other psychological processes that describe basic human experiences in response to environmental, interpersonal, and even intrapersonal challenges. These psychological processes shape our sense of self, contribute to our abilities to form relationships, and determine whether we feel safe in various contexts or with specific people. Although these processes can be objectively observed and subjectively described, they represent a complex interplay between our psychological experience and our physiology.

This chapter will provide a novel insight into the traditions of music as a therapy aiding physical and mental health. Music therapy is more than listening to music or singing or playing a musical instrument. Music therapy involves active interactions among three features: 1) therapist, 2) client, and 3) music. In the following pages, the Polyvagal Theory will be used to present a plausible model to explain how and why music therapy would be helpful in supporting physical health and in enhancing function during compromised states associated with mental and physical illness, including the consequences of trauma. The Polyvagal Theory provides a strategy to understand the mechanisms and processes that enable music and music therapy to improve social engagement behaviors and to enhance the regulation of bodily and behavioral state. The theory provides insights that bridge music therapy to the nervous system and health outcomes. The Polyvagal Theory will deconstruct music therapy into two components: 1) the interpersonal relationship between therapist and client, and 2) the acoustic features of music being used in the therapeutic setting.

The Polyvagal Theory: A Primer

Our nervous system functions as a sentry by continuously evaluating risk in the environment. Through neural surveillance mechanisms (i.e., neuroception), our brain identifies features of risk or safety (Porges, 2004). Many of the features of risk and safety are not learned, but are hardwired into our nervous system and reflect adaptive strategies associated with our phylogenetic history. The way we react to the specific acoustic frequency bands that constitute music is determined by the same neural circuits that evaluate risk in our environment. For example, low frequency sounds elicit a sense of danger associated with an approaching predator. Prokofiev, in *Peter and the Wolf*, exploits this biological feature by conveying the impending and predictable danger with the low frequency sounds of the kettledrums.

Due to our phylogenetic history, the rumble of low frequency sounds shifts our attention from social interactions to potential dangers in the environment. This reaction is shared with other vertebrates including reptiles and amphibians. In contrast, high-pitched screams from another mammal (not just our children, but also our dogs and cats) elicit a sense of urgent concern or empathy for a targeted other, the individual who may be feeling pain or being injured. In humans, high frequency screams shift our attention from the social group or our focus on an object to the specific individual who is screaming. However, music in the frequencies of human voice elicits visceral and emotional states that are neither associated with impending doom or a sense of urgency. In contrast, music in the frequency band of human voice is used in compositions to convey the melody, which is functionally and metaphorically the "voice" that the composer desires to express. Thus, in the orchestra the instruments that duplicate the human voice range (e.g., violins, flutes, clarinets, trumpets, oboes, and French horns) become the vehicles for the composer to express an emotional narrative.

Specific acoustic frequency bands in the environment elicit different emotional experiences, which are paralleled by adaptive physiological states. Each of these physiological states is functionally an adaptive state that influences affect regulation, social engagement behaviors, and our ability to communicate. We experience these states with feelings of safety, danger, or ultimate demise (i.e., life threat). Physiological state is an implicit component of the subjective experience of listening to or producing music. Music changes not only our emotive state, but also elicits changes in our physiology that parallel the feelings of anxiety, fear, panic, and pain. For example, while listening to certain melodies, we relax, slow our heart rate, and smile. However, while listening to other music, we may start to imagine danger and visualize marching off to war or protecting our loved ones. The feelings of danger will change our facial expression and increase our heart rate.

As Oliver Sacks discussed in *Musicophilia* (Sacks, 2007), music appears to be part of the human experience, yet no brain area or circuit has been identified to explain or represent music. This chapter approaches this question differently and asks a different question. Rather than seeking specificity in the neural regulation required to process and to express music, the chapter will discuss the convergence and similarity between the neural mechanisms required to process music and the neural mechanisms required to process features of social engagement behaviors and risk in the environment. This convergence between physiological state and music-related emotional experience is neurophysiologically determined and explained by the Polyvagal Theory (Porges, 1995, 1997, 1998, 2001, 2003, 2007). The Polyvagal Theory will be used as an organizing principle to explain how music, and especially music when expressed via music therapy, can recruit the neural mechanisms that integrate facial muscles and visceral state, which in turn promotes restorative affective states and prosocial behavior.

