The Multiscale Resonance Model

Toward a Musical Theory of Consciousness

Matthew Bennett

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Successions of tones are motions… in respect to an order based on forces in tones… Musical tones point to one another, attract and are attracted… The dynamical quality of musical tones makes melodies out of successions of tones, and music out of acoustical phenomena.

— Victor Zuckerkandl, The Sense of Music (1959)

Abstract

The Multiscale Resonance Model (MRM) proposes that consciousness and the feeling of self are what multiscale resonance in living tissue feels like from the inside. The model makes two original contributions. **First**, it claims that multiscale resonance—the coupling of oscillatory processes across spatiotemporal scales, from subcellular continuous dynamics through neural oscillations through bodily rhythms to interpersonal synchronization—is essential for consciousness. **Second**, it identifies entrainment as the specific physical mechanism by which this inter-scale coupling is achieved and maintained in biological systems. These claims are supported by synthesizing three converging lines of research: (1) the unified entrainment framework demonstrating that bodily rhythms genuinely entrain brain oscillations and gate conscious perception (Lakatos, Gross, & Thut, 2019); (2) neural resonance theory showing that nonlinear dynamical principles—mode-locking, stability and attraction, Hebbian attunement—govern musical cognition across both rhythmic and tonal timescales (Large et al., 2023; 2025); and (3) biological computation theory arguing that consciousness requires inter-scale integration via continuous, bidirectionally coupled dynamics uniquely available in biological substrates (Milinkovic & Aru, 2026).

Together, these two contributions generate a further claim: that consciousness has an inherently musical structure—hierarchical temporal organization, tension-resolution dynamics, anticipatory forward motion, and affective contour—because the resonance dynamics that constitute awareness are the same dynamics that constitute musical experience. Music, on this account, is not merely a stimulus that affects consciousness but the culturally evolved technology for amplifying, elaborating, and sharing the very dynamics that constitute awareness. The model generates testable predictions about the relationship between inter-scale coupling measures and states of consciousness, and provides a theoretical foundation for the deliberate composition of conscious experience through sound.

1. Introduction: The Problem

Consciousness remains the central unsolved problem of the natural sciences. We know a great deal about what neural activity correlates with conscious experience, but the explanatory gap between physical process and subjective experience—the hard problem (Chalmers, 1995)—persists. Most approaches to this problem work within one of two broad strategies: either they treat consciousness as an emergent property of sufficiently complex information processing (functionalist approaches), or they identify consciousness with specific physical properties of neural tissue (biological naturalism). The Multiscale Resonance Model offers a third path.

The MRM proposes that consciousness is neither an abstract computational property nor a mysterious addition to physical processes. Rather, **consciousness and the feeling of self are what multiscale resonance in living tissue feels like from the inside**. When

oscillatory systems at multiple spatiotemporal scales—subcellular, cellular, population, organ, organism, interpersonal—become coupled through nonlinear resonance, and when this coupling is bidirectional, continuous, and embedded in metabolically constrained biological substrate, the result is not a system that *produces* conscious experience as an output. The result is a system whose interior—whose what-it-is-like-ness—*is* conscious experience. The structure of that experience—its temporal flow, its hierarchical organization, its tension-resolution dynamics, its anticipatory character—is determined by the structure of the resonance.

This proposal carries a striking corollary: consciousness has a musical structure. The dynamical properties that constitute awareness—nested temporal hierarchies, stability and attraction relationships, expectation and surprise, affective contour—are precisely the properties that define musical experience. This is not metaphor. The same physical principles (nonlinear resonance, mode-locking, phase-amplitude coupling, Hebbian attunement) that organize musical perception at fast timescales organize the body-brain coupling that constitutes the self at slow timescales. Music, on this account, is humanity's oldest and most powerful technology for working directly in the medium of consciousness.

1.1 Scope, Sources, and Original Contributions

The MRM synthesizes three bodies of research that have developed largely independently. These provide the empirical and theoretical foundation, but the MRM's own contributions go beyond what any of them individually claims.

The **unified entrainment framework** (Lakatos, Gross, & Thut, 2019) provides a comprehensive account of how oscillatory entrainment operates across the brain, demonstrating that bodily rhythms—gastric, respiratory, cardiac, saccadic—genuinely entrain neural oscillations and gate what reaches conscious awareness. **Neural resonance theory** (Large et al., 2023; Large et al., 2025) demonstrates that nonlinear dynamical principles govern music perception, action, and cognition across both rhythmic and tonal timescales, and that musical cognition is the actual embodiment of resonance relationships rather than symbolic representation. The **biological computation framework** (Milinkovic & Aru, 2026) argues that consciousness requires inter-scale integration via continuous, bidirectionally coupled dynamics—a form of computation uniquely available to biological tissue.

From these foundations, the MRM makes **two original contributions** that are not made by any of the source frameworks individually:

Contribution 1: Multiscale resonance is essential for consciousness. The MRM claims that consciousness and the feeling of self are what multiscale resonance feels like from the inside. This is not a correlation claim (that resonance accompanies consciousness) or a causal claim (that resonance produces consciousness as an output). It is an identity claim from the

first-person perspective: the interior of the process that physics describes as multiscale resonance in living tissue *is* what we call consciousness.

Contribution 2: Entrainment is the mechanism. The MRM identifies entrainment—the temporal coordination of independently oscillating, self-sustaining systems through nonlinear resonance—as the specific physical mechanism by which the inter-scale coupling required for consciousness is achieved in biological systems. This gives the first contribution operational teeth: entrainment can be measured, manipulated, enhanced, and disrupted, generating a full program of testable predictions.

Together, these two contributions generate the MRM's further claims about musical structure, the self, and the possibility of composing consciousness through sound.

2. The Neural Resonance Theory Foundation

Of the three source frameworks, NRT plays a distinctive role in the MRM. While Lakatos et al. provide the evidence that body-brain entrainment is real and Milinkovic & Aru argue that inter-scale integration requires biological substrate, NRT provides the dynamical principles that the MRM extends from music perception to consciousness itself. The MRM's central move is to recognize that the physical dynamics NRT identifies in musical cognition—nonlinear resonance, mode-locking, stability and attraction, Hebbian attunement, strong anticipation—are the same dynamics that, at slower timescales, organize body-brain coupling and constitute the felt sense of self.

