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The Use of Music Therapy as a Clinical Intervention for Physiologic Functional Adaptation

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Abstract—Survival depends on the maintenance, within very narrow limits, of physiologic variables critical to life, leading to a condition known as *homeostasis.* Homeostasis is achieved by cascading networks of sophisticated feedback/feedforward control systems that operate in accordance with prescribed reference set-points. In diagnosed populations (such as autistic), these set-points often deviate from those that optimize physiologic performance. Combined with misinterpretation of sensory information, these deviant set-points act to maintain the body in a perpetual survival mode that derives from the fear response. When this is the case, clinicians prescribe therapy in an attempt to re-set the reference control quantities to more desirable values through the process of *functional adaptation.* Recent research and clinical applications have verified that *music* therapy is one particularly effective clinical intervention that accomplishes this goal. Its effectiveness derives from its ability to function through sub-cortical, non-cognitive pathways that are indigenous to fundamental physiological response mechanisms. The instinct to track music is innate; it parallels and reflects the human condition. Having been invented by humans to express emotion, music speaks the language of the body through its six basic elements: *rhythm, melody, harmony, dynamics, timbre,* and *form.* This paper develops a paradigm describing how and why these music elements can be utilized, in combination or individually, as a medical intervention to redirect fear responses and specifically target sensory integration dysfunction. Applied clinically as a *continuous disturbance* to malfunctioning feedback-control pathways, music therapy can thus succeed in stimulating *functional adaptation*, driving the physiologic system towards more optimal responses to sensory inputs.

Keywords: Biomedical engineering—music therapy—music—functional adaptation—biomusical engineering—physiologic function—brain—fear responses—homeostasis

Introduction

The *survival instinct* is the most fundamental human drive. *Fear,* the physiologic response to an event perceived as being a threat to survival, is the strongest human emotion[1,2]. It is the *fear* response that causes physiologic *dissonance*

within the organism. When *fear* derives from inaccurate, uncoordinated, and systemically misinterpreted sensory information, the *amygdala*, *thalamus*, and *hypothalamus* of the paleoencephalon thrust the organism into continuous "911" survival mode. In a feedback-control sense, homeostatic reference operating points are set to invoke perpetual fight-or-flight reaction cycles in which behavior becomes governed by surges of endocrine hormones (mainly adrenaline) and sympathetic nervous system (noradrenaline) discharges[3,4]. Constant repetition of adrenaline-driven fight-or-flight responses becomes self-sustaining, conditioned responses resulting in system toxicity and dysfunctional adaptations. These adaptations include involuntary avoidance behaviors, diversional escape tactics, self-protective retaliative mannerisms, and a virtually complete shut-down of "rational" cognitive processing[5]. In short, the system is on emotionally driven auto-pilot. These characteristics are typically noted in diagnosing autism, attention deficit hyperactive disorders (ADHD), learning and language delays, strokes and brain injuries, and other clinical conditions.

Music, a sonorous image created by humans to express, parallel, and reflect human emotional and physiologic states, resonates with those states, echoing basic physiologic elements: *periodicity* (rhythm), *complex frequencies* (giving rise to pitch-melody, Fourier-induced sound quality or timbre, harmony), *energy* (dynamics, proportional to sound wave amplitude), and *structure* (form). We distinguish here the difference between using music for temporary *therapeutic* purposes, and the application of music as *therapy* to affect long-term physiologic functional adaptation. As a *therapeutic* tool, music is capable of conjuring alternative behaviors to bring about meditative, calming distractions which temporarily redirect limbic system (primarily *amygdaloid*, *thalamic*, and *hypothalamic*) responses away from fear.

As a medical *therapy*, music applied as ongoing treatment can directly target these "emergency, 911" states to evoke permanent systemic changes in physiologic accommodation (i.e., changes in the system's operating set-points). Music *therapy* invokes "continuous disturbances" (in the language of engineering control theory) into an organism's information processing matrix. Such persistent excitation ("driving" of the system) has been noted to be particularly effective in inducing adaptive accommodations in systems with faulty sensory interpretation, as diagnosed in autism, behavioral and language disorders, strokes, brain injuries, and others in which fear demeanor abounds[6]. Precisely because music embodies and speaks the same language as the human body, this acoustic medical intervention—applied consistently over extended periods of time—helps mitigate the brain/body reinterpretation and coordination of sensory stimuli. Thus, interpretive feedback-feedforward mechanisms act to modify homeostatic set-points, replacing physiologic "dissonance" with physiologic "consonance". The role of music therapy in arousing *permanent* changes in operating set-points ultimately leads to functional adaptation, which propels the system asymptotically towards a "strange attractor" that is defined to be a physiologic state of *cenesthesia*[3,4,6].