The Polyvagal Theory emerged from the study of the evolution of the vertebrate autonomic nervous system. The theory is based on the functions of a part of our nervous system that automatically regulates several major organs such as the heart, the lungs, and the gut. Since the neural regulation of these organs occurs automatically and often without our awareness, the neural structures regulating these organs are known as the autonomic nervous system, which is dynamically regulated by our brain. The regulation is bidirectional, with the brain and its neural sentries continuously monitoring body state, and body state dynamically influencing brain function. Moreover, the neural regulation of the autonomic nervous system is linked to the neural regulation of the muscles of the face and head, which are involved both in listening to and in producing music. The muscles that we use to signal our emotional state are involved not only in the production of vocal and instrumental music (i.e., via wind instruments), but also in the process necessary to actively listen to music (i.e., the modulation of our middle ear muscles).

The theory assumes that many of our social behaviors and vulnerabilities to emotional disorders are "hardwired" into our nervous system. Based on the theory, it is possible to understand various aspects of mental health and to develop treatment techniques that can help people communicate better and relate better to others. The term "polyvagal" combines "poly," meaning "many," and "vagal," which refers to the important nerve called the "vagus." To understand the theory, we need to investigate features of the vagus nerve, a primary component of the autonomic nervous system. The vagus nerve exits the brain stem and has branches that regulate several organs, including the heart. The theory proposes that the two branches of the vagus are related to different behavioral strategies. One branch is involved in regulating physiological state during social interactions in safe environments, and the other branch is involved in regulating an adaptive physiological state in response to life threat.

The Polyvagal Theory is particularly important in understanding the mechanisms underlying music therapy, which requires within the therapeutic setting both the processing of acoustic stimuli and face-to-face social interactions. Thus, the Polyvagal Theory provides insights into the beneficial effects of music therapy, since it provides an understanding of the neural control of structures involved in the two features of music therapy: 1) social interactions between the client and the therapist, and 2) listening and expressing music.

Historically, the autonomic system was described as having two opposing components, one labeled sympathetic and the other parasympathetic. This organizational model was used to describe the function of the autonomic nervous system in the late 1800s and the early 1900s. In the 1920s, this paired-antagonism model was formalized (Langley, 1921). The paired-antagonism model characterized the function of the autonomic nervous system as a constant battle between the sympathetic nervous system (associated with fight/flight behaviors) and the parasympathetic nervous system (associated with growth, health, and restoration). Because most organs of the body, such as the heart, the lungs and the gut, have innervations from both sympathetic and parasympathetic components, the paired-antagonism model evolved into "balance theories." Balance theories attempted to link "tonic" imbalances to both physical and mental health. For example, a sympathetic dominance might be related to symptoms of anxiety, hyperactivity, or impulsivity, while a parasympathetic dominance might be related to symptoms of depression or lethargy. In addition to the tonic features of autonomic state, the balance theories were assumed to explain the reactive features of the autonomic nervous system. .

The Polyvagal Theory proposes that the autonomic nervous system reacts to real world challenges, not as a balance system, but in a predictable hierarchical manner that parallels, in reverse, the phylogenetic history of the autonomic nervous system in vertebrates. In other words, if we study the evolutionary path through which the autonomic nervous system unfolded in vertebrates (i.e., from ancient jawless fish to bony fish, amphibians, reptiles, and mammals), we learn not only that there is an increase in the growth and complexity of the cortex, but also that there is a change in composition and function of the autonomic nervous system. In mammals, the autonomic nervous system functions as a hierarchical system that parallels phylogenetic states in reverse and not as the balance between sympathetic/ parasympathetic systems.