NRT, developed principally by Edward Large and colleagues, is a theory of musical cognition grounded in the physics of nonlinear dynamical systems. Its central assertion is that music cognition is the actual embodiment of resonance relationships—physical states of the brain that have lawful relationships to external events (sounds), determined by physical principles. This contrasts with the dominant view in cognitive neuroscience, which treats musical cognition as abstract symbolic representation or statistical inference. In NRT, the brain does not build a model of the music and then experience the model. The resonance pattern is the cognition. NRT focuses on canonical models, which capture common dynamical properties of a family of neural models, generating robust formal hypotheses using sometimes only general information about neurophysiology and behavior.

NRT combines five physical principles that govern music cognition. Each of these becomes foundational for the MRM's extension to consciousness.

2.1 Neural Oscillation and Nonlinear Resonance

NRT begins from the observation that the brain is pervasively oscillatory, and that these oscillations are nonlinear. Unlike linear resonators, which respond only at the driving frequency, nonlinear oscillators generate responses at frequencies not present in the input but related to

input frequencies by integer ratios. This is observed biologically in critical oscillations of cochlear outer hair cells, auditory brainstem neurons, and cortical auditory and motor populations entrained to rhythmic sequences.

The key phenomenon is **mode-locking** (n:m synchronization): two neural oscillations with different natural frequencies can synchronize when their frequency ratio is near a simple integer ratio and coupling is sufficiently strong. The stability of this synchronization increases with the simplicity of the ratio and the strength of the coupling. Mathematical analysis (Arnold tongue diagrams) shows that resonance regions are wider for simple ratios (1:1, 2:1, 3:2) than for complex ratios (7:4, 45:32), meaning simple-ratio synchronization is more stable under perturbation and noise.

Why this matters for the MRM: Mode-locking is not specific to auditory processing. It is a property of any coupled nonlinear oscillatory system. The MRM recognizes that body-brain coupling—cardiac-cortical entrainment, respiratory-neural phase-locking, gastric-cortical modulation—involves the same physics. The same Arnold tongue analysis that predicts which musical intervals are consonant also describes the stability of coupling between your heartbeat and your cortical oscillations.

2.2 Stability and Attraction

Mode-locking is an instance of a broader dynamical principle: stability and attraction. Dynamical systems in less stable states are attracted to and gravitate toward more stable states. NRT asserts that the stability of neural resonances leads to the perception of musical structure, and that musical expectancy is the feeling of a less stable state being attracted toward a more stable one.

This single principle predicts a remarkable range of musical phenomena. It explains why consonant intervals (simple ratios like 3:2) sound pleasant and dissonant intervals (complex ratios like 45:32) sound tense. It predicts the tonal hierarchies of both Western major keys and North Indian ragas from pure dynamical analysis, outperforming purely statistical models. It explains why bimanual coordination is harder for complex polyrhythms than simple ones. And it suggests a physical basis for musical affect: the more-stable major mode may be experienced as ‘happy’ and the less-stable minor mode as ‘sad’ not through arbitrary cultural convention but through the intrinsic dynamics of nonlinear oscillation.

Why this matters for the MRM: If expectancy is the feeling of dynamical instability being attracted toward stability, then affect—the felt quality of experience—is a direct consequence of resonance dynamics, not something added on top of them. The MRM generalizes: all felt experience is what resonance dynamics feel like from the inside. Tension, resolution, anticipation, surprise—the phenomenology of consciousness—are the interior of the stability and attraction dynamics NRT identifies.

2.3 Scale Invariance: Rhythm and Pitch Are the Same Physics

A core insight of NRT, and the one most consequential for the MRM, is that rhythmic and tonal perception are governed by identical dynamical principles operating at different timescales. A 3:2 polyrhythm and a perfect fifth (3:2 frequency ratio) occupy the same position in the Arnold tongue analysis. Mode-locking stability predicts both which polyrhythms are easiest to coordinate and which intervals are heard as most consonant. Between rhythm (~0.5–12 Hz) and pitch (~30–4,000 Hz) lies a "roughness" zone (~20–30 Hz) where stable experiential structures fail to form—frequencies too fast for rhythm, too slow for pitch.

Why this matters for the MRM: Scale invariance is the bridge from music to consciousness. If the same dynamical principles govern perception at rhythm timescales and pitch timescales, and if body-brain coupling operates at even slower timescales (gastric ~0.05 Hz, respiratory ~0.25 Hz, cardiac ~1 Hz), then the same physics extends across the entire hierarchy relevant to consciousness. The MRM claims this is not coincidence but a single dynamical regime operating across six or more orders of magnitude in frequency. Consciousness is what this entire hierarchy of resonance feels like from the inside.

2.4 Attunement and Hebbian Learning

Attunement in NRT is the process whereby resonating neural circuits tune themselves through interaction with the environment. It unfolds over multiple timescales, increasing the stability of patterns experienced more often. Attunement occurs via two primary mechanisms: Hebbian learning through synaptic plasticity (connections between oscillators strengthen when they resonate together) and adaptation of individual oscillator parameters such as natural frequency. NRT uses attunement to explain enculturation: how growing up immersed in a particular musical culture shapes the attractor landscape of the oscillatory network, creating culturally specific listening biases while preserving cross-cultural invariances rooted in intrinsic dynamical stability.

Why this matters for the MRM: Attunement explains why ENTRAIN environments produce lasting effects. When a listener's oscillatory network is entrained for an extended period, Hebbian learning strengthens the connections between mode-locked oscillators. The entrainment leaves a residue in coupling strengths—what the MRM calls post-experience integration. Repeated listening progressively reshapes the resting attractor landscape. This is the same mechanism as musical enculturation, applied deliberately through composition.

