



THE DRUM PROTOCOLS

Structured rhythm designed to support nervous system regulation

Neurological Foundations and Clinical Rationale — Version 5

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NOTE: *This document is an internal reference for users and clinicians working with the Drum Protocols system. It is not a peer-reviewed publication. Where specific claims are made, supporting literature is indicated in brackets. The mechanisms described reflect current scientific consensus in auditory neuroscience and rhythm cognition research.*

1. Introduction and Conceptual Foundation

The central premise of the Drum Protocols is straightforward but has significant implications: rather than using secondary acoustic phenomena—such as binaural beats, isochronic tones, or specially processed carrier signals—to induce a desired brainwave state, the Drum Protocols embed the entrainment signal directly within the music itself as a rhythmic pulse operating at a therapeutically meaningful frequency. This document explains why that distinction matters, traces the neurological pathway by which the signal reaches and influences the brain, and provides a comparative analysis of embedded pulse entrainment versus the principal alternative methods currently in use.

The approach originates in a straightforward mathematical relationship: given a percussion hit rate measured in hits per second (Perceived Rhythmic Cycle, or PRC), the nervous system experiences a periodic auditory stimulus at that exact frequency. When that frequency falls within the theta brainwave band (3.5–14 Hz), the auditory brainstem and thalamocortical systems that process rhythmic timing information will, under the right conditions, begin to synchronize their oscillatory activity to match it. This is the fundamental mechanism of auditory entrainment, and it is the same mechanism whether the entraining signal is a click track, a binaural beat, or the groove of a polyrhythmic drum pattern.

What changes is everything surrounding that mechanism—the richness and naturalness of the stimulus, the pathway it travels through the nervous system, the depth of structures it activates, the absence of required headphone use, the compatibility with social or group listening, and the degree to which the listener's attention and engagement can be maintained over a 40–60 minute therapeutic protocol. These differences are not trivial. They are, in fact, the clinical rationale for the Drum Protocols approach.

Core Definition: *The Perceived Rhythmic Cycle (PRC) is the rate of percussive events per second experienced by the listener. At therapeutic PRC values of 3.5–14 Hz, the rhythm itself becomes the entrainment carrier—no secondary signal is required.*

1.1 The Dysregulation Premise: Why External Scaffolding Is Needed

The nervous system is, at its foundation, a timing system. Its capacity to regulate arousal, sustain attention, coordinate movement, process sensory input, and generate coherent behavior depends not simply on the presence of neural activity, but on the temporal organization of that activity—the precise coordination of oscillatory rhythms across interconnected structures operating at different frequencies and timescales [Welsh et al., 2005; Tordjman et al., 2015; Başar et al., 2001].

When this internal timing architecture is intact, the nervous system moves with coordinated fluency: arousal rises and falls adaptively, attention anchors and releases appropriately, and the organism can shift between states—from high alert to deep rest—in response to genuine environmental demand. Rhythm, in this sense, is not background to neural function. It is the structural medium through which regulation happens.

Dysregulation, within this framework, is not simply a state of being too activated or too shut down. It is more precisely a loss of temporal coherence—a condition in which the internal oscillatory

architecture has become unstable, fragmented, or unable to maintain the coordinated rhythmic relationships that underpin adaptive functioning. The system continues to generate activity, but that activity has lost its organizing structure. The result is a nervous system that cannot reliably find its own timing [*Welsh et al., 2005; Neo et al., 2023; Dickinson et al., 2025*].

This has a direct and consequential implication. When internal rhythmic architecture is compromised, the nervous system may seek temporal structure from outside itself. Behaviors that appear purposeless, repetitive, or symptomatic may, from a timing perspective, represent exactly this—spontaneous attempts to generate external rhythm that substitutes for missing internal coherence. The body reaches for a beat because the brain needs one [*Tordjman et al., 2015; Kawasaki et al., 2017; Dickinson et al., 2025*].

The Drum Protocols are founded on this premise. The embedded rhythmic pulse is not offered merely as a pleasant accompaniment to a therapeutic session, or as an attention management tool, or even simply as a brainwave entrainment stimulus. It is offered as external temporal scaffolding—a designed, stable, biologically calibrated rhythmic structure that the dysregulated nervous system can use as an anchor. By providing a coherent, consistent oscillatory reference at therapeutically meaningful frequencies, the Drum Protocols offer the nervous system a timing scaffold from outside when its own internal architecture is insufficient to generate one reliably from within.

This reframes the entire mechanism described in the sections that follow. The auditory pathway, the subcortical entrainment response, the theta-band frequency specificity, the autonomic modulation—all of it is in service of a single underlying purpose: to give a dysregulated nervous system something external to synchronize with, until or while it recovers the capacity to generate that coherence internally.

2. The Auditory Pathway: From Eardrum to Cortex

To understand how an embedded rhythmic pulse entrains neural oscillations, it is necessary to trace the complete auditory pathway from peripheral transduction to cortical processing. Each station along this pathway plays a distinct role in how rhythmic timing information is extracted, encoded, and ultimately used to modulate brain state.

2.1 The Peripheral Auditory System

2.1.1 The Outer and Middle Ear

Sound enters as mechanical pressure waves through the external auditory canal, causing the tympanic membrane (eardrum) to vibrate. The ossicular chain—malleus, incus, and stapes—transmits and amplifies these vibrations, delivering them to the oval window of the cochlea. This mechanical stage is not passive: the middle ear muscles (tensor tympani and stapedius) contract reflexively in response to loud sounds and can modulate transmission gain, a process relevant to the variable amplitude transients characteristic of percussion.

2.1.2 The Cochlea and Frequency Analysis

The cochlea performs a Fourier-like decomposition of the incoming signal along its basilar membrane. High frequencies activate basal regions; low frequencies activate apical regions. This tonotopic organization is preserved throughout the entire auditory pathway up to and including primary auditory cortex (A1).

Critical relevance for the Drum Protocols: Percussive sounds are broadband transients—they contain energy across a wide frequency range. The attack portion of a drum hit (the initial sharp onset) is rich in high-frequency content (roughly 800 Hz–8 kHz) and drives strong activation across the cochlear partition. This is why percussive onsets are among the most salient stimuli the auditory system processes, and why a Multiband Dynamics stage targeting 800 Hz–4 kHz is an effective strategy for isolating the entrainment-relevant portion of the signal in a mix.

