FROM EAR TRAINING TO COGNITIVE EAR TRAINING: ESTABLISHING THE *CETra* FRAMEWORK

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The article introduces *Cognitive Ear Training (CETra)* as a novel framework that reconceptualizes ear training as more than technical skill acquisition. While traditional approaches have emphasized pitch, rhythm, harmony, and sight-singing, they often overlook the cognitive prerequisites – such as attention, working memory, and executive control – that shape learning outcomes. *CETra* addresses this gap by integrating insights from cognitive neuroscience, music psychology, and pedagogy, positioning auditory training as both a musical and cognitive practice. Drawing on evidence from neural plasticity, music–language transfer, evolutionary and cross-cultural research, predictive coding, emotional engagement, and developmental studies, the paper demonstrates how *CETra* harnesses the interdependence of perception, attention, memory, self-regulation, and creativity. The framework is articulated through a Spotlight Model comprising seven interrelated dimensions – psychoacoustic, behavioral, psychoemotional, neurophysiological, physical, social, and pedagogical – each linking auditory processes with broader, cognitive functions. By reframing ear training as a multidimensional practice that cultivates transferable skills, *CETra* offers a paradigm shift for music education and establishes a foundation for future interdisciplinary research.

Keywords: Cognitive Ear Training (CETra), music education, auditory cognition

INTRODUCTION

Cognitive ear training is closely linked generally to the processes of perception and understanding. At its core, it emphasizes focus to cognitive functions such as perception, attention, memory, and creativity. Cognitive training refers to structured techniques designed to strengthen these components, thereby improving not only musical skills and knowledge about music, but also broader intellectual functions.

In research practice, there is a term *cognitive training*, widely used to describe interventions that aim to activate and reinforce specific cognitive components. Cognitive training has emerged as a promising approach to enhancing executive function and general cognition across diverse populations – from children to older adults (Bogataj et al. 2025; Diamond et al. 2016; Lampit et al. 2014; Simons et al. 2016). Evidence shows that such training can improve working memory, attention control, processing speed, and cognitive flexibility, while also promoting resilience against age-related decline and supporting neuroplastic changes in the brain. Well-designed training programs often generalize beyond task-specific skills, contributing to improvements in academic achievement, problem-solving, and everyday functioning (Jaeggi et al. 2011; Karbach et al. 2014). Even the cognitive training is widely broad it is not connected directly to sound material included in the training. Possible reasons will be discussed later.

In this article, *ear training* is used as a general umbrella term for pedagogical practices aimed at developing musical listening skills. The designation *traditional ear training*, most commonly associated with solfège-based approaches, does not refer to a formally standardized theoretical construct, but is used descriptively to denote historically established pedagogical practices that have been widely adopted in music education. These practices have typically been organized around solfège- and notation-based exercises, including interval and chord identification, melodic and harmonic dictation, and sight-singing within structured pitch and rhythmic systems.

These terminological distinctions provide a conceptual basis for positioning Cognitive Ear Training (*CETra*) as a framework that builds upon established ear-training practices while explicitly addressing the cognitive mechanisms underlying listening, perception, and learning processes.

Historically consolidated solfège-based ear training remains a deeply effective pedagogical tool, supported by its long pedagogical tradition as well as modern empirical validation. (Guido of Arezzo, ca. 1025/1978; Curwen 1870; Kodály 1974; Apfelstadt 1984; Demorest et al. 1995; Agbenyo 2021; Zhao 2024; Lumbantoruan et al. 2024). More than an exercise, solfège serves as a cognitive and expressive toolkit that bridges hearing, understanding, and performance – central to its enduring value in music education. Traditionally, ear training is organized into structured exercises in pitch recognition, interval identification, dictation of pitch and rhythm, and melodic-harmonic analysis. These activities foster not only musical literacy but also a distinctive form of cognitive training. Both pedagogical practice and empirical research indicate that solfège cultivates auditory discrimination, working memory, sustained and selective attention, and executive control – skills essential not only for musical performance but also for broader cognitive functioning (Schellenberg 2004; Tierney et al. 2013; Moreno et al. 2014). When focused on technical exercises – often modelled on stylistic conventions or style-imitative structures – traditional ear training can enhance cognitive capacities. By requiring learners to decode complex auditory input, retain musical phrases in memory, and anticipate structural patterns, ear training fosters neuroplastic adaptations that extend beyond music learning. Research indicates that such training can enhance linguistic processing, second-language acquisition, and general problem-solving abilities (Patel 2011; Besson et al. 2011). Furthermore, solfège exercises engage both convergent and divergent thinking, promoting creative flexibility while maintaining accuracy in auditory perception. Yet in practice, teachers often observe that learners encounter limitations: not all are equally able to process the curriculum. In fact, many of the very cognitive components that ear training aims to develop are already prerequisites for engaging with it effectively.