2.5 Strong Anticipation

One of NRT's most striking findings is strong anticipation: the capacity of a delay-coupled oscillatory system to precede its driver. In sensorimotor synchronization, taps consistently anticipate metronome clicks—not as error but as an intrinsic property of entrained oscillatory

systems with transmission delays. The driven system literally gets ahead of the driver, emerging naturally from the coupling dynamics without requiring any internal predictive model.

Why this matters for the MRM: Consciousness is constitutively anticipatory—the present moment leans forward into what is coming. The predictive processing framework explains this through Bayesian inference. NRT offers a radically different account: anticipation is an intrinsic property of the physical dynamics, not a cognitive computation. The MRM follows NRT. The forward-leaning quality of conscious experience is not the brain running a prediction algorithm. It is what delay-coupled resonance feels like from the inside.

2.6 Implied Harmony and Self-Organization

When a nonlinear oscillatory network is driven by a single unaccompanied melody, it spontaneously generates the implied harmony—the chords that a trained musician hears in a Bach violin partita, even though only one note sounds at a time. Oscillators tuned to chord tones resonate at high amplitudes after stimulus tones end; oscillators tuned to non-chord tones are suppressed. The network's model of implied harmony matched annotated harmony better than the statistics of tone duration.

Why this matters for the MRM: This is structurally analogous to the MRM's account of the self. The self is not explicitly represented anywhere in the body-brain system. It emerges as an organizational pattern of coupled oscillations—just as implied harmony emerges from the resonance dynamics of a network driven by a melody. In both cases, what appears to be a thing (a chord, a self) is actually a process: a stable pattern of resonance that organizes the system's behavior without being localized in any single element.

2.7 Embodiment: Not Metaphor but Physics

NRT defines embodiment as "a state of the brain and/or body that has a lawful, physical relationship to external events (for example, sounds) determined by physical principles." This is explicitly contrasted with symbolic representation, where symbols have *arbitrary* relationships to what they represent. A neural oscillation entrained to a rhythm is not a representation of the rhythm—it is an actual rhythm that operates in accordance with physical laws. It is a physical embodiment, not an abstract representation.

Why this matters for the MRM: This is the single most important contribution NRT makes to the MRM. If musical cognition is physical embodiment rather than symbolic representation, then the MRM can extend this claim to consciousness generally: conscious experience is the actual physical state of multiscale resonance, not a representation constructed by neural computation. There is no gap between the physical process and the experience because they are the same thing. This is what licenses the "from the inside" formulation—the physical process described from outside as resonance is, from inside, experience.

3. Entrainment: Resonance in Living Systems

Entrainment is the specific form that resonance takes when the resonating systems are *independently oscillating* and *self-sustaining*. A wine glass resonates passively. A neuron, a heart, a respiratory center, a gastric pacemaker—these oscillate continuously on their own. When they couple, neither is passive. Both contribute their intrinsic dynamics to the interaction. The result is not a driven response but a **mutual adjustment** toward synchrony. **Resonance becomes entrainment when the resonating systems are alive.**

A terminological note: Lakatos et al. (2019) define entrainment in the strict sense as unidirectional and distinguish it from bidirectional phase synchronization. The MRM uses "entrainment" in the broader sense encompassing both mechanisms. In biological reality, most brain-body-environment coupling involves elements of both.

The unified entrainment framework identifies three categories of entrainment in the brain: externally driven entrainment (neural oscillations synchronize to rhythmic sensory input), self-produced entrainment (the brain's own rhythmic outputs feed back to entrain neural oscillations), and neuromodulatory entrainment (arousal-related rhythmic processes modulate cortical excitability). These operate simultaneously, creating a rich, multi-layered entrainment landscape.

The key empirical finding is that bodily rhythms genuinely entrain brain oscillations. There is emerging evidence that the gastric rhythm (~0.05 Hz) modulates cortical dynamics. The evidence is stronger for respiration (~0.25 Hz), which modulates fear discrimination, memory retrieval, and limbic oscillatory power. The cardiac cycle (~1 Hz) modulates visual detection and the neural representation of self versus other. Saccadic rhythms (~4–8 Hz) sample the visual environment in discrete temporal windows. Across these systems, the phase of bodily oscillation gates what reaches conscious awareness. The body does not merely accompany consciousness; it participates in constituting it.

4. Inter-Scale Coupling: The Requirement for Consciousness

The biological computation framework argues that consciousness may require a specific computational architecture: **inter-scale integration**. Integration within a single scale is necessary but insufficient. What distinguishes conscious from unconscious processing is integration *across* spatiotemporal scales. Wakeful conscious states exhibit greater multiscale integration than anaesthetic states.

This inter-scale integration depends on properties unique to biological tissue. Continuous-valued dynamics—electric fields, ion gradients, oscillatory patterns—provide a medium for coupling that exists simultaneously across scales, enabling bidirectional real-time constraint. Digital systems lack such continuous media. Information at one layer is computed, stored, and

passed to the next in discrete steps; there is no field that simultaneously spans scales. This may explain why purely discrete systems cannot replicate the phenomenology of consciousness.

The temporal continuity of conscious experience—the flowing, stream-like quality described by William James—may depend on this physical and dynamical continuity. A melody is not a sequence of isolated pitches but a continuous trajectory that passes through discrete notes. Similarly, consciousness is not a sequence of computational states but a continuous process that contains discrete events.

5. The Core Claim: Two Contributions

5.1 Contribution 1: Consciousness Is What Multiscale Resonance Feels Like from the Inside

The MRM's first original contribution emerges from the intersection of the three source frameworks, but it is not a claim any of them makes individually.

If entrainment is the mechanism by which oscillatory systems in the brain synchronize with each other, with the body, and with the environment (Lakatos et al.); if this entrainment operates through nonlinear resonance dynamics that are scale-invariant from subcellular to behavioral levels (NRT); and if consciousness requires inter-scale integration via continuous, bidirectionally coupled dynamics (Milinkovic & Aru)—then these three frameworks are all describing different aspects of the same underlying process. The MRM's claim is that this process has an interior: **consciousness and the feeling of self are what multiscale resonance in living tissue feels like from the inside**.