2.1.3 Inner Hair Cells and Phase-Locking

Inner hair cells (IHCs) transduce basilar membrane motion into neural firing patterns. A crucial property of auditory nerve fibers is phase-locking: at frequencies below approximately 4–5 kHz, individual fibers fire preferentially during specific phases of the stimulus waveform, creating a temporal code that preserves timing information in the neural output. This phase-locking is highly precise and forms the foundation for all subsequent temporal processing of rhythmic events [Joris et al., 2004].

The envelope of a rhythmic percussion pattern—the slowly-varying pattern of amplitude over time created by the succession of hits—is itself a lower-frequency signal. When individual drum hits arrive at 3.5–14 Hz, the auditory nerve ensemble encodes not just each individual hit but the rhythm's envelope as a coherent neural event stream at that repetition rate.

2.2 The Brainstem Auditory Pathway

2.2.1 The Cochlear Nucleus

The first central processing stage is the cochlear nucleus (CN) in the medulla, which receives direct input from auditory nerve fibers. The CN contains multiple cell types that perform different operations on the incoming signal, including onset detection (spherical bushy cells firing sharply at transient onsets), sustained encoding, and temporal edge detection. The dorsal cochlear nucleus in particular receives input from non-auditory sources including the somatosensory system, creating a site of early multimodal integration [Shore et al., 2016].

Key Point: *The cochlear nucleus is the first site where the sharp attack onset of a percussion hit is translated into a discrete neural event. The precision of this encoding—measured in microseconds—is what gives percussive rhythm its power as a temporal anchor for subsequent neural synchronization.*

2.2.2 The Superior Olivary Complex

The superior olivary complex (SOC) is the first site of binaural convergence, receiving input from both ears. It is best known for its role in sound localization, but its medial nucleus (MSO) also performs coincidence detection that is relevant to temporal processing. The SOC projects to the inferior colliculus and is part of the corticofugal feedback pathway that can modulate processing at earlier stages.

2.2.3 The Inferior Colliculus

The inferior colliculus (IC) in the midbrain is a mandatory relay for nearly all ascending auditory information. It integrates inputs from multiple brainstem nuclei, performs further spectrotemporal analysis, and is heavily involved in the processing of amplitude modulation—that is, the variation in signal level over time that constitutes rhythmic patterning. The IC shows strong neural entrainment to amplitude-modulated stimuli at modulation frequencies in the theta range (4–8 Hz), producing what are sometimes called auditory steady-state responses (ASSRs) when the modulation is periodic [Galambos et al., 1981; Picton et al., 2003].

The IC is also a major target of descending cortical projections, making it a bidirectional integration hub rather than a simple relay. Changes in attention, arousal, and prior experience modify IC processing—a finding directly relevant to the question of how intentional listening context affects entrainment efficacy.

2.2.4 The Medial Geniculate Body

The medial geniculate body (MGB) of the thalamus is the final subcortical relay before auditory cortex. It has three subdivisions: the ventral (specific, tonotopic, projects to A1), dorsal (non-specific, polymodal, projects broadly to association areas), and medial (projects to amygdala and frontal cortex). The MGB is a critical site for the modulation of auditory responses by attention and arousal state—neurons in the MGB show dramatically different response properties depending on the animal's behavioral state [Edeline, 2003].

The thalamus is also the site where the thalamocortical oscillations that produce alpha and theta rhythms are generated and maintained. The reticular nucleus of the thalamus forms inhibitory feedback loops with relay nuclei including the MGB, creating the rhythmic bursting patterns that

correspond to various EEG states. This means that the auditory thalamus is not just a waystation—it is directly embedded in the oscillatory machinery that the Drum Protocols aim to influence.

2.3 The Auditory Cortex

2.3.1 Primary and Secondary Auditory Cortex

Primary auditory cortex (A1), located in Heschl's gyrus within the superior temporal plane, receives tonotopically organized input from the ventral MGB. A1 performs detailed spectrotemporal analysis and is responsive to complex sound features including onset sharpness, periodicity pitch, and temporal modulation.

The superior temporal gyrus (STG) and superior temporal sulcus (STS) constitute secondary auditory areas that process increasingly abstract representations of auditory objects, including the meter and beat structure of music. Neuroimaging studies consistently show robust activation of the STG in response to rhythmic musical patterns, with activity modulated by the predictability and periodicity of the rhythm [Zatorre et al., 2007].

2.3.2 Neural Entrainment in Auditory Cortex

A foundational finding in auditory neuroscience is that cortical neural oscillations entrain to the temporal structure of auditory input—a phenomenon well-documented across species [Nozaradan et al., 2011; Zion Golumbic et al., 2013]. Specifically, **the phase of low-frequency cortical oscillations (delta: 1–3 Hz, theta: 4–8 Hz) aligns to the beat and meter of music in real time**. This is not metaphorical synchronization—it is a direct phase-coupling between the neural oscillator and the acoustic periodic structure, visible in both EEG and intracranial electrophysiology.

This entrainment serves functional purposes: neural excitability is highest at the phases that align with expected beat onsets, creating a predictive mechanism that enhances the processing of temporally expected sounds while suppressing responses during less informative periods. In the context of the Drum Protocols, this means that a well-structured rhythmic pattern is not merely stimulating the auditory system—it is actively coordinating the timing of neural processing across auditory and associated cortical areas.

3. Neural Entrainment: Mechanisms and Evidence

3.1 What Entrainment Is and Is Not

The term 'neural entrainment' is sometimes used loosely to mean a variety of phenomena, creating confusion in clinical discussions. For the purposes of this document, neural entrainment refers specifically to the phase-locking of endogenous neural oscillations to an external periodic signal. This is distinct from, though related to, the broader concept of neural synchrony (coherent oscillations within or between brain regions that are not necessarily driven by external stimuli).

Entrainment is a bidirectional interaction: the external rhythm influences the phase of the endogenous oscillator, but the sensitivity of that influence depends on the match between the driving frequency and the natural frequency of the oscillator, the strength of the driving signal, and the current state of the oscillator. This means entrainment is not passive—it involves active neural dynamics that respond differently depending on arousal state, attention, and prior context.