The phylogenetic changes in the autonomic nervous system (including changes in neural pathways and brainstem areas regulating the peripheral organs) determine how the autonomic nervous system reacts to challenges. In humans and other mammals, the hierarchy is composed of three neural circuits, with the newer circuits having the capacity to override the older circuits. Under most challenges in our environment, we initially react with our newest system (i.e., myelinated vagus). If that circuit does not satisfy our biobehavioral quest for safety, an older circuit spontaneously reacts (i.e., sympathetic nervous system). Finally, if the former strategies are unsuccessful, as our last option, we reflexively trigger the oldest circuit (i.e., unmyelinated vagus). Functionally, in humans, the older vagal circuit is involved in adaptive reactions characterized by immobilization and decreases in metabolic output, while the newer vagal circuit is involved in regulating the calm states that promote both spontaneous social engagement behaviors and health, growth, and restoration. Along the phylogenetic continuum, describing the vertebrate autonomic nervous system, the sympathetic nervous system that supports fight and fight behaviors emerged between the two vagal circuits.

Three Phylogenetically Defined Autonomic Circuits Supporting Adaptive Behaviors

The Polyvagal Theory emphasizes the neurophysiological and neuroanatomical distinction between the two branches of the vagus (i.e., tenth cranial nerve) and proposes that each vagal branch is associated with a different adaptive behavioral and physiological response strategy to cope with stressful events. The theory describes three phylogenetic stages in the development of the mammalian autonomic nervous system. These stages reflect the emergence of three distinct subsystems, which are phylogenetically ordered and behaviorally linked to *social engagement*, *mobilization*, and *immobilization*.

The theory emphasizes the phylogenetic origins of brain structures that regulate social and defensive behaviors. For example, prosocial behaviors cue others that the environment is safe. Safe environments signal the individual to dispense with the hypervigilance required to detect danger, and allow this precautionary strategy to be replaced with social interactions that further calm and lead to close proximity and physical contact. The prototypical prosocial behaviors in mammals are related to nursing, reproduction, interactive play, and being able to be calm in the presence of another. In contrast, defensive behaviors could be categorized into two domains: one related to mobilization, including fight and flight behaviors, and the other related to immobilization and death-feigning that might be associated with dissociative psychological states. Thus, if music therapy can trigger the circuits of social engagement, it will not only support affect regulation and social interactions, but also promote health, growth, and restoration.

The Social Engagement System

As mammals evolved from more primitive vertebrates, a new face-heart circuit emerged to detect and to express signals of safety in the environment (e.g., to distinguish and to emit facial expressions and intonation of vocalizations) and to rapidly calm and turn off the defensive systems (i.e., via a myelinated vagal pathway to the heart) to foster proximity and social behavior. This recent neural circuit can be conceptualized as a Social Engagement System, which involves pathways that travel through several cranial nerves (V, VII, IX, X and XI). These pathways regulate the expression, detection, and subjective experiences of affect and emotion. The Social Engagement System is an integrated system with both a somatomotor component regulating the striated muscles of the face and a visceromotor component regulating the heart and bronchi. The system is capable of dampening physiological arousal and stress reactions (e.g., activation of the sympathetic nervous system and HPA-axis activity). By calming the viscera and regulating facial muscles, this system enables and promotes positive social interactions in safe contexts. Neuroanatomically, this system includes special visceral efferent pathways that regulate the striated muscles of the face and head and the myelinated vagal fibers that regulate the heart and lungs (see Porges, 1998, 2001, 2003). The source nuclei for both the special visceral efferent and myelinated vagal pathways communicate with each other and originate in a similar area of the brainstem.