Physiologic Accommodations of Emotional Organisms

Interpretation of Sensory Information = Response

Cognition is not the precursor to behavior. Emotion is. Humans are not thinking machines that feel, but rather, *feeling* machines that think[7–9]. To believe otherwise is to exhibit a naive understanding of the most basic of physiologic processes—the instinctive drive for survival that is coded into automatic responses to perceived threats endangering survival. Understanding ourselves as being, first and foremost, *emotional* animals forces us to rethink fundamental aspects of physiologic function. That realization immediately places into perspective the role of music in physiologic accommodation.

For example, illustrated in the information flow diagram (Figure 1) is the fact that, as far as the brain's response to sensory inputs is concerned, it is totally irrelevant whether or not fear is recognized at the cognitive level of perception. In fact, before they even get that far, having passed through the *reticular formation* (reticular activating system, labeled *RASH* in Figure 1), sensory inputs perceived to be threatening are immediately directed to the limbic system (predominantly the *amygdala*, *thalamus*, and *hypothalamus*) of the brain's 500-million-year-old *Paleoencephalon*[3,4,6]. This "emotional brain" now takes over, becoming a key player in determining how the system will respond to perceived threats jeopardizing its safety and survival.

Thinking again in terms of the canonical form for feedback-control systems, the criteria utilized by the *RASH* and *Paleoencephalon* to determine how the physiologic system will respond to those sensory inputs are coded into homeostatic set-points that are the "reference signals" to which the system attempts to conform. All sensory stimuli are thus interpreted, checked, and coordinated against these reference signals. "Error signals" that result from a deviation of *actual* sensory inputs from *desirable* sensory inputs generate predetermined physiologic responses to such errors. Fear-generating information, as illustrated in Figure 1, will activate protective emergency action (the 911 response), which is mediated by the autonomic nervous and endocrine systems, depending on how immediately, and to what extent, the desired response is expected to be manifest.

Long before "cognition" and "psychology" became buzz words for analyzing and defining human experience, the organism responded first and continues to so respond, even in its most recent evolutionary version, *sub*-cognitively, intuitively, and spontaneously by means of genetically inscribed, *emotionally driven* instincts. The emotional instinct for survival in the face of perceived threats (real or imagined) is the engine that propels physiologic function. *Thought* (the cognitive awareness of internal and external events) is a luxury afforded after the fact, literally an *after*-thought, entering into our consciousness long after a response has already taken place instinctively[2,8,10] (first your heart races, hands sweat, and stomach cramps, before, or if ever, you even know why).

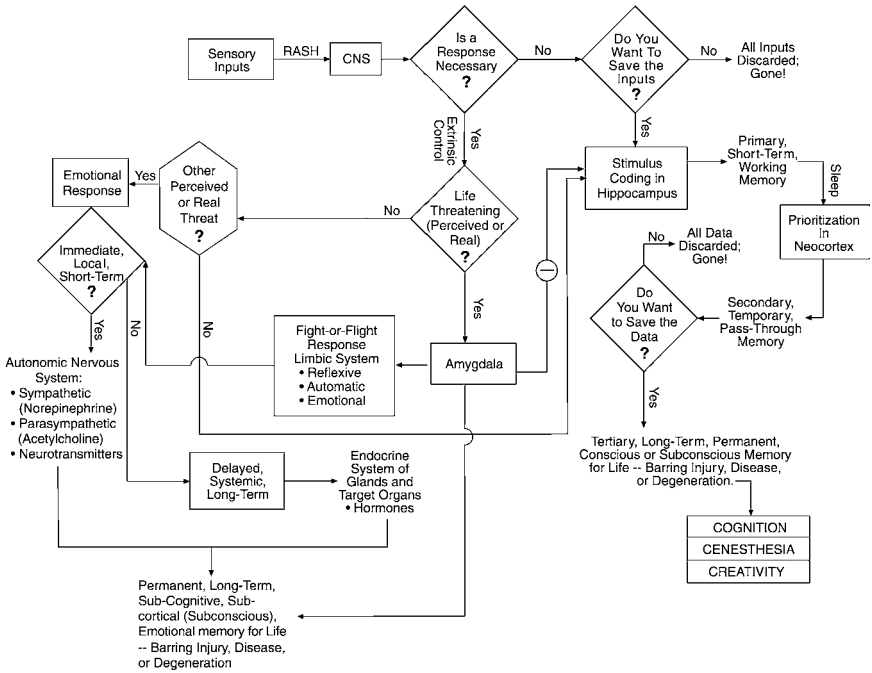

Fig. 1. Schematic of the canonic information processing route indicating the flow of stimuli from sensory input to motor output via a series configuration that tracks first through the limbic system (fear response) and then to the cerebral cortex (cognition).