Based on our experience as teachers, we have observed that traditional ear training often places a narrow emphasis on the reproduction of intervals, chords, or dictations. Although these skills are essential, this approach may inadvertently foster a rigid mode of listening, in which students "train for the test", yet struggle to transfer their abilities to novel or creative contexts. In many music schools, vocational institutions, music academies or conservatory settings, ear training has traditionally emphasized musicianship through skills such as interval recognition, harmonic hearing, melodic dictation, and rhythmic accuracy. Although effective in developing technical proficiency, these practices often prioritize auditory recognition at the expense of domain-general processes that support flexible and robust listening. As a result, many students plateau in their progress because foundational capacities such as selective attention, short-term auditory memory, or cognitive flexibility are not sufficiently cultivated (Lehmann et al. 2007, 80–83, 141–147).

Integrating modern cognitive training principles into this long-standing pedagogical framework of traditional ear training may optimize its benefits, establishing a stronger foundation for both music learning and the development of transferable skills across educational and developmental contexts. This perspective reconceptualizes ear training as a structured platform for the cultivation of fundamental cognitive capacities, thereby enhancing the efficiency of the learning process and enabling individuals to mobilize their cognitive resources with greater depth and precision.

Despite these established connections, *cognitive ear training* as a targeted pedagogical construct has not yet been systematically conceptualized or applied. Traditional ear training continues to be framed primarily as a method for musical skill acquisition – emphasizing pitch, rhythm, harmony, and sight-singing – while its broader cognitive mechanisms remain largely under examined. To address this gap, we advance *cognitive ear training* as a novel framework: one that reconceptualizes auditory training not merely as a vehicle for musical development, but as a structured approach to cultivating cognitive components through the dynamic interplay of sound, silence, and spatial perception.

There are several possible reasons why this concept has not yet been used in research:

a) Historical framing. Ear training (solfège) has traditionally been seen as a pedagogical tool for musical literacy – interval recognition, melodic dictation, harmonic analysis – rather than as a cognitive intervention. As a result, research has emphasized practical knowledge and performance skills over cognitive outcomes (Karpinski 2000: ch. 1, Part I; McPherson et al. 2002, 99–115).

b) Terminology gaps. Music education and cognitive neuroscience operate within distinct disciplinary vocabularies. In pedagogy, the discourse centres on *aural skills* or *musicianship training* – implicitly engaging cognitive components such as perception and attention – whereas cognitive psychology emphasizes constructs like perception, working memory, executive function, and selective attention. This terminological divide has hindered the explicit conceptualization of ear training as a form of cognitive training, despite its reliance on the same underlying neural and cognitive systems (Patel 2011; Besson et al. 2011).

c) Methodological barriers. Cognitive training research typically employs controlled, quantifiable tasks with clearly measurable transfer effects (e.g., the *n*-back paradigm for assessing working memory). By contrast, ear training is inherently open-ended, context-dependent, and highly variable across institutions, which makes standardization and rigorous scientific measurement difficult (Simons et al. 2016; Diamond et al. 2016). Furthermore, ear training methodologies are often shaped less by empirical validation than by institutional traditions and the subjective pedagogical orientations of individual instructors. For example, in seminar settings, presenters often introduce new exercises for recognizing cadences; however, there is typically little consideration of the cognitive prerequisites for such tasks – namely, the foundational knowledge and cognitive flexibility required to process information efficiently and to transition fluidly between different musical contexts.

d) Research silos. Music cognition research often examines the effects of music training broadly – comparing musicians and non-musicians – without isolating ear training as a distinct component. This overlooks the possibility that ear training itself contributes uniquely to auditory attention, memory, and cognitive flexibility (Schellenberg 2004; Tierney et al. 2013).

e) Lack of an operational definition. To date, no clear framework for *cognitive ear training* has been articulated. In the absence of such a definition, ear training continues to function primarily as an educational construct rather than a scientifically grounded one. This conceptual gap highlights the need – and provides the opportunity – to advance *cognitive ear training* as an integrative framework that systematically bridges pedagogical practice with cognitive science.