This formulation is chosen with care. It is not a correlation claim: the MRM does not say that multiscale resonance *accompanies* or *correlates with* consciousness. It is not a production claim: the MRM does not say that resonance *generates* or *gives rise to* consciousness as a separate output. It is an identity claim stated from the first-person perspective. The physical process that, described from outside, is multiscale resonance in living tissue is the same process that, experienced from inside, is consciousness. There is no explanatory gap to bridge because there are not two things—a physical process and an experience—but one process described from two perspectives.

Consider the evidence. Gastric rhythms entraining cortical oscillations represent coupling between organ-level and population-level dynamics. Respiration modulating gamma power through phase-amplitude coupling represents coupling between body-level and fast neural timescales. Heartbeat-evoked responses feeding back to cortical self-representation represent coupling between cardiac rhythm and the neural process that constitutes selfhood. In each case, the mechanism is entrainment, the dynamics are nonlinear resonance, and the result is integration across spatiotemporal scales. The MRM says: the interior of this integration is what

we call awareness. More of it, across more scales, with deeper coupling, is richer awareness. Less of it is diminished awareness. The complete absence of it is unconsciousness.

5.2 Contribution 2: Entrainment Is the Mechanism

The MRM's second original contribution identifies **entrainment**—the temporal coordination of independently oscillating, self-sustaining systems through nonlinear resonance—as the specific physical mechanism by which inter-scale coupling is achieved and maintained in biological systems.

This claim transforms the first contribution from a philosophical position into a scientific research program. Entrainment can be measured (phase-locking values, coherence spectra, cross-frequency coupling indices). It can be manipulated (rhythmic stimulation, music, movement, breathing exercises). It can be disrupted (anesthesia, lesion, phase perturbation). It can be enhanced (musical training, meditation practice, deliberate compositional design). Each of these operations, if the MRM is correct, is an operation on consciousness itself.

The entrainment claim also explains why music has such profound effects on consciousness: music is a structured entrainment signal that can capture, reshape, and release the very multiscale resonance patterns whose interior is conscious experience. The composer is not creating something that consciousness perceives. The composer is reshaping the dynamics whose interior is consciousness.

6. How NRT's Principles Become a Theory of Consciousness

The MRM's central move is to recognize that every principle NRT identifies in musical cognition has a direct counterpart in the phenomenology of consciousness:

Mode-locking → The nested structure of experience

Music organizes time hierarchically: subdivisions nest within beats, beats within measures, measures within phrases. NRT shows the brain extracts this through nested oscillatory entrainment at multiple timescales. Consciousness exhibits the same structure: gamma flicker of sensory sampling nests within the alpha perceptual present, within the delta "felt now," within narrative arcs spanning seconds to minutes. The nesting is what gives experience its texture. This is precisely the structure of musical meter.

Stability and attraction → Tension, resolution, and affect

NRT asserts that musical expectancy is the feeling of dynamical instability attracted toward stability. The MRM generalizes: all of conscious experience moves between states of tension and resolution, uncertainty and recognition, desire and satisfaction. This is the felt quality of the stability and attraction dynamics operating across the full resonance hierarchy.

Strong anticipation → The forward-leaning present

Consciousness is experienced not as a knife-edge but as a thick temporal window that leans into the future. NRT's strong anticipation explains this as an intrinsic property of delay-coupled resonance—not a computational prediction but a physical consequence of the dynamics.

Attunement → The culturally shaped self

Just as Hebbian learning creates culturally specific musical attractor landscapes, it creates culturally and experientially specific self-structures. The particular quality of your consciousness—your characteristic patterns of attention, affect, and response—is the attunement history of your oscillatory network, shaped by a lifetime of entrainment.

Implied harmony → The emergent self

The self, like implied harmony, is not explicitly represented anywhere. It is a stable organizational pattern that emerges from the resonance dynamics of body-brain coupling—present in the system's behavior, not localized in any component.

Embodiment → The identity of process and experience

NRT's insistence that musical cognition is physical embodiment, not symbolic representation, becomes the MRM's core philosophical move: consciousness is the physical process of multiscale resonance, not a representation constructed by that process. The "from the inside" formulation is a direct extension of NRT's embodiment principle to the hard problem of consciousness.

Temporal flow requires continuity

A melody is not a sequence of discrete pitches but a continuous trajectory through pitch space. Consciousness shares this structure. The biological computation framework argues that the stream-like quality of conscious experience may depend on the physical continuity of biological dynamics—oscillatory fields that provide temporal extendedness within which discrete events are embedded. Music and consciousness are both fundamentally continuous processes containing discrete events, not sequences of discrete states.

7. The Self as Resonant Process

On this account, the self is not a thing but a process—specifically, the ongoing pattern of resonant coupling between bodily rhythms and neural oscillations. **The feeling of being a self is what body-brain entrainment feels like from the inside.** Evidence for this claim comes from research on heartbeat-evoked responses and self-representation. Neural responses to heartbeats have been shown to distinguish self-related from other-related thought content, with distinct spatiotemporal signatures for the agentive ("I") and narrative ("Me") dimensions of self-experience.

Further evidence comes from the suppression of self-produced rhythmic sensory input. Walking, speaking, and other self-generated rhythmic activities produce sensory consequences that are systematically suppressed compared to externally generated equivalents. This creates a primitive, pre-cognitive form of self-other distinction: what I generate rhythmically is muffled; what the world generates is amplified. The boundary of the self is a boundary in the entrainment landscape.

Because the self is constituted by entrainment, it is inherently open to modification through entrainment. External rhythmic signals—music, dance, chanting—can capture the body-brain coupling patterns that constitute selfhood and reshape them. This is the basis of the ENTRAIN compositional practice.

8. Mechanisms Across Timescales

8.1 The Vibrational Hierarchy

The MRM identifies a continuous hierarchy of oscillatory processes extending across at least six orders of magnitude in frequency, all governed by the same nonlinear resonance principles:

Subcellular dynamics (continuous, sub-Hz to kHz): Ion gradients, dendritic membrane oscillations, calcium waves, and graded electrotonic potentials. These are continuous-valued, real-time processes that bidirectionally couple with cellular-level dynamics, providing the substrate for continuous-discrete hybrid computation.