Since *fear* is the underlying emotion driving human behavior, it follows that in uncoordinated sensory systems, where stimulus coding is distorted or inaccurate, the system will be thrust into a perpetual state of fear and survival behaviors will be the norm. Such systems will routinely operate in fight-or-flight modes, characterized by internal hyperactivity, ambient vision and hearing, and other forms of stress responses that mobilize the body to defend itself or flee. When conditioned, such responses will predominate, eventually becoming self-sustaining habits—pathologic "set-points"—even when one might never be fully "cognizant" of the fact that this behavior is being perpetuated by *fear*. Thus,

$$\text{fear} \rightarrow \text{stress} \rightarrow \text{response}_{(\text{sub-cognitive})} \rightarrow \text{desired result}_{(\text{survival, safety, comfort...})}$$

Stress might subsequently (after the fact) be consciously (neo-cortically) attenuated by adaptive mechanisms which, over time, modulate (hopefully minimize or eliminate) fear responses to certain stimuli. But that comes later. In fact, functional adaptation through cognitive attenuation of fear responses is undoubtedly one of the ways by which our organism has managed to survive to date, but in order to fully comprehend this process, we must understand

the organization of the human system made by *nature*, the way engineers conceptualize, understand, build, and control, systems made by *humans.*

If the fear-factor survives being mitigated by the *amygdala* and manages to reach higher levels of cognitive processing and conscious interpretation (the primary, secondary, and tertiary memory illustrated in Figure 1), what is referred to as *psychological* stress then manifests itself as the conditioned *attitude* toward *fear.* Utilizing instinctive fear–response mechanisms, this cognitively derived attitude of fear now nurtures the *conscious* stress related to fear. Cognition has now stepped in (after the fact) and taken over in an attempt to explain those earlier, spontaneous responses that were originally the result of feedback to *sub*-cortical instincts.

At this point, the fear responses become further "learned" and are fed *forward*, leading to states of fight-or-flight even when the original stimulus is no longer present (akin to conditioned behavior reflexes, i.e., "Pavlov's dog"). Consequently, instinctive reactions become further conditioned by a feedback–feedforward tango choreographed by the "cognitive" brain's awareness of fear[6,10].

Interestingly, a fear event that has once occurred, even if the person experiencing it was not aware of it at the time (i.e., there was no conscious realization that accompanied the event because it bypassed cognitive channels in favor of instinctive ones) can become permanently recorded into the memory of the *amygdala.* That is to say, the fearful event never reached the *hippocampus* for further coding and cognitive processing, but rather remained inscribed into archives of the *amygdala* (the sub-conscious)[1]. At this level, even the slightest reference to the original event will conjure the "fear" response unconsciously, triggering panic attacks, hyperventilation, and a state of agitation common to a fight-or-flight response, while the person wonders what is going on, and why. If, on the other hand, the fear event has passed into "conscious" mode of operation, then the added *"attitude"* factor will alter the previous instinct-derived paradigm of fear response and create an infinite, cyclic *do-loop* (borrowing a term from computer language):

$$\text{fear} \rightarrow \text{perceived-threat stress}_{(\text{amygdala, thalamus, et al.})} \rightarrow \text{instinctive response}$$
$$\rightarrow \text{cognitive recognition/attitude}_{(\text{hippocampus et al., memory, thought, learned response})}$$
$$\rightarrow \text{fear} \rightarrow \text{perceived-threat stress} \rightarrow \text{instinctive response}$$
$$\rightarrow \text{cognitive recognition/attitude} \rightarrow \text{fear} \rightarrow \ldots \text{ad infinitum}$$

Even worse, the cycle becomes a *spiral* that is extremely difficult to redirect once "thought" has imposed itself as an integral part of the equation. Sensory mis-interpretations appearing in autistic and other developmentally delayed populations operate in such a spiral, beginning with *uncoordinated sensory information processing*, which leads to inaccurate assessment of survival conditions, which leads to a constant physiologic state of fear, which results in a continual survival behavior mode, which keeps academic learning and social

accommodation at a distance, which precipitates environmental disapproval, which is perceived as a further threat to survival, which exacerbates fear responses, and so on. Academic learning cannot take place while the organism is in this fear-response spiral and while conditioned responses have set the system's feedback-control reference signals at a "911" configuration. The brain is simply too busy protecting the body from what it has erroneously concluded to be an environment of elements threatening its survival[10].

To break the loop or reconfigure the spiral, the system's inscribed emotional/instinctive response to perceived fear threats must be systemically reprogrammed so that comfortable, functionally adaptative processing and evaluation of sensory information can proceed relative to "calmer" homeostatic reference points that replace those derived from criteria of fear. As sensory integration and response reprogramming begin to take hold, feedback–feedforward control responses will change and later be redirected, when possible, to the higher level thought processes that might also have been contributing to the chaos. Only after the system's fears are first placated away from emergency responses will the gates to thinking and learning open. Enter music as a clinical intervention.