In practice, the positive influence of musical training on cognition is widely recognized. Learning music and active music-making foster the development of attention, perception, and flexible thinking. Through ear training, students often encounter their cognitive limits, sharpening their pitch awareness, rhythmic sensitivity, and harmonic understanding. Yet, the connection between ear training and broader psychological processes remains insufficiently researched – a limitation that constrains its further development.

Cognitive Ear Training (*CETra*) reframes the concept of ear training by recognizing that musicianship and auditory perception rely on the integration of perceptual and cognitive processes. Rather than limiting training to reproduction, *CETra* emphasizes adaptability, problem-solving, and flexible listening strategies that prepare learners to engage actively and creatively with sound. Its structured exercises are designed to strengthen selective attention, working memory, prediction, and higher-order decision-making, while still incorporating the listening skills that remain central to musicianship. In this way, *CETra* extends the tradition of ear training by uniting technical mastery with cognitive development, fostering a more transferable and resilient foundation for musical learning. This reconceptualization provides the rationale for developing a structured framework in which ear training is organized into spotlights, each highlighting a distinct dimension of listening and learning that, taken together, support a more holistic philosophy and practice of ear training.

A key aspect of effective ear training is what we call *the freedom of hearing* – the ability to adapt to new contexts and apply previously acquired knowledge in unfamiliar situations. This involves the transfer of knowledge across domains, for example, connecting the recognition of classical harmonic progressions with the more complex structures of jazz. In our teaching practice we often use comparative exercises, such as asking students to notate the same melodic fragment in both classical and jazz notation, or to recognize harmonic substitutions across different styles. Such strategies strengthen cognitive flexibility and highlight that musical hearing is not fixed but can expand across genres and contexts. In this way, ear training fosters not only musicianship but also the cognitive agility to navigate diverse auditory environments.

The relevance of *CETra* is underscored by findings in neuroscience. Musical training is a robust driver of neuroplasticity: long-term practice induces structural and functional changes in the auditory and motor cortices, the corpus callosum, and networks supporting executive function (Gaser and Schlaug 2003; Hyde et al. 2009; Schlaug et al. 2009). These results suggest that *CETra* can deliberately harness neural plasticity to strengthen listening and learning. Beyond musicianship, such adaptations extend to language learning, auditory rehabilitation, and cognitive development across the lifespan – including children, adults, and older adults (Kraus et al. 2014; Moreno et al. 2009).

CETra also addresses practical needs. In music education, traditional exercises such as dictation or interval recognition can be insufficient for real-world performance demands that require rapid adaptation, improvisation, and integration of multiple auditory cues. In clinical contexts, cochlear-implant and hearing-aid users often struggle with speech-in-noise perception and subtle timbral distinctions. *CETra* proposes targeted tasks that train auditory filtering, rhythm–motor coordination, and cognitive flexibility to mitigate these challenges (Gohari et al. 2023; Shukor et al. 2020).

The concept of Cognitive Ear Training (*CETra*) must first be defined before turning to the supporting literature. *CETra* may be understood as a structured framework for the development and interconnection of core cognitive components through aural information, employing sound, silence, and spatial perception as its operative environment. By fostering integrated cognitive networks, *CETra* aims to enhance overall cognitive potential, grounded in the premise that dynamic correlations among perception, attention, memory, self-regulation, and creativity constitute essential prerequisites for meaningful musical experience and for the long-term acquisition of musical knowledge and skills.