3.1.1 A Probabilistic Model of Entrainment

A critical clarification for clinical contexts: entrainment is not a binary event in which the brain “locks to” an external frequency with certainty. It is better understood as a probabilistic tendency of neural oscillatory systems to partially align their phase and frequency with a persistent, salient external rhythm — the degree of alignment varying with signal strength, predictability, the listener’s current arousal state, and the match between the driving frequency and the natural frequency of the relevant endogenous oscillator.

Three distinct but interacting mechanisms contribute to the regulatory effect, and it is important to resist reducing entrainment to only one of them. **Phase alignment of neural excitability cycles** — the mechanism most directly described by “brainwave entrainment” — produces the strongest effects when the driving signal is highly periodic, spectrally clean, and operating near the natural frequency of the target oscillator. **Attentional sampling alignment** occurs when the predictability of a rhythm reduces the cognitive cost of temporal parsing: the auditory system “knows when” the next event will occur, freeing attentional resources and reducing vigilance load. **Sensorimotor coupling** engages the motor and cerebellar timing systems via the auditory-motor network, anchoring the listener’s internal timing to the external rhythm even without deliberate movement.

These three mechanisms produce overlapping but distinct therapeutic effects. A given protocol may produce strong phase alignment in one listener and primarily sensorimotor coupling in another, depending on individual neural architecture, arousal state, and listening engagement. This is why individual variability in response is expected and should not be interpreted as protocol failure: multiple pathways to regulation are active simultaneously, and their relative contributions differ across people and sessions.

Clinical Note: *When explaining the mechanism to patients or caregivers, describing the rhythm as a “timing scaffold for the nervous system” is more accurate and more useful than “it puts your brain into theta.” The scaffold metaphor captures the probabilistic, supportive nature of the effect without implying deterministic frequency control.*

3.2 The Frequency Specificity of Therapeutic Entrainment

Brainwave oscillations are organized into frequency bands that correspond to different functional brain states. The bands most relevant to the Drum Protocols therapeutic targets are:

Brainwave Frequency Reference	
Delta (0.5–3 Hz)	Deep sleep, unconscious processing, restorative states. PRC < 3 Hz.
Theta (3.5–14 Hz)	The primary therapeutic target. Meditation, emotional processing, memory consolidation, hypnagogic states. Accessible via PRC 3.5–14 Hz.
Alpha (8–13 Hz)	Relaxed wakefulness, calm focus. Accessible via PRC 8–12 Hz at 1/24 or 1/32 denominations.
Beta (13–30 Hz)	Active cognition, problem-solving, anxiety at high end.
Gamma (30–100 Hz)	Sensory binding, high-level cognition. Not a Drum Protocols target.

Theta-band oscillations (4–8 Hz) are generated primarily in the hippocampus and entorhinal cortex but are coordinated broadly across prefrontal, parietal, and temporal cortices during states of relaxed alertness, emotional regulation, and memory encoding. Hippocampal theta is strongly associated with the consolidation of emotional memories, and disruption of theta is observed in PTSD, anxiety disorders, and depression [Lega et al., 2012; Klimesch, 1999].

The theta range is also the natural frequency range for working memory maintenance in prefrontal cortex, and theta-gamma coupling—where gamma-band activity is nested within the phase of theta oscillations—is a proposed mechanism for the temporal multiplexing of information in working memory [Lisman & Jensen, 2013]. These multiple associations between theta and key aspects of emotional and cognitive function make it a compelling therapeutic target.

Clinical Relevance: *Therapeutic use of the Drum Protocols at PRC values of 3.5–14 Hz spans the theta and alpha bands for a specific reason: the lower portion of this range (3.5–8 Hz, theta) is the oscillatory signature of emotional regulation, nervous system downregulation, and trauma integration — the target for calming and stabilization protocols. The upper portion (8–14 Hz, alpha) corresponds to relaxed alert readiness, focused attention, and calm activation — the target for morning activation, focus, and pre-performance protocols. The full 3.5–14 Hz range represents the complete therapeutic arc from deep stabilization to functional, organized readiness.*

3.3 The Role of Rhythm Salience and Transient Sharpness

Not all periodic stimuli are equally effective at driving neural entrainment. The salience of a rhythm—the degree to which it captures the attentional and synchronization resources of the auditory system—depends on multiple factors, including the sharpness of event onsets, the signal-to-noise ratio in the entraining frequency range, the presence of a hierarchical metrical structure (beat within meter), and the engagement of the listener.

Onset sharpness is particularly critical. Percussion instruments produce among the sharpest acoustic onsets available in music, with rise times measured in milliseconds. These sharp onsets produce strong, time-locked responses in auditory cortex and brainstem, maximizing the precision of phase-locking. The Dynamics (PSR) value is a proxy for this property: a higher PSR means individual events are punching through clearly relative to the average level, which corresponds to preserved onset sharpness and therefore higher entrainment efficacy.

Metrical hierarchy amplifies entrainment to the beat level by creating a predictive framework. When the listener perceives a meter (e.g., 4/4), beat-level expectation enhances the neural response at the beat frequency even before the beat arrives, through a mechanism of predictive coding. The polyrhythmic architecture of the Drum Protocols—where multiple percussion layers create interlocking patterns—generates a rich metrical scaffold that maintains this predictive entrainment across extended durations without listener fatigue.

3.4 Subcortical Entrainment and the Frequency Following Response

An important and often underemphasized aspect of auditory entrainment is that it occurs not just at the cortical level but throughout the subcortical auditory pathway. The Frequency Following Response (FFR) is an electrophysiological measure of brainstem phase-locking to the temporal fine structure of sound, recorded at the scalp. The FFR demonstrates that subcortical auditory structures actively track the periodic features of complex sounds with millisecond precision [Kraus & Chandrasekaran, 2010].

This subcortical entrainment matters for two reasons. First, it means that the brainstem itself—not just the cortex—is being synchronized by the rhythmic input. The inferior colliculus, superior olive, and cochlear nucleus are all part of the arousal regulation network via their connections to the reticular activating system, locus coeruleus, and other neuromodulatory centers. Rhythmic entrainment of these structures can therefore influence arousal and alertness regulation directly, not only through top-down cortical mechanisms.