As *a physiologic tool for functional adaptation*, music therapy interventions can effectively change set-points that keep a system functioning perpetually in survival mode. Acting as a forcing function, music can drive a feedback-control system to adjust its reference signals through functionally adaptive mechanisms that redirect physiological patterns and psychological "attitudes". In short, music can truncate the fear spiral. Music does not need the thinking brain nor semantic interpretation; it is not constrained by cognition and mental thinking. Because it resonates symbiotically with instinctive physiologic attributes, music has the ability to bypass the cognitive feedforward "*attitude toward*" problem. Furthermore, *because* music requires no cognitive assistance in order to be efficacious, a huge literature addressing clinical work[11] corroborates that music applied as *therapy* can be one of the most efficacious and effective non-invasive, non-chemical, non-pharmacological ways to address and adjust sensory perception difficulties at the sub-cortical, instinctive accommodation level.

So What Is It about the Elements of Music That Makes It So Effective as a Clinical Therapy for Physiologic Accommodation?

Intervention from Inside-Out, Not from Outside-In

The answer to the question posed above can be summarized in one word: *Periodicity.* Music speaks the periodic language the body understands, at a level consistent with basic aspects of physiologic function, because the body *invented* music—from inside-out, not the other way around. We invent music as a vehicle for emotional expression and embed into it those elements we want expressed. In essence, the entire spectrum of human emotions, from the very lowest (despair, sadness, dismay, depression, anxiety) to the very highest (joy, jubilation,

ecstasy, exhilaration, elation, love) and everything in-between, is expressed through music, coded into a syntax (the elements of music) that mirrors the very nature of the system that created it. To understand the role of music in the human experience is to understand physiologic systems as creatures of emotion and creatures of *rhythm* in need of expressing those emotions.

With that in mind, the converse immediately follows. Certain *external* applications of carefully analyzed, well thought-out interventions that use music elements for targeting sensory misinterpretation will drive physiologic systems to respond and change on levels that the body both understands and to which it attends. This includes patients with chronic pain distress and those with a variety of diagnoses from autistic to Alzheimer's, from psychotic to typically high functioning.

Music therapy is a pro-active, interactive co-participation between client(s) and therapist which *produces and uses* music elements to effect change. It has no relationship to music "training", trained music-making, or music entertainment (although it is fun); rather, it functions completely at the human impulse level. Interventions capitalize on the human instinct to "tune in" and track contoured linear sounds, the impulse to move arms and legs, the compulsion to beat on drums, the arousal to emit vocal sounds, the curiosity to wait for the next event (i.e., to remain in a state of attention), and many other reflexive mechanisms that accompany organized physiologic responses to multi-sensory stimulation.

To provide multiple sensory experiences for the clinical purpose of inducing and redirecting some less efficient reflexive adaptations, music therapy has at its disposal six basic elements of music. All six are derived from corresponding aspects of biological *rhythms* and the mathematical and scientific methods that have evolved over the years to define and quantify those rhythms in an attempt to formalize the human need for emotional expression. It is not surprising that the most important music element calling the human system to attention is *rhythm.*

Rhythm. One of the most fundamental principles of physics is that all forms of energy are cyclic (both large-scale and small) in their regular manifestations from some indeterminate reservoir[12], i.e., that "*All God's creations got rhythm!*"[13] Periodicity, or *rhythm*, is everywhere on the planet; it is intrinsic to the nature of physiologic function and so is one of the first elements automatically detected when experiencing music (or, was music perhaps invented to be rhythmic as an expression of physiologic periodicity?). The close relationship between physiologic rhythms and music rhythms makes the latter very effective in capturing one's attention.

Furthermore, being so natural to the body, rhythm requires no training in order to be effective. It tends, immediately and automatically, to organize the body into a state of conformity—a state of *entrainment*—wherein physiologic functions (heart rate, breathing, movement, etc.) synchronize with, and are driven by, an on-going pulse. Going one step further, since the auditory and motor cortexes are close neighbors, rhythmic input serves the motor cortex as

musculotropic stimulation[14]. And because the rhythm of music has a complex structure, the brain is curiously challenged to attend to rhythm's complexities, adding ''motivation'' to the adaptation picture.

The structure of rhythm can be analyzed in terms of three *P's*: *pulse*, the ongoing steady ticking beat that underlies all other music information; the regular throbbing that gives music a characteristic cadence not unlike the heart beat or soldiers marching in strict formation (individual pulses are grouped into repeating units called *measures*, each containing a type of pulse grouping, i.e., 2, 3, 4, etc. ''beats'' per measure, called *meter*); *pace*, the speed of the persistent ongoing ticking pulse, ranging from very fast (''tachycardia'') to very slow (''bradycardia''), referred to in music as the *tempo* of the beat (how fast the troops are marching); and *pattern,* the ''lub-dup'' (in cardiac language) nature of the pulse or style of versification (prosody) in poetry; the Morse-Code–like variables of long-short-stop-start sound combinations interacting and teasing the pulse.