Neural population oscillations (0.5–100+ Hz): Delta, theta, alpha, beta, gamma bands. These entrain to environmental rhythms, to each other through phase-amplitude coupling, and to bodily rhythms through interoceptive pathways.

Body rhythms (0.01–4 Hz): Gastric (~0.05 Hz), respiratory (~0.25 Hz), cardiac (~1 Hz), saccadic (~4–8 Hz). All endogenous oscillators that entrain with neural oscillations, providing the embodied dimension of consciousness.

Brainstem and cochlear oscillations (30–4,000+ Hz): Cochlear outer hair cells, auditory nerve fibers, brainstem neurons processing pitch and timbre through the same nonlinear resonance dynamics that process rhythm at slower timescales.

Interpersonal synchronization (0.5–2+ Hz): Inter-brain coherence during ensemble performance, synchronized movement during dance, coordinated breathing during choral singing—entrainment at the social scale, the outermost layer of the multiscale resonance hierarchy.

8.2 Rhythm and Pitch: The Same Dynamics at Different Speeds

A 3:2 polyrhythm and a perfect fifth (3:2 frequency ratio) occupy the same position in the Arnold tongue analysis. Between rhythm and pitch lies a "roughness" zone (~20–30 Hz)—frequencies too fast for rhythmic perception but too slow for pitch. The MRM offers a speculative interpretation: this roughness zone may represent a gap in the resonance hierarchy where entrainment dynamics fail to form stable experiential structures. This interpretation should be treated as a hypothesis.

8.3 Melody, Tonality, and Micro-Consciousness Composition

If consciousness is what multiscale resonance feels like from the inside, then perceiving a melody is a moment-to-moment reconfiguration of the attractor landscape that is the listener's awareness. Each new tone arrives into an oscillatory network already resonating with traces of previous tones (sustained through Hebbian coupling) and already anticipating the future (through strong anticipation dynamics). A melody is a temporal score for micro-transitions in conscious state.

Tonality—the hierarchical sense that some pitches are more stable than others—emerges as an attractor landscape shaped by both intrinsic oscillator dynamics and cultural attunement. NRT models predict the tonal hierarchies of both Western music and North Indian raga from dynamical stability analysis, outperforming purely statistical models. Different tonal systems create genuinely different attractor landscapes—different topologies of the dynamical space that organizes moment-to-moment awareness during music.

9. Key Theoretical Distinctions

9.1 A Non-Functionalist Position

The MRM rejects computational functionalism—the dominant view that consciousness depends solely on the right pattern of information processing regardless of physical substrate. The rejection operates at multiple levels:

From NRT: Musical cognition is physical embodiment, not symbolic representation. The relationship between the brain's resonance state and external sound is lawful (determined by physics), not arbitrary (determined by convention). If cognition is embodied rather than represented, it cannot be substrate-independent.

From Milinkovic & Aru: Consciousness requires continuous-valued dynamics providing a medium for simultaneous cross-scale coupling, metabolic constraints shaping computational architecture, and bidirectional real-time co-determination between scales. Digital systems compute layer by layer in discrete time steps. The substrate is the algorithm—the physical dynamics are the computation.

From the MRM's own formulation: If consciousness is the interior of a physical process (not a product of a computation), then changing the physical process changes the consciousness. A system simulating the same functional relationships in a different substrate, at a different temporal resolution, without continuous cross-scale coupling, would not have the same interior—and might have no interior at all.

9.2 Embodiment as Physical Relationship, Not Metaphor

NRT defines embodiment as a physical state of the brain and/or body that has a lawful relationship to external events, determined by physical principles. Musical cognition *is* the resonance pattern—the brain does not build a model of the music and then experience the model. The MRM extends this to consciousness generally: conscious experience is the actual, physical, dynamical state of multiscale resonance in living tissue. There is no gap between the physical process and the experience because they are the same thing described at different levels.

10. Predictions and Empirical Program

Both contributions generate testable predictions. Contribution 1 predicts that states of consciousness should covary with measures of inter-scale coupling. Contribution 2 predicts that manipulating entrainment should manipulate consciousness.

10.1 Measurable Signatures of Inter-Scale Coupling

Phase-Amplitude Coupling (PAC): States of enhanced consciousness should show stronger, more organized PAC across broader frequency pairs. Anesthesia should show reduced PAC.

Body-Brain Coupling Indices: Heartbeat-evoked responses, respiratory-brain phase coupling, and gastric-cortical entrainment should covary with the richness of self-experience. Altered states should show measurable changes in body-brain coupling patterns.

Inter-Subject Coherence: Music designed to maximize multi-scale entrainment should produce broader and stronger inter-subject coherence than single-timescale music. Coherence at one frequency band should predict coherence at other bands.

Causal Emergence and Scale Closure: Wakeful conscious processing should exhibit greater causal emergence than unconscious states—a prediction already supported by initial findings comparing wakefulness and anesthesia.

10.2 Predictions for Musical Experience

Compositions designed to entrain multiple oscillatory timescales simultaneously should produce measurably greater inter-scale coupling than compositions operating at a single timescale. The depth of reported experiential effects should correlate with the breadth of inter-scale coupling.

10.3 Disruption Predictions

Conditions characterized by altered selfhood—depersonalization, dissociation, certain meditation states—should show measurable changes in body-brain entrainment patterns. Anesthesia should show global decoupling across scales.

10.4 Repertoire Diversity

The preceding predictions focus on the strength and breadth of inter-scale coupling. But the MRM generates a further prediction about the diversity of entrainment states, not merely their intensity. If consciousness is the interior of multiscale resonance, then the richness of conscious experience should correlate not only with how strongly oscillatory systems are coupled, but with how many distinct metastable coordination patterns are accessible to the system at a given time. We term this construct repertoire diversity: the entropy of the dynamic state space available to the entrained system.