Second, subcortical entrainment does not require sustained conscious attention to the rhythm. The brainstem processes occur automatically and preattentively, meaning that entrainment begins even before the listener has explicitly focused on the beat. This is clinically important for populations where voluntary attentional engagement may be limited, including individuals in acute stress states, those with trauma-related hyperarousal, or children.

4. Comparative Analysis: Embedded Pulse vs. Alternative Entrainment Methods

Multiple approaches to auditory entrainment exist, and each has a distinct neurological mechanism, a different set of requirements, and a different clinical profile. Understanding the differences—particularly at the level of which neural structures are engaged and how—provides the scientific rationale for the design choices embodied in the Drum Protocols.

4.1 Binaural Beats

4.1.1 Mechanism

Binaural beats are an auditory illusion produced when two tones of slightly different frequencies are presented simultaneously to the two ears via headphones. The auditory system, in attempting to localize the apparent source of the combined stimulus, generates a perceived beating at the difference frequency. A tone of 400 Hz in the left ear and 404 Hz in the right ear produces a perceived beat at 4 Hz. This beat is not physically present in either ear's signal—it is generated by the binaural processing of the superior olivary complex and subsequent auditory areas [Oster, 1973].

4.1.2 Neurological Pathway

Because the binaural beat is generated centrally (at the SOC and above), it does not produce a peripheral acoustic onset. The driving signal is an internally generated oscillation in the binaural disparity processing system, not a physical transient that phase-locks cochlear nucleus and auditory nerve fibers. This means the stimulus engages the upper brainstem and cortex but does not generate the sharp, onset-locked subcortical response that physical percussive transients produce.

4.1.3 Limitations Relative to Embedded Pulse

- **Headphones required:** The binaural beat mechanism depends on isolating different frequencies to each ear. Speaker playback collapses the binaural separation, eliminating the effect entirely.
- **Narrow effective frequency range:** Binaural beats are perceptible only when the carrier frequency is within a range that supports reliable binaural processing (generally 200–900 Hz). At frequencies above or below this range, the perceived beat weakens or disappears.
- **Absence of peripheral entrainment:** The stimulus engages central auditory processing but does not produce the millisecond-precision onset encoding at the auditory nerve and cochlear nucleus levels that physical percussion generates. The entrainment pathway is therefore cortically weighted rather than encompassing the full brainstem-to-cortex hierarchy.
- **Carrier tone monotony:** Sustained pure or near-pure tones at carrier frequencies produce sensory adaptation relatively quickly, limiting the sustainable duration of a binaural beat protocol without listener discomfort or inattention.
- **Ineffective for group settings:** Group delivery is impossible without individual headphone setups.

- Inconsistent evidence base: Meta-analyses of binaural beat research show mixed results, with effect sizes that are inconsistent across studies and populations [Wahbeh et al., 2007; Garcia-Argibay et al., 2019].

4.2 Isochronic Tones

4.2.1 Mechanism

Isochronic tones are regular pulses of a tone, switched on and off at a target entrainment frequency. Unlike binaural beats, the pulsing is physically present in the audio signal and can be heard through speakers without headphones. The entrainment mechanism is the amplitude modulation of the tone carrier at the desired frequency—each pulse creates an auditory onset event that drives subcortical phase-locking.

4.2.2 Neurological Pathway

Isochronic tones do activate the subcortical auditory pathway via onset encoding at the cochlear nucleus, which gives them an advantage over binaural beats in terms of depth of neural engagement. They produce a clear Auditory Steady-State Response (ASSR) at the modulation frequency when that frequency is in the theta or alpha range.

4.2.3 Limitations Relative to Embedded Pulse

- Highly artificial stimulus: A periodically gated tone is acoustically simple to an extreme degree. It activates very limited regions of the auditory cortex (narrow frequency channels) and provides essentially no semantic, emotional, or metrical content for higher-level auditory areas to process.
- Rapid adaptation and fatigue: The simplicity of the stimulus means the auditory cortex adapts to it relatively quickly. Sustained attention becomes difficult, particularly over the 40–60 minute protocols required for deep therapeutic work.
- No recruitment of musical processing systems: Music activates a network extending well beyond core auditory areas, including motor cortex (via the basal ganglia-cerebellar coupling to rhythm), limbic and paralimbic structures (emotional response), prefrontal cortex (expectation and meter), and the default mode network (episodic memory and self-referential processing). Isochronic tones activate none of these.
- Tonally limited engagement: The carrier tone's single pitch eliminates the harmonic richness that natural percussion brings to the entrainment process, reducing the total auditory cortex engagement.

4.3 Spectral Clock Extraction: The DRUM PROTOCOLS Carrier Architecture

Rather than using artificially generated noise signals (white, pink, or brown) as a broadband carrier for embedded entrainment pulses, the Drum Protocols derive the entrainment carrier directly from the active musical spectrum of the drum groove itself. This is accomplished through a dual-stage spectral extraction pipeline: the live output of the TRIAZ drum synthesizer passes first through spectral processing targeting the 800 Hz–4 kHz cochlear sensitivity band. The resulting signal is the CLOCK — a spectrally extracted, timbral distillation of the groove itself, shaped for maximum subcortical onset precision.

This architecture represents a fundamental departure from noise-carrier approaches. Where white or pink noise provides a spectrally flat or sloped broadband backdrop that is acoustically

foreign to the music it accompanies, the spectral clock is timbral kin to its source material — extracted from the same kit, shaped by the same frequencies, and therefore experienced by the nervous system as continuous with the groove rather than as a separate synthetic signal riding beneath it. The ultra-slow spectral drift (~ 0.02 Hz) introduced by the SpecOps stage prevents perceptual fatigue without disrupting the temporal regularity of the clock, and the 27 Hz perceptual ceiling identified empirically in system calibration marks the practical upper boundary of the CLOCK's useful entrainment range. Unlike noise-masked pulse approaches, this method preserves full musical salience while delivering a precision subcortical timing reference — broadband enough to activate the cochlear partition widely, yet spectrally coherent with the listening context that contains it.

4.4 Embedded Rhythmic Pulse (The Drum Protocols Approach)

4.4.1 Mechanism

In the Drum Protocols, the entrainment signal is a percussive rhythm operating at a PRC of 3.5–14 Hz, embedded directly within a musical composition. The musical rhythm is produced by multiple instances of a professional drum sampler — a system with a massive sound library and groove presets — generating overlapping polyrhythmic patterns combined with a dedicated percussive entrainment layer. Sound samples for the entrainment layer can be heavily processed such as through EQ shaping and Multiband Dynamics processors focused on the 1000 Hz–3 kHz band—the cochlear region most associated with the sharp onset transients that drive subcortical entrainment.