MUSIC TRAINING AND COGNITIVE TRANSFER: TOWARD A NEW PARADIGM OF EAR TRAINING

Music training demonstrates wide-ranging transfer effects that form the conceptual foundation for the philosophy of *CETra*. Neuroscientific research has established that training reshapes both brain structure and function: musicians exhibit greater gray-matter density and stronger auditory–motor connections, while even short-term interventions yield measurable cognitive and perceptual gains in both children and adults (Gaser et al. 2003; Hyde et al. 2009; Moreno et al. 2009). At the functional level, training enhances neural phase-locking, predictive coding, and cortical tuning to pitch and timbre (Colverson et al. 2024; Kraus et al. 2014). Furthermore, music-evoked pleasure engages dopaminergic reward circuits that sustain motivation and consolidate learning (Zatorre et al. 2013a; Blood et al. 2001; Koelsch, 2014). For cognition, this plasticity translates into stronger auditory working memory, improved attentional control, and greater motivational resilience, capacities that support both musical performance and general learning.

Transfer effects extend across rhythm, timbre, and spatial dimensions. Rhythm-based training strengthens neural entrainment and temporal prediction, directly benefiting speech-in-noise perception and prosody recognition (Goswami 2022; Hennessy et al. 2022; Vuust et al. 2014). These processes enhance temporal attention, sequencing, and predictive monitoring – skills crucial for executive function and language processing. Timbre-oriented exercises refine fine-grained auditory discrimination and support emotional coding (McAdams 2008; Bellmann et al. 2024). Such training sharpens perceptual sensitivity, expands emotional awareness, and strengthens auditory categorization, thereby fostering flexible pattern recognition. Spatial-hearing tasks, meanwhile, enhance auditory scene analysis, stream segregation, and localization – skills critical for ensemble music-making and everyday listening (Maillard et al. 2023; Reis et al. 2021). Cognitively, these tasks train selective attention, multi-source information integration, and spatial working memory.

Music–language transfer adds another crucial dimension. Incorporating tonal language components, musical training has been shown to enhance phonological awareness, tonal language acquisition, and prosody perception, while linguistic expertise reciprocally refines pitch processing (Patel 2008, 356–378; Wong et al. 2007; Hennessy et al. 2022). Enhanced brainstem encoding of both linguistic and musical pitch patterns further illustrates experience-dependent plasticity (Krishnan et al. 2010). The cognitive benefits include strengthened verbal working memory, heightened auditory discrimination for speech, and increased cross-domain transfer between symbolic systems. In this context, language itself can serve as a valuable material for ear training.

Building on the evidence from music–language transfer, it is equally important to recognize that the foundations of ear training extend beyond formal music education into evolutionary and cross-cultural domains. This perspective underscores that music training draws not only on learned symbolic systems, such as language, but also on deeply ingrained human predispositions for rhythm, coordination, and collective practice. Evolutionary and anthropological research demonstrates that music leverages these innate capacities as mechanisms of social bonding and communication (Mehr et al. 2019; Savage et al. 2020). At the cognitive level, such collective engagement promotes joint attention, synchronization, and social cognition, which in turn enhance cooperative problem-solving and emotional regulation. Predictive coding studies further reveal that musical prediction errors activate neural systems for adaptive processing, thereby cultivating tolerance for uncertainty and cognitive flexibility (Koelsch et al. 2019; Ueno et al. 2024). These mechanisms strengthen error monitoring, adaptive updating, and resilience to ambiguity – core components of higher-order executive function. Emotional engagement and group participation also sustain motivation and consolidate memory (Zatorre et al. 2013a; Savage et al. 2020), contributing to affective learning, long-term retention, and persistence in complex tasks.

Developmental evidence highlights the importance of early interventions: sensitive periods facilitate accelerated growth of auditory, cognitive, and linguistic capacities (Hyde et al. 2009; Moreno et al. 2009). Engaging in *CETra* during these windows enhances neuroplasticity, scaffolds metacognitive awareness, and builds enduring foundations for learning. Complementing these findings, large-scale data demonstrate that psychosocial skills – such as grit, self-efficacy, and prosocial behaviour – are significant contributors to musical development alongside cognitive and technical abilities (Voitova et al. 2025). These traits reinforce self-regulation, perseverance, and collaborative learning, extending the cognitive reach of ear training into broader developmental domains.

Taken together, these strands of evidence articulate a paradigm of transfer in which *CETra* is grounded. Music training operates not only as a vehicle for technical development but as a multidimensional practice that leverages neuroplasticity, language transfer, evolutionary predispositions, predictive processing, emotional engagement, developmental timing, and psychosocial growth. Within this paradigm, *CETra* organizes its approach into a Spotlight Framework: seven interrelated spotlights, each illuminating a distinct but interconnected dimension of listening and learning.