The prediction is specific: conscious access will correlate more strongly with repertoire diversity—the number and variety of metastable states through which the system can transition—than with peak global activation or the strength of any single entrainment pattern. A system locked rigidly into one resonance regime, however strongly coupled, would correspond to a narrow, impoverished form of awareness. A system capable of fluid transitions among many distinct metastable coordination patterns would correspond to rich, flexible consciousness. This aligns with emerging evidence that repertoire diversity indices (entropy of dynamic functional connectivity states) distinguish wakeful consciousness from anaesthetic states more reliably than static connectivity measures (Hancock et al., 2025; Ibanez et al., 2026).

For the ENTRAIN compositional practice, this has a direct implication. The goal of consciousness composition is not merely to lock the listener into a single deep entrainment state but to guide them through a sequence of distinct yet related entrainment regimes. The three-mode arc—entraining, reshaping, releasing—described in Section 11 can now be understood as a trajectory through the repertoire: entraining narrows the accessible state space into coherence, reshaping navigates through a curated sequence of metastable states, and releasing expands the repertoire past its habitual boundaries. A measurable repertoire diversity index, computed from time-varying phase-amplitude coupling patterns or dynamic functional connectivity, could serve as a quantitative signature of compositional efficacy.

11. Composing Consciousness: Applied Implications

If the MRM is correct, then music composition operates in the same medium as consciousness itself. The composer's materials—rhythm, harmony, timbre, temporal form—are entrainment operators that reshape the multi-scale resonance dynamics whose interior is the listener's

awareness. NRT describes the listener's neural state as evolving on an attractor landscape. A composition is a time-varying attractor landscape that the composer designs.

11.1 Three Modes of Consciousness Composition

Entraining: Captures and synchronizes the listener's oscillatory patterns. Sustained pulse, simple harmonic content, layered repetition. Creates coherence, presence, deep groove. The experiential correlate is arrival. NRT's stability and attraction dynamics are being applied to gather dispersed oscillatory processes into a shared pattern.

Reshaping: Once entrained, the composer deforms the attractor landscape. Gradual shifts in harmonic density, rhythmic complexity, or spectral content change the kind of consciousness being sustained. A descent from dissonance to consonance *is* resolution—the listener's neural dynamics literally moving from a less stable to a more stable attractor, as NRT's stability and attraction principle predicts.

Releasing: The most powerful mode. At or near bifurcation points, the composition pushes the entrained system past its stability threshold. The old attractor collapses. The system enters a region of high sensitivity and openness between states. This may be the mechanism behind transcendent and ego-dissolving experiences.

Duration matters: 13–15 minutes appears to be a threshold for qualitative shifts in neural entrainment—from surface phase-locking to deeper reorganization. Only after this threshold can the composer meaningfully reshape or release the attractor landscape.

11.2 Music as Consciousness Technology

Every musical tradition—shamanic drumming at 4–4.5 Hz, Tibetan singing bowls, cathedral drones, West African polyrhythm, Indian raga—represents accumulated cultural knowledge about how to compose conscious states. The MRM provides a unified theoretical account of why these diverse practices work: they all target the same underlying dynamical system.

12. Relationship to Existing Theories

IIT: Agrees on integration, specifies mechanism (resonance not information), substrate-dependent where IIT is substrate-independent.

Global Workspace Theory: Global broadcast may = large-scale entrainment. MRM adds scalar integration (across timescales) and embodiment (body participates).

Predictive Processing: Overlapping predictions on expectation. NRT grounds it in physical dynamics, not Bayesian inference. May be complementary.

Hunt & Schooler's General Resonance Theory: Most direct competitor. MRM differs: multiscale + embodied (not just neural), entrainment as mechanism (experimental traction GRT lacks), "from the inside" vs. "arises from" (avoids production metaphor).

Orch-OR: Shares emphasis on substrate and sub-population scales. MRM does not require quantum coherence; classical biophysics provides the substrate for multi-scale coupling.

Ibanez et al.'s Music as Scientific Metaphor (2026): Ibanez and colleagues propose music as a central scientific metaphor for mind and brain, arguing that musical principles—polyphony, improvisation, temporal modulation, contextual embedding—can scaffold research programs across connectivity, consciousness, emotion, development, and brain disorders. The MRM shares the conviction that musical structure illuminates brain dynamics, and several of Ibanez et al.'s constructs—particularly their "triplicate interface" (listener, performer, composer as simultaneous cognitive modes) and their emphasis on repertoire diversity as a marker of healthy function—are convergent with the MRM's claims. However, the two frameworks differ in a critical respect. Ibanez et al. deliberately remain agnostic between Bayesian and dynamical-entrainment models, operating at a metatheoretical level that organizes research programs without committing to a specific mechanism. The MRM is more committed: it identifies nonlinear resonance as the physical principle and entrainment as the biological mechanism, makes a specific identity claim about consciousness (not a metaphorical one), and grounds the self in visceral body-brain coupling through interoceptive entrainment. In short, Ibanez et al. propose that the brain is like music. The MRM proposes that the brain is music—that the physical dynamics whose interior is consciousness are the same dynamics that constitute musical experience—and specifies the physics that explains why.

13. Open Questions and Future Directions

13.1 The Hard Problem

The MRM's formulation does not explain *why* physical processes have an interior at all. But it dissolves the structure of the problem. If consciousness is not *produced by* a physical process but is *the interior of* a physical process, then "why does this process produce experience?" is malformed. The structural correspondence between the fine-grained structure of experience and the fine-grained structure of resonance dynamics is so thorough that the burden of proof shifts to anyone who insists these are two separate things requiring a bridge.

13.2 Formal Specification

A fully developed MRM would require a unified multiscale formalism capturing resonance coupling across the full hierarchy simultaneously. Point process theory and multiscale continuous-time information-theoretic measures are promising pathways.

13.3 Cross-Cultural Variation

If different musical traditions create different attractor landscapes for consciousness, do cultures with profoundly different tonal systems cultivate subtly different structures of awareness? NRT's attunement framework provides the mechanism. Comparing inter-scale coupling patterns across culturally diverse populations would test one of the MRM's most distinctive predictions.