The Social Engagement System regulates facial muscles, including the sphincter muscles around the eyes (e.g., promoting social gaze and emotional expressivity), middle ear muscles (e.g., extracting human voice from background sounds), muscles of mastication (e.g., ingestion), laryngeal and pharyngeal muscles (e.g., sucking, swallowing, vocalizing, breathing), and muscles of head turning and tilting (e.g., social gesture and orientation). Collectively, these muscles act as filters that limit social stimuli (e.g., observing facial features and listening to human voice) and determinants of engagement with the social environment. Interestingly, the neural pathways regulating the orbicularis oculi, a sphincter muscle around the eye involved in expressive displays, also are involved in the dynamic regulation of the stapedius muscle in the middle ear (Djupesland, 1976). Thus, the neural mechanisms for emotional cueing via eye contact are shared with those needed to listen to human voice. As a cluster, difficulties in behaviors associated with the Social Engagement System (e.g., avoidant gaze, nonresponsiveness to human voice, reduced facial affect and vocal prosody, and atypical or lack of head gesture) are common features of individuals with autism, PTSD, and other psychiatric disorders. Thus, astute clinicians infer from facial expressions and vocal prosody difficulties in both social engagement behaviors and physiological state regulation

Several psychiatric disorders have deficits in both the somatomotor (e.g., poor gaze, low facial affect, lack of prosody, difficulties in mastication) and visceromotor (difficulties in autonomic regulation including cardiopulmonary and digestive problems) components of the Social Engagement System**.** For example, clinicians and researchers have documented these deficits in individuals with autism. Deficits in the Social Engagement System compromise spontaneous social behavior, social awareness, affect expressivity, prosody, and language development. Interventions designed to improve the neural regulation of the Social Engagement System**,** hypothetically would enhance spontaneous social behavior, state and affect regulation, reduce stereotypical behaviors, and improve vocal communication (i.e., including enhancing both prosody in expressive speech and the ability to extract human voice from background sounds).

In our laboratory, we have not only demonstrated relations between vagal regulation of the heart and social engagement behaviors, but also have demonstrated that it is possible to improve social engagement behaviors and lower heart rate in autistic individuals by using computer-altered music to stimulate the neural regulation of the Social Engagement System.

This is more than a plausible hypothesis. In our laboratory, we have not only demonstrated relations between vagal regulation of the heart and social engagement behaviors, but also have demonstrated that it is possible to improve social engagement behaviors and lower heart rate in autistic individuals by using computer-altered music to stimulate the neural regulation of the Social Engagement System. These findings provide a neurophysiological basis to explain how music may change facial expressivity and calm behavior.

Human responses to trauma are devastating and compromise subsequent social behavior and emotion regulation. Understanding the mechanisms underlying the mammalian "hardwired" response to life threat may demystify these debilitating consequences. From this neurophysiological perspective, a variety of clinical features, including severely compromised social behavior and difficulties in emotion regulation, are predictable.

An understanding of the mechanisms mediating these atypical behaviors in response to trauma is helpful to the client, the family, and the therapist in developing supportive and restorative contexts and treatments. Functionally, our nervous system is continuously evaluating risk in the environment through an unconscious process of neuroception (see above). Specific features in the environment trigger physiological states associated with feelings of safety, danger, or ultimate demise. The human nervous system evolved efficiently to shift between conditions of safety and danger. We easily adjust and calm following situations requiring fight or flight maneuvers. We use social interactions with appropriate and contingent facial expressions, intonation of our voice (i.e., prosody), and gaze to

calm and be calmed. However, in contrast to challenges of danger, reactions to life threat are not easily remediated. Attempts to socially engage a traumatized individual, rather than calming, may result in defensive strategies of rage and anger. Life threat triggers a very ancient neural circuit that severely limits social engagement behaviors and may distort neuroception, resulting in a detection of risk when there is no apparent risk. Thus, treatment of trauma requires a new model distinct from the traditional psychotherapeutic strategies of face-to-face dialog to trigger the calm states associated with the Social Engagement System. Music may provide this portal to the social engagement system and avoid the initial face-to-face interactions that may be misinterpreted as threat by a traumatized individual.