4.4.2 Full-Pathway Neural Engagement

Because the entrainment signal is a real physical acoustic event with a sharp onset, it activates the complete ascending auditory pathway from cochlear hair cells through auditory nerve, cochlear nucleus, inferior colliculus, medial geniculate, and auditory cortex. Each station encodes the timing of the percussion event with high precision, creating a cascade of neural phase-locking that propagates from periphery to cortex.

Simultaneously, the musical context of the rhythm activates the extended auditory-motor-limbic network:

- Motor cortex and supplementary motor area via basal ganglia-cerebellar circuits involved in beat and meter representation
- The **mesolimbic dopaminergic system** via music-evoked anticipation and reward responses in the nucleus accumbens and ventral tegmental area
- Amygdala and hippocampus via emotional and memory associations with musical patterns
- Prefrontal cortex via predictive processing of metrical structure
- The default mode network when the music is personally meaningful or evokes autobiographical associations

This whole-brain engagement is not merely a pleasant bonus—it is therapeutically meaningful because the structures engaged (particularly the hippocampus, amygdala, and prefrontal cortex) are precisely the structures targeted by evidence-based trauma and anxiety therapies. A rhythmic

stimulus that simultaneously entrains brainstem timing circuits, activates limbic emotional processing, and engages prefrontal regulatory circuits is doing something qualitatively different from a pure tone being switched on and off.

4.4.3 No Headphone Requirement

Because the entraining rhythm is physically present in the acoustic signal rather than generated by binaural disparity processing, it is fully effective through speakers. This removes a significant barrier to clinical use, enables group delivery, and eliminates the sensory isolation that headphone use imposes—which can itself be an aversive stimulus for individuals with hypervigilance or somatic anxiety.

4.4.4 Sustained Engagement and Attentional Compatibility

The richness of a musical stimulus—its harmonic content, textural variation, timbral complexity, and evolving structure—engages the auditory cortex in a way that resists adaptation over extended durations. The brain processes music through multiple parallel subsystems (melody, rhythm, harmony, timbre, lyrics, emotional tone), and the interplay between these channels maintains engagement across the 40–60 minute sessions required for sustained nervous system regulation.

Furthermore, the embedded nature of the entrainment signal means it does not compete with the therapeutic environment. Isochronic tones and binaural beats require the patient to focus on the entrainment signal itself as the primary auditory stimulus. Embedded percussion allows the entrainment to occur while the listener engages with the music as a whole—or while therapist and client converse, while the patient journeys internally, or while other somatic interventions are conducted in parallel.

Clinical Advantage: *Because the rhythmic pulse is embedded in music rather than being the explicit focus of the listener's attention, the entrainment occurs without requiring the patient to perform a sustained attentional exercise. This is particularly significant for individuals with attentional deficits, trauma-related dissociation, or anxiety-driven inability to sustain directed focus.*

4.4.4a Sensorimotor Coupling and Embodied Agency

An advantage of the embedded rhythmic pulse approach that has no parallel in binaural or isochronic methods is its capacity to engage the sensorimotor system through voluntary or involuntary motor entrainment. When the rhythm is physically present in the acoustic signal and perceptually salient, many listeners — and particularly neurodivergent individuals — will naturally begin to tap, rock, sway, or entrain their breathing to the groove. This is not incidental: it is the auditory-motor network operating as it is designed to.

The basal ganglia, supplementary motor area, and cerebellum all participate in beat-based timing even in the absence of overt movement. When the listener does move with the rhythm, proprioceptive and vestibular feedback creates a closed loop between the internal timing system and the external rhythmic scaffold — reinforcing the temporal prediction cycle and deepening the sensory grounding effect. For populations where “generating calm internally” through attentional effort is difficult or inaccessible, this motor pathway provides an alternative regulatory route that does not depend on directed cognitive effort.

This mechanism also has an important implication for clinical agency: the listener can **interact** with the rhythm rather than being a passive recipient of it. The ability to tap, move, or align one's breath to a groove creates a felt sense of participation and controllability that is absent from binaural beats, which are experienced as a purely internal and passive phenomenon. For trauma-adjacent presentations, anxiety disorders, and ASD profiles, this distinction between active engagement and passive reception can significantly affect both tolerability and clinical outcome.

Clinical Note: *Encouraging listeners to move lightly with the rhythm — tap a finger, sway slightly, or consciously match breathing to the beat — can amplify the regulatory effect significantly, particularly in early sessions before passive entrainment becomes automatic. This is especially relevant for ADHD presentations where active engagement with a sensory scaffold is more sustainable than passive listening.*

4.4.5 The 800 Hz–4 kHz Band Selection

The choice to process the dedicated entrainment percussion layer through a Multiband Dynamics stage focused on 800 Hz–4 kHz is neurologically informed. This frequency range corresponds to the region of maximum cochlear sensitivity in most adult humans (the audiogram shows lowest thresholds in this range), and it contains the high-frequency content of percussion attack transients that drive the sharpest onset encoding at the auditory nerve and cochlear nucleus levels.

By isolating this band, the entrainment layer is positioned to maximize the precision of subcortical onset encoding while sitting in a register that does not mask the lower-frequency musical content of the percussion ensemble. The result is an entrainment signal that is simultaneously present in the mix (audible and real) and spatially/spectrally distinct enough to function as a clear neurological clock signal for brainstem timing structures.