Pulse coupled with *pace* are time-keepers controlling most of what happens in a piece of music, and consequently, in body movement. We instinctively tap a pencil, finger, or toe to the pulse—the beat—of music. The organism becomes animated, lulled, or pacified depending on the tempo (pace) of the pulse. Pulse also encompasses strong–weak or weak–strong (as in ''lub-dup'') fall-rebound attributes akin to those of gravity. The application of cyclic, steady, medium-paced pulses of music applied to patients with stroke or brain-damage demonstrates the efficacy of rhythm in triggering an impulse to move and stimulating organized movement through paced (forcing function, driven) *entrainment*—conformity to pulsation—in systems with otherwise dormant or chaotic mobility[14,15]. The pace of a pulse tends to alter the pace of a system, either animating or calming body rhythms in subjects with hypotonic or hypertonic responses. Pulse also aids in pacing, breathing, word recognition, and stabilized visual attention in patients with nystagmus and ocular-motor scanning difficulties[6,16].

Pulsed and well-paced rhythms applied to children with autism, behavior problems, or erratic, disorganized, or unmodulated muscular control provoke those systems into becoming immediately organized and paced. Some of the interventions administered clinically using techniques of music therapy[6,14–16] to induce functional motor planning (praxis) adaptations, including the re-setting of vestibular and proprioceptive feedback-control reference signals, employ tasks such as rhythmic marching while drumming; jumping on a trampoline to the beat of the music; activities engaging gross-motor movement coordination; pulsed and patterned bilateral drumming for uncoordinated upper-body and hypotonic arms; and other activities[6,11,15,16].

Rhythmic verbal articulation of syllables and words has demonstrated that systems will instinctively attempt to imitate, coordinate, and ''conform'' synchronously with the pulse and pace of the verbal element[17,18]. Paced rhythmic speaking affords the brain additional processing time that normal

conversational speech often does not. When rhythm is systemically internalized (internally adopted and regulated) it transforms both oral and physical motor planning (praxis) and sensory organization[16–19].

Rhythm activities that incorporate use of special weighted mallets and drum sticks, heavy maracas, and various hand-held percussion instruments can provide proprioceptive sensory information to advise the brain of where limbs and body are located in space, thus helping to coordinate auditory/visual information to verify that what the eyes are seeing is in fact consistent with what the ears are hearing[6]. Pulse and pace are particularly effective interventions in autism, Down and Rett's syndromes, cerebral palsy, and language delays, among others[16]. Patients exposed to ongoing rhythm interventions exhibit improved attention, ability to stay on task or focus on cognitive information, and the inclination to imitate rhythmic verbal enunciations that induce speech. Many diagnosed children retain organized physical movements and focused learning after several years of continuous rhythmic interventions[6,16–19].

Rhythmic pattern (and persistence) keeps the brain "tuned in", whereas a simple metronome or clock pulse without changing patterns eventually bores the brain, causing the brain to "tune out", and often even lulls it to sleep. Because multiple, complex patterns evolve over the steadiness of a pulse, the brain continues to track evolving musical events, learning eventually to make it a habit to continue processing incoming information, thereby extending its attention span. Language-delayed children are particularly aided by the patterned rhythmic enunciation of words since rhythmic speaking slows the flow of verbal input enough for the brain to track and link tones and speech patterns[17,19]. Thus, slowly and effectively, information can be efficiently retained and interpreted. The elements of safety and grounding that a pulse provides also assure the brain of environmental safety, allowing for the processing of cognitive information.

Rhythm—cyclic, periodic repetition—carried into the 20–20,000 Hz (audible) range, gives rise to a fourth *"P," pitch*, from which is derived the second major element of music, *melody*.

Melody. Just as one of the most fundamental principles of physics is periodicity, one of the most fundamental principles of cerebral information processing is the human brain's affinity for tracking and linking tones (pitches) in search of meaning that could be the difference between life or death. Perhaps evolving from basic primitive human calls, *melody,* with or without lyrics, is one element of music within which is embedded all human emotion. The linear, consecutive linking of high-frequency and low-frequency sounds (pitches) that is defined to be *melody* captures the brain's attention, and because it can do so without words, melody does not require semantic interpretation in order to be understood. It goes well beyond words in expressing feelings. The brain is attracted to, is intrigued by, and remains attentive to melodic contour in anticipation of forthcoming pitch information. Paralleling prosodic speech inflecting emotional contents of words, melodic contours are prosodic inflections echoing emotional states of music[6,19].

Like rhythm, melody, too, can be analyzed in terms of three *''P's''*. *Pattern* involves the relationship between consecutive pitches, introducing the concept of musical *intervals* (vertical leaps of varying magnitude). Intervals provide the syntax of music's melodic expression, which goes along with a corresponding pitch contour—a musical panorama, or sound-scape. *Prosody* involves all of the features that characterize the sound-scape, including accents on certain notes, inflections from downward-moving to upward-moving pitch patterns, modulations from major to minor tonalities, and so on.

Phrasing refers to how melodic lines are structured to convey meaning. Phrasing has the same connotation in music as it does in language; that is, it is a manner or style of expression, such as timely pauses in articulating ideas so as to separate one thought from another, grouping of notes to convey a specific message (like syllables combined into words, words into sentences, sentences into paragraphs, etc.), and so on.