In practice, *CETra* can be implemented across education, therapy, and technology: from studio pedagogy that embeds adaptive dictations and rhythmic flexibility (Berkowitz 2010), to classroom games that strengthen entrainment and phonological awareness (Goswami 2022), to AI-driven tools and VR simulations that personalize auditory training and expand access (Reis et al. 2021; Han et al. 2024). Clinical applications demonstrate improvements in speech-in-noise perception, timbre recognition, and spatial listening for cochlear-implant and hearing-aid users (Shukor et al. 2020; Dornhoffer et al. 2024).

TOWARD A MULTIDIMENSIONAL SCIENCE OF EAR TRAINING: THE SPOTLIGHT FRAMEWORK

The Spotlight Framework addresses this need by articulating seven interrelated dimensions of listening and learning that collectively define *CETra*. Each spotlight illuminates a distinct domain – spanning psychoacoustic precision, social interaction, behavioural regulation, psychoemotional engagement, neurophysiological grounding, physical embodiment, and pedagogical design. Viewed through these multiple lenses, *CETra* reframes ear training from a narrow focus on technical reproduction to a holistic practice that unites knowledge with pleasure, accuracy with creativity, and discipline with motivation.

1. Psychoacoustic Spotlight: From Acoustic Cues to Cognitive Interpretation

The psychoacoustic spotlight examines how listeners perceive, discriminate, and interpret the fine-grained acoustic features of environmental and musical sounds, emphasizing the integration of perceptual, attentional, and memory processes that support auditory mechanisms. A particularly important component is sound density, as the layering and overlap of spectral information directly affect clarity and perceptual load in both musical and ecological contexts. Research on timbre perception demonstrates that subtle spectral and temporal cues – such as attack transients, spectral centroid, and harmonic inharmonicity – enable individuals to reliably distinguish between instruments and sound sources, even when pitch or rhythm remain constant (McAdams 2008). Neuroimaging studies further reveal that these discriminations recruit bilateral auditory cortices as well as higher-order networks related to working memory and decision-making, indicating that psychoacoustic processing is inherently cognitive and distributed across neural systems (Koelsch 2014). Behavioural evidence supports this account: musicians consistently outperform non-musicians in tasks requiring micro-interval discrimination and spectro-temporal analysis, reflecting experience-driven sharpening of auditory representations and enhanced attentional control. Parallel findings show that both musical training and tone-language experience enhance subcortical pitch encoding, underscoring the plasticity of the auditory system (Wong et al. 2007; Krishnan et al. 2010).

Training interventions that target psychoacoustic acuity – such as adaptive timbre contrast paradigms, micro-interval dictations, and spectro-temporal masking tasks – improve not only accuracy and just-noticeable-difference (JND) thresholds but also transfer meaningfully to real-world contexts such as speech perception in noise and the interpretation of subtle timbral nuances in repertoire (Hennessy et al. 2022; Bellmann et al. 2024). Taken together, these findings position psychoacoustic training as a cornerstone of *CETra*, particularly in the early stages of musical development, where improvements in auditory precision are reinforced by cognitive engagement and validated through their transfer to ecologically relevant performance domains.

In traditional ear training, this dimension is often overlooked,, as instruction quickly prioritizes explicit knowledge of pitch, interval, and harmony. This emphasis risks neglecting the acoustic discrimination processes necessary for robust auditory representations and for the neural foundations of higher-order cognitive and musical skill functions.

Infants as young as 3 and 7 months can reliably detect fine-grained changes in pitch (F0) and timbre, performing on par with musically trained adults and even surpassing untrained adults (Lau et al. 2021). This evidence suggests that sensitivity to microtonal distinctions emerges early, yet such perceptual capacities are rarely cultivated in music schools or vocational curricula, which typically focus on tempered pitch systems. Integrating microtonal training into ear training could therefore harness and extend these innate psychoacoustic abilities.

By reinstating the psychoacoustic dimension as a primary focus, *CETra* ensures that ear training does not leap prematurely into symbolic domains, but rather develops from the perceptual bedrock that enables both musical literacy and broader cognitive flexibility.