Feature	Binaural Beats		Isochronic Tones		Embedded Pulse (DP)
Physical acoustic signal	No — internally generated		Yes		Yes
Subcortical onset encoding	Minimal		Moderate		Full — cochlear to cortex
Headphones required	Yes — essential		No		No
Group delivery	No		Yes		Yes
Musical engagement	None		None		Full musical network
Limbic/emotional activation	Incidental		Incidental		Intentional
Adaptation/fatigue risk	High — monotone		High		Low — musical richness
Duration practical limit	~30 min		~30 min		60+ min
Clinician integration	Difficult		Moderate		Seamless
Evidence base	Mixed		Limited		Strong — rhythm entrainment literature
Spectral Clock extraction (TRIAZ → SpecOps → CLOCK)	Not applicable	Not applicable	Native DP architecture: spectral-extracted, timbral CLOCK — groove-coherent, not synthetic	Native DP architecture: spectral-extracted, timbral CLOCK — groove-coherent, not synthetic	Primary architecture (see 4.3)

5. Autonomic and Limbic Pathways

Neural entrainment at the cortical and subcortical auditory levels is the proximal mechanism of the Drum Protocols effect, but the therapeutic outcomes—reduced arousal, emotional regulation, somatic calming—are mediated by downstream effects on the autonomic nervous system and limbic structures. This section traces those connections.

5.1 The Auditory-Limbic Interface

The medial geniculate body of the thalamus sends projections not only to primary auditory cortex but directly to the amygdala—a pathway that bypasses cortical processing entirely and allows auditory stimuli to trigger rapid emotional responses before conscious appraisal [LeDoux, 1996]. This fast pathway is the basis for the startle response to sudden loud sounds and, conversely, for the rapid calming effect of familiar, rhythmically predictable music.

The amygdala is central to the encoding and expression of emotional memories, particularly fear-related memories. In PTSD and anxiety disorders, the amygdala is characteristically hyperactive, and its hyperactivity suppresses the regulatory influence of the prefrontal cortex. Theta-band oscillations play a specific role here: prefrontal-hippocampal theta coherence is a proposed mechanism for the top-down regulation of amygdala activity [Adhikari et al., 2010], and increasing theta power is associated with improved emotional regulation capacity.

A sustained rhythmic stimulus at theta frequency, by entraining theta oscillations in the hippocampal-prefrontal circuit, may therefore support the reestablishment of prefrontal regulatory control over amygdaloid reactivity—precisely the mechanism that is disrupted in trauma-spectrum conditions.

5.2 The Autonomic Nervous System

The autonomic nervous system (ANS) regulates arousal, heart rate, respiration, and the physiological stress response. Its two primary divisions—the sympathetic (activating, 'fight-or-flight') and parasympathetic (calming, 'rest-and-digest')—are modulated by multiple brain centers including the anterior cingulate cortex, insular cortex, hypothalamus, and brainstem nuclei including the nucleus tractus solitarius and dorsal vagal complex.

Rhythmic auditory stimulation has well-documented effects on autonomic parameters. Heart rate variability (HRV), a sensitive measure of parasympathetic tone, increases in response to music with a tempo matching respiratory resonance frequency (approximately 0.1 Hz or six breaths per minute) [Bernardi et al., 2006]. At the PRC values used in the Drum Protocols, a different but complementary mechanism operates: the rhythm's regularity and predictability activates the neural systems associated with safety signaling—the ventral vagal pathway of the polyvagal system [Porges, 2011].

Polyvagal Perspective: *Stephen Porges' Polyvagal Theory proposes that prosodic vocalizations and rhythmically regular sounds in the human frequency range activate the ventral vagal circuit via the social engagement system—a circuit connecting middle ear muscles, facial musculature, laryngeal control, and the vagus nerve. Well-structured rhythmic music may function as a persistent 'safety signal' activating this ventral vagal pathway and supporting parasympathetic dominance.*

5.2.1 Predictive Processing and the Felt Safety Signal

A mechanism that complements the direct autonomic effects of rhythm is the role of temporal predictability in threat appraisal. The brain continuously models the environment to predict what will happen next; unpredictability increases vigilance demand and sympathetic activation, while predictability reduces it. A stable, regular rhythm — particularly one that does not startle, does not accelerate unexpectedly, and maintains consistent spectral character — functions as a persistent “safety signal” in the predictive processing framework: evidence that the immediate environment is structured, non-threatening, and controllable.

Reduced temporal uncertainty is experienced as decreased vigilance demand, reduced sensory surprise, and increased perceived controllability. These are not peripheral effects: they directly reduce threat appraisal at the level of the prefrontal-amygdala regulatory circuit, supporting the shift from sympathetic dominance toward parasympathetic tone. This predictive processing route to autonomic regulation operates independently of — and additively with — the direct limbic and thalamocortical effects described elsewhere in this document.

For this reason, the production rules of the Drum Protocols are not merely aesthetic: the prohibition on abrupt tempo changes, sudden layer additions, and high-transient onset events in the opening phase of a protocol are direct implementations of predictive processing theory. Each design constraint exists to preserve the rhythm’s function as a safety signal rather than a novelty or threat signal. The conservative gradient ceiling (0.20 PRC Hz per minute) is the temporal analogue of this principle: change occurs slowly enough that the predictive system can model it continuously, experiencing the descent as smooth and expected rather than as an unmodeled perturbation.

Clinical Note: *For patients with hypervigilance — particularly those with PTSD, severe anxiety, or ASD sensory profiles — the therapeutic entry point is not the target PRC frequency but the safety signal established by the rhythm’s predictability. Begin sessions with an explicit verbal orientation to the rhythmic structure before the protocol starts. This pre-attunes the predictive system, reducing initial vigilance and improving the quality of the first minutes of the transition phase.*

6. Mathematical Structure: Phi as Algorithmic Constant and Protocol Design Standard

The Drum Protocols are built on a single, invariant mathematical constant: the golden ratio (phi, $\varphi \approx 1.6180339887$). Phi is not applied selectively or stylistically — it is the algorithmic backbone of the entire protocol architecture. Every timing relationship, every transition curve, every proportional division in the system is derived from or governed by this one constant. This section explains why phi was selected, what it produces neurologically, and — crucially — what its adoption as a fixed constant makes possible at the level of protocol design and comparative research.

6.1 The Golden Ratio in Biological Systems

The golden ratio appears throughout biological structures — the spiral of nautilus shells, the branching patterns of trees and blood vessels, the arrangement of seeds in sunflowers, the proportions of DNA helices — in contexts where efficient packing, growth optimization, or structural stability are primary constraints. In neuroscience, phi has been identified in the critical branching ratios of cortical connectivity and in the frequency ratios of neural oscillation bands [Roopun et al., 2008].