How Music and Prosodic Vocalizations Can Trigger the Social Engagement System

As vertebrates evolved from reptiles to mammals, the structures at the end of the mandible (i.e., jaw bone) that define the middle ear bones became detached (Luo, Crompton, & Sun, 2001; Rowe, 1996; Wang, Hu, Meng, & Li, 2001). For humans and other mammals, sound in the environment impinges on the eardrum and is transduced from the eardrum to the inner ear via the small bones in the middle ear known as ossicles. When the stapedius (innervated via a branch of the facial nerve) and the tensor tympani (innervated via a branch of the trigeminal nerve) muscles are innervated, the ossicular chain becomes more rigid and dampens the amplitude of the low-frequency acoustic stimulation from the environment reaching the inner ear. This process is similar to tightening the skin on a kettledrum. When the skin is tightened, the pitch of the drum is higher. When the ossicular chain is tightened, similar to the stretched skin, only higher frequencies bouncing against the eardrum are transmitted to the inner ear and to the auditory processing areas of the brain.

The functional impact of the middle ear muscles on the perceived acoustic environment is to markedly attenuate the low-frequency backgrounds sounds that dominate most acoustic environments and to facilitate the extraction of high-frequency sounds associated with human voice (and other vocalizations made by mammals). Loud low frequency sounds functionally mask the soft high-frequency sounds associated with human voice. In humans, the ossicular chain is regulated primarily by the stapedius muscle and tensing the stapedius prevents this masking effect (Borg & Counter, 1989). In fact, individuals who can voluntarily contract middle ear muscles exhibit an attenuation of approximately 30 dB at frequencies below 500 Hz, while there is no or minimal attenuation at frequencies above 1000 Hz (Kryter, 1985).

The evolution of the mammalian middle ear enabled low amplitude, relatively high-frequency airborne sounds (i.e., sounds in the frequency of human voice) to be heard, even when the acoustic environment was dominated by low frequency sounds. Detached middle ear bones were a phylogenetic innovation that enabled mammals to communicate in a frequency band that could not be detected by reptiles. Reptiles can only hear lower frequencies due to a dependence on bone conduction.

Studies have demonstrated that the neural regulation of middle ear muscles, a necessary mechanism to extract the soft sounds of human voice from the loud sounds of low-frequency background noise, is defective in individuals with language delays, learning disabilities and autistic spectrum disorders (Thomas, McMurry, & Pillsbury, 1985). Middle ear infection (i.e., otitis media) may result in a total inability to elicit the ''reflexive'' contraction of the stapedius muscles (Yagi & Nakatani, 1987). Disorders that influence the neural function of the facial nerve (i.e., Bell's palsy) not only influence the stapedius reflex (Ardic, Topaloglu, Oncel, Ardic, & Uguz, 1997), but also affect the patient's ability to discriminate speech (Wormald, Rogers, & Gatehouse, 1995). The observed difficulties that individuals with a variety of physical and mental disorders have in extracting human voice from background sounds may be dependent on the same neural system that regulates facial expression. Thus, deficits in the Social Engagement System would compromise, not only the expression of emotion, but also social awareness and even language development.

The perception of sound is not equal at all frequencies. We hear sounds at low frequencies as if they were softer than they really are. In contrast, we are relatively accurate in estimating the acoustic energy of human voice. This phenomenon was initially reported as the Fletcher-Munson equal loudness contours (Fletcher & Munson, 1933), and illustrated how human perception attenuated the "loudness" of low frequency sounds. As measurement technologies improved, researchers refined the perceived loudness contours, and sound meters were modified to include a scale known as dBA, which adjusted for the perceived differences in loudness as a function of frequency (i.e., the acoustic energy of lower frequencies had to be greatly increased to be perceived at the equivalent loudness of higher frequencies). This contrasts to sound pressure level, which describes the physical energy of the signal and does not apply any perceptually-based weighting to the frequencies that constitute the acoustic stimulation. The perceptual process of hearing low frequency sounds as softer parallels the antimasking functions of the middle ear muscles (attenuating the sounds at low frequencies).