Since a melody is evolutionary (as are language sounds), the limbic system must follow and continually peruse this information for safety features. The combination of melodic contour, slow tempo (pace), elongated rhythmic patterns, and soothing vocalized tones of the melodic contours allow the brain to sense levels of safety. When safety is sensed in the sounds, the fight-or-flight fear spiral is diverted and the system relaxes. This is exactly how a baby is lulled to sleep by its mother's vocalized lullaby, and why an adult tends to fall asleep when listening to slow streams of music.

If the human instinct for tracking linked sounds is combined with the ability of certain melodic sound-scapes to relax the human system out of its ''911'' spiral (disengaging the *amygdala*), then concurrently, the cerebral gates of higher level information processing in the neo-cortex are opened (Figure 1). By redirecting the ''fear'' response in this manner, a single melodic unit can bring about a corresponding desire in non-verbal populations to vocalize by imitating pitch, which has significant implications in promoting language development, behavior modification, memory, cognition, and pleasure. Moreover, to follow a melodic stream requires accurate auditory tracking, often problematic in diagnosed populations. It is not surprising to find that improved auditory tracking abilities have been observed[6,16] when melodic lines are continually introduced as music therapy treatment for special needs populations.

Finally, diverting the system away from the ''fear'' spiral and enhancing its ability to track auditory information accurately can implicate language and cognitive learning. The accurate tracking of melodic contours can also provide one of the better training methods for developing astute and focused listening and learning skills.

When several melodic lines are sounded simultaneously, displaced vertically from one another at varying levels of pitch, there is added to music another dimension, giving rise to yet *another ''P''—polyphony*—from which is derived the third major element of music: *harmony.*

Harmony. Harmony supports and synergizes with the emotional context of a melody, adding color and mood while providing implied *dimensional/spatial references* to audition. As the superimposition of several melodic lines (pitches ''stacked'' vertically over one another) presented simultaneously (referred to as chords), *harmony* adds height and depth to the overall music environment and is the texture of the music fabric, built vertically and flowing horizontally. From a physics point of view, when sounds of different frequency are superimposed upon one another, there arises the phenomenon of *beats*, with which are associated the corresponding concepts of *dissonance* and *consonance.* These characteristic concepts tend to be culturally specific and learned, based on exposure. However, despite its specificity to culture norms, any physiologic system can become either relaxed or stressed to varying degrees, based on whether harmonies are perceived to be *consonant* (comfortable, devoid of disturbing sonic ''beats'') or *dissonant* (uncomfortable at specific beat frequencies)[20,21]. Consonance generally yields pleasantness whereas dissonance tends to induce stress responses.

In music therapy interventions, there are times when creating stress by presenting dissonant music harmonies in the environment can effectively serve as the ''continuous disturbance'' to the then-existing, quasi-equilibrated physiologic state, pushing the system to adapt (modulate) to the sounds of dissonance without the need for the ''911'' response.

The mechanism of such intervention is not unlike infusing the body with an allergen in order to establish immunity to the allergen; this may be the only way that a system will be coerced into accepting negative sensations and learning to modulate efficiently its behavioral *response* to such sensations. Since our planet is not always ''a comfortable place to be,'' and sensory information may, at times, be inaccurately assessed to be dissonant, music therapy need not always provide a ''comfortable'' environment, but at times may deliberately utilize a *continuous disturbance* intended to induce change (adaptation).

Dissonant harmonic interventions in music therapy sessions have aided many clients in learning to ''accept'' an environment of auditory/physical discomfort without resorting to the fight–flight mode[6].

Harmony also forces a new kind of *auditory perception.* To track a melody above a harmonic structure involves, in addition to auditory tracking abilities, a keen sense of *auditory figure-ground*—the ability to focus on and decipher foreground from background. *Auditory figure-ground perception*[6,21] is crucial for proper hearing, tracking, and learning both spoken language and verbalized cognitive information inputs. Systems perpetually in survival, ambient hearing modes often do not have this ability. To their ears, all sounds have equal presence and importance, essentially becoming walls of homogeneous sound without focus or distinction.

Music therapy treatment for this problem provides the opportunity to focus on and follow (track) a melody above or below harmonic accompaniment. Such persistent tracking (continuous disturbance) eventually compels the system

(adaptation) into a state of auditory focus and figure-ground perception. For instance, learning to listen for particular musical cues as commands for undertaking tasks specific to those cues (e.g., changing one's direction of motion in response to hearing, suddenly, a higher pitched trill on the keyboard, while simultaneously beating a hand-drum in pulse with the accompanying music, and, at the same time, singing [or tracking] the melody) cannot help but eventually ''order'' the auditory system and brain to attend to specific elements of the music. Clinical practice with patients lacking auditory figure-ground has successfully yielded positive results[6,16]. As the music element of harmony supports and intensifies the emotional content of a melody, so the emotional content of rhythm, melody, and harmony combined are further expressed through yet another *''P''*: *power*, from which is derived the fourth major element of music, *dynamics.*