The ratio between adjacent brainwave band boundaries (delta:theta, theta:alpha, alpha:beta) approximates phi at 1.618, suggesting that the brainwave frequency architecture is itself organized around golden-ratio relationships. A rhythmic system whose structural proportions mirror this same constant is therefore not imposing an external mathematical framework on the nervous system — it is operating in the same proportional language the nervous system already uses to organize its own oscillatory architecture. This alignment is the foundational rationale for selecting phi as the system constant.

6.2 Phi as Algorithmic Constant: The Three-Variable Protocol Space

The most significant practical consequence of adopting phi as a fixed algorithmic constant is what it eliminates from the design space. Because phi governs the shape of every transition curve — its inflection point, its ease-in and ease-out proportions, the ratio of its accelerating to decelerating phases — the curve itself is never a free variable. It is fully determined by the constant. This collapses the entire protocol design space to exactly three independent variables:

1. **PRC Start** — The starting Perceived Rhythmic Cycle value in Hz
2. **PRC End** — The ending Perceived Rhythmic Cycle value in Hz
3. **Duration** — The total protocol length in minutes

Everything else follows from phi. The inflection point falls at $0.618 \times \text{Duration}$. The ease-in phase spans the first 38.2% of the transition. The ease-out phase spans the remaining 61.8%. The gradient at any moment is a deterministic function of ΔHz , Duration, and φ . No additional parameters need to be specified, estimated, or held constant between protocols.

This reduction is not merely a convenience — it is a prerequisite for rigorous comparative research. When phi is fixed as the system constant and only three variables are free, any two

protocols that share two of those variables differ along exactly one dimension. Protocols with identical PRC range and identical duration but different start and end points can be compared directly for population-specific response. Protocols with identical start and end PRC but different durations isolate the effect of transition time at constant ΔHz . Protocols with identical duration and start PRC but different end points isolate the effect of descent depth. This creates a structured experimental space in which efficacy questions — which protocol lengths work best, which PRC ranges produce the strongest regulatory response, how the overall descent magnitude interacts with session duration — can be answered cleanly, without confounds introduced by varying curve shape between conditions.

Design Principle: *Because ϕ is fixed, every protocol is fully specified by three numbers: PRC Start (Hz), PRC End (Hz), and Duration (minutes). All proportions, gradients, and curve shapes are derived from the constant. The designer chooses the therapeutic parameters; the architecture follows automatically.*

6.3 The Phi S-Curve: Neurological Rationale for the Fixed Shape

The asymmetric sigmoid defined by ϕ places the inflection point — the moment of maximum rate of change — at 61.8% of the total transition time, not at the midpoint. This asymmetry is neurologically specific. The opening 38.2% of the transition is a containment and trust-establishment phase: the curve is moving toward its steepest point but has not yet reached it. During this window the nervous system encounters the rhythmic scaffold as stable, predictable, and non-threatening — the conditions required for the predictive processing system to register safety before the primary regulatory shift is delivered. The steepest descent arrives only after that registration has occurred. After the inflection, the curve decelerates, and the final portion of the transition allows the nervous system to begin stabilizing before the HOLD phase begins.

A linear curve does not provide this containment window. An ease-in curve front-loads the steepest descent into the most vulnerable phase of the session. Only the ϕ sigmoid — inflection at 0.618, deceleration into arrival — produces the three-phase structure of containment, transition, and settling that the neurological evidence supports. Because this shape is derived entirely from ϕ , it applies uniformly to every protocol in the system regardless of start PRC, end PRC, or duration. The constant does the work. The designer specifies three numbers. The architecture follows.

7. Clinical Applications and Considerations

7.1 Indicated Populations

Based on the neurological mechanisms described, the Drum Protocols are particularly well-suited for conditions characterized by:

- Dysregulation of autonomic arousal (hyperarousal in PTSD, anxiety disorders, acute stress)
- Disrupted theta-band oscillations (PTSD, depression, ADHD, traumatic brain injury)
- Impaired prefrontal-hippocampal regulation of amygdala reactivity
- Conditions requiring nervous system downregulation as a therapeutic precondition (somatic therapies, EMDR preparation, psychedelic-assisted therapy contexts)
- Chronic pain states where attentional distraction and autonomic modulation are relevant
- Populations where sustained attention for active therapeutic exercises is limited

7.2 Contraindications and Precautions

Clinicians should exercise caution and consult appropriate specialists in the following contexts:

- Photosensitive or audiogenic epilepsy: Rhythmic stimuli at specific frequencies can trigger seizures in susceptible individuals. Medical clearance should be obtained for any patient with a seizure history before using rhythmic entrainment protocols.
- Psychotic spectrum disorders: The altered states facilitated by deep theta entrainment may be contraindicated in individuals with active psychosis or at high risk for psychotic episodes.
- Severe dissociative disorders: Deep relaxation states may facilitate unwanted dissociation in individuals with complex dissociative presentations. Clinician presence and grounding supports are advisable.
- Volume and hearing sensitivity: The Multiband Dynamics processing and overall mix levels should be calibrated to remain below 85 dB SPL for extended sessions to protect hearing and avoid stress responses.

7.2a Acoustic Design Constraints with Clinical Rationale

The following production constraints are derived directly from the neurophysiological mechanisms described in this document. Each represents a case where a specific acoustic property of the protocol material has a documented effect on arousal regulation, sensory processing, or entrainment efficacy. Clinicians should be aware of these constraints when evaluating protocols or requesting modifications, as deviating from them has predictable neurological consequences.

Avoid high-intensity transient onsets (2–5 kHz) in the opening phase

Sharp, high-frequency onsets in this range activate the cochlear nucleus' onset-detection cells with high salience. In a dysregulated or hypervigilant nervous system, this triggers the auditory startle reflex via the inferior colliculus-amygdala pathway before the predictive safety signal has been established. Protocols open with reduced transient energy and allow full spectral content to emerge gradually across the first 25% of the DELTA phase.

Limit rhythmic density — avoid “machine-gun” percussive textures

When percussive onsets crowd temporally, individual events cease to be resolvable by the brainstem timing circuits. The cochlear nucleus and inferior colliculus require sufficient inter-onset interval to encode each event as a discrete temporal marker. When events blur together, the entrainment signal degrades and the texture becomes fatiguing and irritating rather than regulating. This is the practical upper boundary of PRC Hz usability.