2. Social Spotlight: Collaborative Dimensions of Auditory Learning

The social spotlight emphasizes how auditory training extends beyond individual perception into the dynamics of interaction, coordination, and communication. Cognitive domains central to this area include attention, language, problem-solving, and creativity, which are recruited when individuals make music or communicate together. Research on ensemble synchronization demonstrates that musicians develop superior skills in maintaining temporal alignment with others, even under conditions of uncertainty or without external cues (Vuust et al. 2014). Such coordination depends on attentional networks (Markett et al.2022) and rapid adjustment, highlighting the cognitive flexibility required for successful group performance. Beyond music, these capacities contribute to turn-taking in conversation and cooperative problem-solving, underscoring the transfer value of social listening skills (Savage et al. 2020).

Evidence further shows that conversational prosody – the rhythm and intonation of speech – is closely tied to the same auditory mechanisms that underlie musical synchronization. Neurocognitive studies reveal that training in rhythmic entrainment enhances sensitivity to speech boundaries and improves comprehension in noisy environments (Goswami 2022). Ensemble and call-and-response paradigms, therefore, not only strengthen musical timing but also reinforce language processing skills. This connection is particularly relevant in early childhood, where collective music-making accelerates both linguistic and social-emotional development (Moreno et al. 2009). Furthermore, it is useful to incorporate different cultural models of interaction, including rhythmic frameworks derived from non-Western scales and tonal language patterns. Research shows that tone-language speakers exhibit enhanced pitch sensitivity and prosodic awareness compared to non-tonal language speakers, highlighting the potential value of cross-cultural integration in *CETra*-based training (Krishnan et al. 2010).

Embedding training in collaborative activities further enhances motivation and creativity, as learners engage more deeply when they are required to interact, co-create, and respond dynamically to peers (Berkowitz 2010; Savage et al. 2020). By situating *CETra* in group environments, the social spotlight demonstrates how auditory training can simultaneously strengthen cognitive flexibility, communicative competence, and social bonding. This emphasis on interaction is reinforced by recent findings that psychosocial skills such as prosocial behaviour and perseverance predict listening ability outcomes in musically gifted adolescents (Voitova et al. 2025).

3. Behavioural Spotlight: From Practice Habits to Cognitive Flexibility in Ear Training

The behavioural spotlight focuses on how learners regulate their listening strategies, consciously manage cognition, and monitor progress during training. Unlike the psychoacoustic or social dimensions, this spotlight emphasizes metacognitive processes – awareness and control of one's own learning strategies – as well as the adaptive regulation of effort. Key cognitive domains include attentional sustainment, working memory, and decision-making. In music education, research shows that expert performers rely on deliberate practice strategies and active self-monitoring to refine their skills, often verbalizing or annotating errors to guide subsequent improvement (Lehmann et al. 2007). Such metacognitive behaviours have been strongly linked to accelerated skill acquisition and long-term retention. Cross-sectional evidence further demonstrates that constructs such as grit and hope interact with practice behaviours and listening skills, suggesting that strategic regulation cannot be separated from broader psychosocial capacities (Voitova et al. 2025).

Empirical findings highlight the importance of adaptive learning in auditory training, particularly under noisy conditions where sustained attention and distractor filtering are critical (Sridhar et al. 2025). Similarly, adaptive systems that adjust task difficulty in real time foster sustained engagement by keeping learners within an optimal zone of challenge and success. Evidence from musical training suggests that tasks which stretch working memory capacity without overwhelming it can strengthen attentional control and decision-making in complex auditory contexts (Román-Caballero 2023).

Another crucial behavioural dimension concerns how individuals respond when faced with novel or unpredictable contexts. The ability to transfer knowledge to unfamiliar circumstances depends on acceptance of uncertainty, flexible strategy generation, and the capacity to reorganize prior knowledge in light of new demands. Research on *far transfer* and adaptive expertise shows that musicians who develop such flexible habits are better able to cope with unexpected performance conditions and apply learned skills in new environments (Hatano et al. 1986, 262–272; Barnett et al. 2002). These findings resonate with educational psychology, where adaptive learning and self-regulated strategy use are seen as predictors of resilience and long-term achievement (Zimmerman 2002; Veenman et al. 2006).