Dynamics. Periodic phenomena are characterized not only by the frequency of the vibrations, but also by the corresponding amplitude of the vibrations. The amplitude of a sound wave is a measure of the energy contained in the wave, which energy, expressed per unit time (power), per unit area (intensity), in non-dimensional decibel units, determines how ''loud'' a sound is perceived to be. The volume in which one speaks a sentence demarcates to the listener the intent of the information. In music, ''loudness'' (volume) is called *dynamics.* As an auditory stimulant, *dynamics* codes into music its corresponding mood and emotion. All the intensity levels of human physical function are exactly mirrored in music's element of dynamics. We shout to express joy or anger; we whisper to convey a sense of calm and/or secrecy.

The dynamic levels of physical energies used by a client when striking a drum loudly or softly impact upon the flexion-extension-relaxation elements of muscular arm activities, addressing hypotonia and proprioception issues. Loud music also provides external vibratory proprioceptive massage to surround and envelop the body, giving further information to the brain about the body, its bulk and location in space.

Dynamics (volume), also serves the role of ''continuous disturbance'' which acts to modify physiologic set-points. Quiet or loud, increasing or decreasing volume (in musical terms, *crescendo* or *decrescendo*, respectively) immediately calls the system to attend (as does a loud voice or megaphone) and respond, both of which also exercise the middle-ear reflex (as if ears were ''squinting'') and present or elicit emotional information with no need for semantic interpretation. Joy, excitement, hope, fear, and anger are generally implied by high volume. Calm, sadness, solitude, peacefulness, and spirituality are generally associated with lower volume.

Human instinct automatically knows what emotional message is embedded in the dynamics of the music, and its physiologic impact is instantaneous, manifested in the feedback/feedforward mechanisms between cortexes. If the volume is too high (80–120 dB), the message is *loud*, confusing or frightening to a system unable to modulate sensory responses. If the volume is too low (0–40

dB), the information might be completely ignored, which could be detrimental to safety. Moreover, if, as is the case in autism, one's auditory system is overly biased one way or the other, what is perceived as "normal loudness" (40–80 dB) to the average listener might be interpreted as being too loud (hyperactive) or too soft (hypoactive)—subjective perceptions in a diagnosed population.

In hyper- or hypo-reactive systems, the use of dynamics can teach the brain to acquire adaptations to extremes of sound information. Music dynamics are a major contributor in tempering fear responses. With enough persistence in focusing dynamics for specific music therapy goals, i.e., in order to calm energetic movement, the use of quiet sounds that require less physical muscular energies (thus releasing muscle tensions) has been effective in stimulating systemic and external behavioral changes to occur[22].

So far, we have discussed the frequency (pitch) of sound energy and its associated amplitude (loudness) as if they are unique to any given musical tone. Alas, we do not live in the perfect world. Sound sources (including the human voice) are *not* uniformly homogeneous, isotropic, perfectly structured, well-behaved devices that completely lack any physical flaws whatsoever. Thus, when stimulated to vibrate, such sources do not vibrate exactly the same way throughout, in all directions, to produce a pure, single-frequency, single-amplitude, perfectly symmetric, alternating compression-expansion wave. Rather, most of the material oscillates at about the same frequency and amplitude (the "fundamental" pitch we hear), but much of it does not, so that superimposed upon these fundamental vibrational characteristics is a variety of other frequencies and amplitudes—some higher than the fundamental, some lower.

This observation was formalized by the mathematician Joseph Fourier (1768–1830), who showed that any complex periodic wave motion can be expressed as the sum of many simple oscillating waves of different frequencies, amplitudes, and wavelengths. This theorem gives rise to the concept of a frequency and energy spectrum for any given musical note, from which is derived the fifth major element of music—*timbre*—or sound quality (associated with the *absence* of perfection, another *"P"* in sound-generating sources). In the language of physics, Fourier Analysis is referred to as "harmonic analysis" (the individual elements of which are called harmonics); in the language of music, frequency and amplitude spectra are referred to as the *"overtone series"* of any given musical note.

Timbre. For survival purposes, the brain, based on information it receives from the auditory system, must *discriminate* and process acoustic information based on all the elements discussed above (i.e., all of the "P's"), to which we now add the location of the sound (two more "P's" if you will, this time designating both the *position* of the sound—the place from where it is emanating, and its *proximity* to the listener—how far or near, etc.) and the *quality* of the sound, its *timbre*, which provides clues to what the sound is and how, or by what/whom, it is being produced. As defined above, *timbre* results from the interaction of multiple

frequencies superimposed on one another due to the imperfections in a vibrating source, which then gives that particular source its own unique sound quality, its own type of wave pattern—its personalized *eigenfunction* (rough, smooth, raspy, mellow, pungent, coarse, etc.). The sawing of wood, for example, has its unique timbre, quite different from that of sawing a steel pipe, and certainly distinguishable from the sound quality produced from scratching a blackboard that sends shivers and goose-bumps up and down one's spine.