This line of inquiry can be sharpened into a cross-cultural empirical program with specific predictions. The MRM's logic entails that cultures with richer polyrhythmic traditions—West African drumming ensembles, Javanese gamelan, Afro-Cuban bata traditions—should produce individuals with measurably different entrainment profiles compared to individuals enculturated in predominantly monometric traditions. These differences should not be understood as deficits or enhancements relative to a single normative baseline, but as alternative stable coordination regimes reflecting different trade-offs among predictability, variability, and coordination.

Three specific predictions follow. First, individuals trained in polyrhythmic musical ecologies should show broader timing priors—wider Arnold tongue regions for complex ratios—and higher tolerance to temporal noise without reduced performance accuracy. This reflects Hebbian attunement to a richer set of stable mode-locking relationships. Second, cross-frequency coupling diversity (the number of distinct frequency-ratio relationships simultaneously sustained) should be measurably greater in polyrhythmically enculturated populations, reflecting a more complex multi-scale entrainment architecture. Third, repertoire diversity indices—the entropy of accessible metastable coordination states—should differ systematically across musical ecologies, with polyrhythmic traditions producing broader repertoires and monometric traditions producing deeper but narrower ones.

These predictions carry philosophical significance for the MRM. If consciousness is the interior of multiscale resonance, and if different musical ecologies shape different resonance architectures through attunement, then the structure of consciousness itself is culturally variable—not in content alone, but in its temporal organization, its tolerance for ambiguity, and its characteristic coordination dynamics. This reframes neurodiversity as variation in dynamic coordination style rather than deviation from a single optimal regime. Non-Western, microtonal, and noise-based musical systems are not exotic alternatives to a Western tonal norm; they represent genuinely different organizational regimes for the resonance dynamics that constitute awareness. The MRM predicts that each such regime will have its own characteristic entrainment signatures, its own repertoire diversity profile, and its own phenomenological texture—testable claims that require cross-cultural collaboration with ethnomusicologists, ethnographers, and culturally embedded practitioners.

13.4 Bridging the Roughness Gap

Can sounds bridging the rhythm-pitch gap (~20–30 Hz) produce unusual or heightened states of awareness? Exploring this zone compositionally represents an empirical frontier unique to the MRM's predictions.

14. Conclusion

The Multiscale Resonance Model makes two original contributions to the science and philosophy of consciousness:

First: multiscale resonance is essential for consciousness. Consciousness and the feeling of self are what multiscale resonance in living tissue feels like from the inside. This is an identity claim, not a production claim.

Second: entrainment is the mechanism. The specific physical process by which inter-scale coupling is achieved in biological systems is entrainment. This gives the first contribution experimental traction.

These contributions synthesize three converging research programs but go beyond what any individually asserts. The dynamics are those NRT has characterized in musical cognition. The MRM's contribution is to recognize that these dynamics extend beyond music, across the full hierarchy of biological oscillation, and that their interior is consciousness itself.

The MRM proposes a four-level architecture:

The physical principle is resonance—nonlinear, mode-locking, stability-and-attraction dynamics governed by integer frequency ratios. This is what NRT characterizes in musical cognition.

The biological realization is entrainment—what resonance becomes in self-sustaining oscillators embedded in metabolically constrained, continuous-valued, scale-inseparable living tissue.

The conscious manifestation is the interior of multiscale entrainment—temporal flow, anticipation, tension and resolution, selfhood constituted by interoceptive coupling.

The cultural technology is music—the evolved practice of designing sound structures that amplify, elaborate, and share the resonance dynamics whose interior is awareness. ENTRAIN is the contemporary compositional practice that makes this explicit.

Each level depends on the one below it. Music works because consciousness has musical structure. Consciousness has musical structure because biological entrainment follows resonance dynamics. Biological entrainment follows resonance dynamics because living tissue

implements nonlinear oscillation with scale-inseparable coupling. It is a single explanatory line from physics through biology through phenomenology to cultural practice.

The process is resonance. The biology is entrainment. And the experience is music, all the way down.

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References

The following references are organized into three tiers. **Primary sources** are the papers whose synthesis constitutes the MRM's core argument. **Supporting sources** provide essential evidence for specific claims within the framework. **Additional references** are cited for individual findings or theoretical positions discussed in the text. Where references are drawn from the primary and supporting sources' own citations, the originating paper is noted.

Note: The framework's central claim—that entrainment is the mechanism of inter-scale coupling, and that this coupling constitutes consciousness—is a synthesis not found in any one of the primary sources individually. This convergence is the MRM's own theoretical contribution.

Primary Sources

Lakatos, P., Gross, J., & Thut, G. (2019). A new unifying account of the roles of neuronal entrainment. *Current Biology, 29*(18), R890–R905. https://doi.org/10.1016/j.cub.2019.07.075

Provides the unified entrainment framework identifying three categories of brain entrainment (externally driven, self-produced, neuromodulatory) and demonstrating that bodily rhythms—gastric, respiratory, cardiac, saccadic—genuinely entrain neural oscillations and gate conscious perception. Note: Lakatos et al. define entrainment in the strict sense as unidirectional (an external rhythm drives an oscillating system), distinguishing it from bidirectional phase synchronization. The MRM uses "entrainment" in a broader sense encompassing both mechanisms; see Section 2.2. Referenced throughout Sections 2.2, 3.1, 3.2, and 4.1.

Large, E. W., Harding, E., Kim, J. C., Demos, A. P., Tichko, P., Salet, L., & Bhutani, R. (2025). Musical neurodynamics. *Nature Reviews Neuroscience*. https://doi.org/10.1038/s41583-025-00915-4

Presents neural resonance theory (NRT) as a comprehensive framework for music cognition, demonstrating that nonlinear dynamical principles—mode-locking, stability and attraction, Hebbian attunement, strong anticipation—govern perception, action, and cognition across both rhythmic and tonal timescales. The assertion that musical cognition is the actual embodiment of resonance relationships (not symbolic representation) is central to the MRM's claim that consciousness has musical structure. Referenced throughout Sections 2.1, 3.3, 4.2, 4.3, 5.1, 5.2, 7.1, 8.3, and 11.2.