Music therapy may provide opportunities to exercise the Social Engagement System. The frequency content of melodies in most musical compositions duplicates the frequency band of human voice. Functionally, acoustic properties of melodies (i.e., the two octaves defined as being above the C above middle C) easily pass through the middle ear structures regardless of the neural tone to the middle ear muscles. Once the frequencies pass through the middle ear, they trigger a neural feedback mechanism to tense the ossicle chain. Vocal music duplicates the effect of vocal prosody and triggers neural mechanisms that regulate the entire Social Engagement System with the resultant changes in facial affect and autonomic state. Basically, we start to look and feel better when we listen to melodies.

Consistent with the parallel between music and social communication, the same frequency band that characterizes melodies defines, in human voice, the frequency band in which all "information" (i.e., verbal content) is communicated. When this frequency band is weighted to enhance the understanding of voice, it is known as the "index of articulation" (Kryter, 1962) and, more recently, as the "speech intelligibility index" (ANSI, 1997). These indices emphasize the relative importance of specific frequencies in conveying the information embedded in human speech. In the normal ear, acoustic energy within the primary frequencies of these indices is not attenuated as it passes through the middle ear structures to the inner ear. The frequency band defining the index of articulation is similar to the frequency band that composers have historically selected to express melodies. It is also the frequency band that mothers have used to calm their infants by singing lullabies. Modulation of the acoustic energy within the frequencies of human voice that characterize music, similar to vocal prosody, will recruit and modulate the neural regulation of the middle ear muscles, functionally calm behavioral and physiological state, and promote more spontaneous social engagement behaviors.

Concluding Comments

Based on the Polyvagal Theory, we are able to deconstruct Music Therapy into biobehavioral processes that stimulate the Social Engagement System. When the Social Engagement System is stimulated, the client responds both behaviorally and physiologically. First, the observable features of social engagement become more spontaneous and contingent. The face and voice become more expressive. Second, there is a change in physiological state regulation that is expressed in more regulated and calmer behavior. The improved state regulation is mediated by the myelinated vagus, which directly promotes health, growth, and restoration. However for some clients, especially those who have been traumatized, face-to-face interactions may be threatening and do not elicit a neuroception of safety. If this is the case, then the Social Engagement System can potentially be triggered through vocal prosody or music while minimizing direct face-to-face interactions. From a Polyvagal perspective, Music Therapy can be deconstructed into two integrated processes. The therapeutic environment involves the face-to-face interaction between the therapist and the client. This face-to-face interaction, if effective, will trigger the client's neuroception of safety. Second, the frequency band associated with melodies functionally duplicates the frequency band conveying information in the human voice. The human nervous system evolved to be very selective of these frequencies. Music, and especially vocal music, produces melodies by modulating these frequencies. This process engages and exercises the neural regulation of the Social Engagement System with the positive effects of improved socio-emotional behaviors and enhanced physiological state. Interestingly, the phrasing of music is also an important component of this process. The phrasing of music, especially when singing or playing a wind instrument, results in short inhalations and extended durations of exhalations. Physiologically, breathing "gates" the influence of the myelinated vagus on the heart. Functionally, when we inhale, the influence of the vagus is attenuated and heart rate increases. In contrast, when we exhale, the influence of the vagus is increased and heart rate decreases. This simple mechanical change in breathing increases the calming impact and health benefits of the myelinated vagus on our body. Thus, music therapy by engaging and exercising the Social Engagement System may promote positive outcomes improving several features related to quality of life.

Stephen W. Porges, **PhD** is Professor of Psychiatry and BioEnginneering and Director of the Brain-Body Center at the University of Illinois at Chicago. His work on the autonomic nervous system has led to a new understanding of mechanisms involved in behavioral regulation and social engagement behaviors. He is developing new biobehavioral assessment tools to monitor individual differences in physiological regulation of behavioral state. His research has led to an innovative intervention, The Listening Project, designed to exercise the neural regulation of middle ear structures to reduce auditory hypersensitivities and to improve the ability to listen and to attend to human speech. Dr. Porges speaks throughout the world about his Polyvagal Theory and its applications to typical and clinical populations. You can access several articles and a full bibliography of his work at www.stephenporges.info and find more information about his research program and the Brain-Body Center at http://www.psych.uic.edu/bbc/.

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