In music therapy interventions, *timbre* can cause a complete reversal of physiologic responses. In combination with rhythm and melody, timbre will animate or quell systemic responses. A lullaby played on a blaring trumpet will conjure a different response than will the same tune played on a violin, harp, or chime (keeping all other variables—pulse, pace, volume, etc., the same). A patient can have adverse reactions—fear reactions—to some timbres, and soothing reactions to others; no two systems will respond the same way(s) to the same timbre(s).

When considering emergency function that includes ambient hearing, the inability of the central nervous system to discriminate timbre appropriately will lead to fight-or-flight reactions via the *amygdala*, et al. Therefore, through music therapy intervention auditory discrimination issues can be best addressed to aid a system, by providing continual arousal to timbre elements. By rendering "continuous disturbances" of uncomfortable timbre stimuli, set-points will eventually adapt, allowing the body to accept the nasty timbre as a "necessary evil". In the process, music tasks and instruments applied to develop functional auditory discrimination will increase the ability to 'tell the difference' and ultimately accept the discomfort without fear.

The reader will be aware by now that music, in some sense, may be thought of as the embodiment of *time*; specifically, periodic events in time. Indeed, music *exists* only in time, where it begins, evolves to a peak (perhaps with some variations and repetitions included), and subsides or culminates. Music's process is exactly parallel to all life on this planet and, in particular, to human life. Hence, music, indeed, is also the embodiment of *physiologic time*, as was proposed earlier in this paper. When all of the elements of music are organized in time to express an idea, to "tell a story," the final element of music emerges: *form*, which gives it meaning—meaning that now embodies as well the entire spectrum of human emotions—and, in a historic sense, tells us a great deal about the cultural norms and behaviors that prevailed when specific pieces of music were composed. In the music therapy setting of creating music together "in the moment", the evolving music also provides information relevant to the physiologic, psychologic, and social behavior norms of the patient.

Form. The element of form is the envelope in which music takes shape. As a type of sensory input, the existence of form in music requires expanded attention and delayed gratification (waiting till the end)[23]. This is invaluable in assisting persons with attention deficits and sensory disorders. That music causes the brain to "stay tuned" has already been noted above. That music, by way of

form, further tells the brain that it ''isn't over 'til it's over'' is exactly how homeostatic set-points for the escape-clause ultimately become re-set. Waiting—patience (delayed gratification)—is perhaps the single most difficult aspect associated with fear responses. Getting out, getting away, hiding, fleeing, are typical behaviors in autism and many other diagnoses, including Alzheimer's. Persons who are physically paralyzed find escape routes by mentally ''tuning out'', making diversionary noises, etc.

Music leaves no room for escape. When a tune is enticing, one tracks it to the end; the interest leaves no choice. The more the brain experiences the ''waiting game'', the sooner its operating set-points will change from anxiety for escape to patience for attendance. Many ADHD children exposed to constant music therapy interventions have learned to wait and attend[6,16]. Motivation is the key. Music *form* provides the motivation to wait until the end (to anticipate the moral of the story). Resolution brings inherent reward that accompanies the relief of reaching the conclusion. The objective of attending to a form that includes beginning–middle–end is much more effective if accomplished through music than it is when taught verbally. Attending involves intuitive knowledge best learned by experience, and music helps to provide that experience, as opposed to verbal interventions that require cognitive information processing that is not quite as instinctive.

Final Remarks

The resources of music outlined in this paper combine to provide a unique medical therapy intervention for steering the system away from set fear responses toward functionally adaptive physiologic changes. One important medical arena among the many mentioned throughout the paper, in which music and sound interventions are especially potent for addressing fear and stress, is that of Chronic Pain Management. The reader is referred to the extensive work of George Patrick[24] at the National Institutes of Health, and several important studies[25–28] demonstrating the efficacy of Vibroacoustic Pain Management[24] and the role of music therapy in altering patient (brain) attitudes toward pain as direct results of such interventions.

To summarize, we suggest that music has the ability to alter fear and stress responses by re-setting homeostatic set-points precisely because music elements synergize with physiologic function and can therefore alter homeostatic set-points to derive positive results. As a medical intervention, music therapy impacts upon stress and fear responses in a manner resulting in stress and pain management, language and cognition[29], memory, attention, functional motor planning (praxis), auditory tracking, figure-ground awareness, depth perception, sound location, auditory/visual integration, auditory/motor coordination, proprioception, vestibular and tactile stimulation, and many other areas of human function.

Once sensory stimulus coding becomes better organized and favorably interpreted, and homeostatic operating set-points are diverted away from fear

responses as a result of music therapy treatment, positive physiologic and psycho-emotional adaptation can take place, yielding the ultimate state of *cenesthesia*.

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