Milinkovic, B., & Aru, J. (2026). On biological and artificial consciousness: A case for biological computationalism. *Neuroscience and Biobehavioral Reviews, 181*, 106524.

Argues that consciousness requires inter-scale integration via continuous, bidirectionally coupled dynamics uniquely available in biological substrates. The distinction between scale-separable digital computation and scale-inseparable biological computation, and the finding that wakeful conscious states exhibit greater multiscale integration than anaesthetic states, provide the architectural argument for the MRM's core claim. Milinkovic & Aru frame inter-scale coupling as something that "may be essential" for consciousness; the MRM adopts this as a central premise. Referenced throughout Sections 2.3, 3.1, 4.1, 5.3, 6.1, 8.4, and 9.2.

Supporting Sources

These papers provide essential evidence for specific claims within the MRM framework.

Large, E. W., Kim, J. C., Harding, E., Demos, A. P., Tichko, P., Savinov, M., … & Palmer, C. (2023). Dynamic models of rhythm perception and production. *Frontiers in Computational Neuroscience, 17*, 1151895. https://doi.org/10.3389/fncom.2023.1151895

Comprehensive review comparing computational approaches to rhythm perception: circle-map phase oscillator models, dynamic attending and perception-action coordination models, Bayesian inference models, and neural resonance theory. Provides the formal mathematical framework (canonical oscillator models, Arnold tongue analysis, Hebbian learning rules, gradient frequency neural networks) upon which the MRM's mechanistic claims are built. Referenced throughout Sections 2.1, 4.2, 7.1, and 9.2.

Babo-Rebelo, M., Richter, C. G., & Tallon-Baudry, C. (2016). Neural responses to heartbeats in the default mode network encode the self in spontaneous thoughts. *The Journal of Neuroscience, 36*(30), 7829–7840. https://doi.org/10.1523/JNEUROSCI.0262-16.2016

Demonstrates that neural responses to heartbeats distinguish self-related from other-related thought content, with distinct spatiotemporal signatures for the agentive ("I") and narrative ("Me") dimensions of self-experience. Provides the most direct evidence that interoceptive body-brain entrainment participates in constituting selfhood—a claim central to MRM Sections 3.2, 6.1, and 11.3.

Kaneshiro, B., Nguyen, D. T., Dmochowski, J. P., Norcia, A. M., & Berger, J. (2020). Natural music evokes correlated EEG responses reflecting temporal structure and beat. *NeuroImage, 214*, 116559. https://doi.org/10.1016/j.neuroimage.2020.116559

Demonstrates that naturalistic music produces correlated neural responses across listeners at beat-related frequencies, using inter-subject coherence as an index of shared neural entrainment. Referenced in Sections 6.1 and 11.4.

Kaneshiro, B., Dmochowski, J. P., Norcia, A. M., & Berger, J. (2017). Beat entrainment to auditory and visual rhythms: Evidence from EEG inter-subject coherence. *Proceedings of the International Society for Music Information Retrieval Conference (ISMIR)*.

Earlier report demonstrating inter-subject EEG coherence at beat-related frequencies during natural music listening. Referenced in Section 6.1.

Will, U., & Makeig, S. (2011). EEG research methodology and brainwave entrainment. In J. Berger & G. Turow (Eds.), *Music, Science, and the Rhythmic Brain: Cultural and Clinical Implications* (Chapter 5). Routledge.

Provides detailed EEG methodology for measuring brainwave entrainment to periodic acoustic stimulation. Referenced in Sections 6.1 and 11.4.

Jovanov, E., & Maxfield, M. (2011). Entraining the brain and body. In J. Berger & G. Turow (Eds.), *Music, Science, and the Rhythmic Brain: Cultural and Clinical Implications* (Chapter 2). Routledge.

Reports laboratory replication of shamanic drumming effects, demonstrating the 13–15 minute threshold for qualitative shifts in neural entrainment during sustained rhythmic stimulation at 4–4.5 Hz. Referenced in Section 11.2.

Bowling, D. L. (2023). Biological principles for music and mental health. *Translational Psychiatry, 13*, 374.

Organizes the neurophysiological effects of music around four core elements: tonality (vocal similarity theory, mood/anxiety applications), rhythm (neural resonance, auditory-motor entrainment), reward (dopaminergic circuitry, motivation applications), and sociality (synchrony, oxytocin, social connection). Provides biological grounding for music as communicative technology and neurochemical context for the affective dynamics the MRM describes. Referenced in Sections 3.3 and 7.3.

De Souza, J. (2018). Entrainment and embodiment in musical performance. In M. Clayton (Ed.), *The Oxford Handbook of Entrainment*. Oxford University Press.

Examines entrainment as embodied practice in musical performance. Referenced in Section 5.2.

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Chalmers, D. J. (1995). Facing up to the problem of consciousness. *Journal of Consciousness Studies, 2*(3), 200–219.

Hameroff, S., & Penrose, R. (2014). Consciousness in the universe: A review of the 'Orch OR' theory. *Physics of Life Reviews, 11*(1), 39–78.

James, W. (1890). *The Principles of Psychology*. Henry Holt and Company.

Meyer, L. B. (1956). *Emotion and Meaning in Music*. University of Chicago Press.

Park, H.-D., & Tallon-Baudry, C. (2014). The neural subjective frame: From bodily signals to perceptual consciousness. *Philosophical Transactions of the Royal Society B, 369*(1641), 20130208.

Tegmark, M. (2000). Importance of quantum decoherence in brain processes. *Physical Review E, 61*(4), 4194–4206.

Thompson, E., & Varela, F. J. (2001). Radical embodiment: Neural dynamics and consciousness. *Trends in Cognitive Sciences, 5*(10), 418–425.

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Zelano, C., Jiang, H., Zhou, G., Arora, N., Schuele, S., Rosenow, J., & Gottfried, J. A. (2016). Nasal respiration entrains human limbic oscillations and modulates cognitive function. *The Journal of Neuroscience, 36*(49), 12448–12467.

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