Minimize novelty during downshift protocols

Novel auditory events — unexpected timbral changes, new rhythmic layers, spectral surprises — re-activate the orienting reflex via the superior colliculus and thalamic alerting networks. During a downshift protocol, where the therapeutic goal is reducing arousal and vigilance, any novelty event partially resets the sympathetic deactivation process. No new rhythmic layers are introduced during the DELTA phase of descent protocols.

Maintain smooth, continuous tempo transitions (no stepped changes)

The predictive processing system models tempo as a continuous variable. Stepped BPM changes create a prediction error — a mismatch between the modeled and actual tempo — that activates the anterior cingulate cortex and triggers a brief reorienting response. Smooth automation curves ensure that the predicted next beat location is always consistent with the actual beat location, maintaining the safety signal.

Provide a fade-in and fade-out transitions

Abrupt beginnings and cessations of a sustained rhythmic scaffold removes the predictive safety signal suddenly, triggering a re-orienting response and partial reversal of the autonomic downregulation achieved during the session. A gradual fade preserves the continuity of the predictive model through the session end, allowing the regulatory state to persist into the post-session period.

7.3 Integration with Clinical Practice

The design of the Drum Protocols specifically supports integration with clinical therapeutic practice rather than requiring the patient to engage with the music in isolation. Because the entrainment does not require attentional focus on the rhythmic stimulus, the music can serve as a regulated background while therapist and client engage in verbal or somatic work, while the patient practices imagery or mindfulness exercises, or as a transition medium before and after more intensive interventions.

The HOLD phase of each protocol—where the PRC is maintained at the target value for 20–30 minutes after the DE-ESCALATION transition—provides a sustained therapeutic window at the target neural state, during which the brain's natural capacity for memory consolidation, emotional integration, and neural plasticity is at its most active.

8. Summary and Key Principles

The following principles encapsulate the scientific rationale for the Drum Protocols approach to auditory entrainment:

- **Full-pathway activation:** Physical percussion transients activate the complete ascending auditory pathway from cochlear hair cells to cortex, engaging subcortical timing circuits that secondary entrainment methods do not reach.
- **PRC = entrainment frequency:** The Perceived Rhythmic Cycle rate in Hz is the direct entraining frequency. At 3.5–14 Hz, the rhythm itself becomes a direct entraining stimulus spanning theta (calming and regulation) and alpha (activation and focus) bands, without requiring additional processing or signal generation.
- **Musical engagement amplifies effect:** The musical context of the rhythm recruits the motor, limbic, and prefrontal systems that participate in emotional regulation, extending the entrainment effect beyond the auditory system into the broader therapeutic network.
- **No headphones required:** The physical acoustic signal is effective through speakers, enabling group delivery, clinical flexibility, and freedom from the sensory isolation of headphone use.
- **Sustained efficacy:** Musical richness resists adaptation, enabling 60+ minute protocols that cannot be achieved with simple tone-based methods without listener fatigue.
- **Phi-based architecture:** Golden-ratio relationships in polyrhythmic structure provide ongoing novelty within a coherent framework, maintaining subcortical entrainment while engaging cortical pattern-recognition systems.
- **Clinician-transparent operation:** The entrainment operates without requiring patient attentional focus, enabling seamless integration with concurrent therapeutic interventions.

9. Limitations and Responsible Clinical Framing

The scientific basis for the Drum Protocols is robust, but rigorous clinical practice requires that its limitations be as clearly understood as its mechanisms. The following principles govern how this system should be described to patients, caregivers, and other clinicians.

9.1 *Entrainment Is Not Deterministic*

Neural entrainment should never be described to patients as “putting your brain into theta” or as a guaranteed outcome. Entrainment is a probabilistic tendency, not a mechanical override. The degree of phase alignment achieved depends on individual neural architecture, current arousal state, attentional engagement, sleep debt, medication, sensory sensitivity, and the listener’s current relationship to the sound. Consistent use over multiple sessions typically strengthens the entrainment response, but no single session can be guaranteed to produce a specific neural state.

9.2 Multiple Mechanisms Contribute to Outcomes

Therapeutic improvements attributed to the Drum Protocols may come from any combination of the following: direct neural phase alignment with the driving rhythm; reduced temporal uncertainty and its downstream effect on threat appraisal; sensorimotor grounding and embodied agency through motor entrainment; emotional and memory associations activated by the musical context; and the therapeutic environment in which the protocol is used. Isolating the contribution of any single mechanism is methodologically difficult and clinically unnecessary — the relevant question is whether the patient’s regulatory capacity improves, not which pathway produced the improvement.

9.3 Individual Variability Is Primary

Neurodivergent sensory profiles vary significantly. A protocol that produces deep relaxation in one ASD individual may be irritating or overstimulating to another with different sensory sensitivities. Clinicians should treat all protocol specifications as starting points rather than fixed prescriptions, and should be prepared to adjust starting PRC, note denomination, mix density, or session duration based on individual response. The production architecture’s separation of PRC and groove layers exists precisely to allow this kind of individualized calibration.

9.4 Clinical Context Mediates All Outcomes

Outcomes depend critically on the clinical context in which the protocols are used. A downshift protocol used in a safe therapeutic environment with a trusted clinician present will produce different results than the same audio used in an unsafe or unpredictable environment. The rhythm provides a regulatory scaffold; the clinical relationship, environmental safety, and the patient’s own agency determine how that scaffold is used. The Drum Protocols are a tool within a therapeutic framework, not a replacement for it.

9.5 This System Is Not a Medical Treatment

The Drum Protocols are a structured audio tool designed to support nervous system regulation. They are not a medical treatment, a diagnostic tool, or a substitute for clinical intervention. They should not be described using medical claims language in public-facing contexts. For populations with seizure disorders, severe dissociative presentations, or active psychosis, clinical clearance should be obtained before use as described in Section 7.2.

Recommended framing for clinician use: *“This is a structured rhythmic audio tool designed to give the nervous system a predictable timing scaffold. Many people find it easier to move toward a calmer state when there is something stable and external to anchor to. It works best when used consistently, in a comfortable environment, and as part of a broader approach to regulation — not as a standalone fix.”*

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The following works provide the primary scientific basis for the claims made in this document. This list is representative rather than exhaustive; full literature reviews are available in the Research Program documentation.

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