Studies of musical performance in adolescents with ADHD, ADD, and dyslexia have highlighted not only neurophysiological differences but also motivational and self-regulatory benefits (Groß et al. 2022). These findings underscore the value of ear-training interventions in fostering self-efficacy, attentional control, and emotional engagement – especially for learners with neurodevelopmental diversity.

CETra incorporates these principles through dual-task dictations, which require learners to divide attention between melody and rhythm or between listening and notating under time constraints. Self-explanation protocols encourage students to articulate their listening strategies, reinforcing metacognitive awareness, while error-tagging tasks train learners to recognize and categorize mistakes systematically. By cultivating flexible listening strategies and reflective learning habits, the behavioural spotlight ensures that *CETra* is not merely about perceptual sharpening but also about equipping learners with lifelong skills for self-directed learning, adaptability, and problem-solving – even in completely new and unexpected contexts.

4. Psychoemotional Spotlight: Emotional Engagement as a Catalyst for Learning

The psychoemotional spotlight addresses the interplay between affective responses, motivational states, and auditory listening and learning. Cognitive domains central to this spotlight include attention, memory, creativity, and decision-making, all of which are influenced by emotional engagement. Research has consistently shown that music-evoked pleasure engages the brain's reward circuitry, particularly dopaminergic pathways in the ventral striatum, leading to enhanced motivation and reinforcement of learning (Zatorre et al. 2013a; Blood et al. 2001). Emotional arousal not only sustains attention but also promotes stronger memory consolidation, thereby linking affective engagement directly to the efficiency of ear training (Koelsch 2014). Empirical results from Latvia confirm that psychosocial skills play a greater role for musically gifted pupils than musical training alone, underscoring how affect, motivation, and perseverance influence not only practice but measurable listening abilities (Voitova et al. 2025).

Affective and motivational processes also play an important role in group music-making, where social bonding enhances persistence and enjoyment. Collective music-making, such as choir singing or ensemble performance, has been shown to elevate endorphin release and increase social cohesion (Savage et al. 2020). These positive affective states in turn improve learners' willingness to persist through challenges and regulate their cognitive effort. In the *CETra* framework, leveraging affect is not peripheral but central: emotionally engaging tasks stimulate reward-based learning mechanisms that amplify both the effectiveness and the sustainability of auditory training.

CETra operationalizes these principles through blueprint tasks designed to link perception with affective response. For example, emotion-labelling exercises train learners to detect subtle timbral or microtiming shifts that evoke distinct feelings, while personalized repertoire tasks allow students to work with music that resonates with their own preferences, thereby strengthening intrinsic motivation. This motivational dimension is critical: learners who engage with material that is personally meaningful show higher persistence, deeper processing, and greater long-term retention (Ryan et al. 2020; Evans et al. 2012). Assessment within this spotlight combines subjective and objective measures, including self-reported valence and arousal, persistence indicators such as practice duration, and behavioural performance under stressors (e.g., dictation in noise or under time pressure).

By embedding affect, motivation, and reward into ear training, *CETra* transforms auditory practice into a psychoemotional spotlight – a framework that not only sharpens perceptual acuity but also activates the very emotional and motivational circuits that sustain lifelong musical engagement. Neuroscientific evidence confirms that dopaminergic reward pathways engaged during pleasurable music listening reinforce both learning and habit formation (Zatorre 2013b; Salimpoor et al. 2011). Educational psychology likewise demonstrates that intrinsic motivation fuels resilience, creativity, and sustained effort in skill acquisition (Ryan and Deci 2020). Within *CETra*, these insights converge: emotionally rewarding training experiences generate motivational momentum, which in turn elevates practice quality and consolidates learning. In this way, *CETra* establishes a self-reinforcing cycle where success breeds further success – a virtuous loop fundamental to both musical growth and cognitive development.

5. Neurophysiological Spotlight: Brain Mechanisms and Plasticity in Auditory Learning

The neurophysiological spotlight emphasizes the biological mechanisms that support ear training, with particular attention to how neural systems adapt to the demands of auditory learning. Core cognitive domains include perception, attention, prediction, and expectation, all of which depend on the precision and flexibility of neural coding. Pitch and rhythm serve as especially powerful activators within this system.

A central mechanism is neural phase-locking – the capacity of neurons to synchronize their firing with rhythmic auditory input. Research demonstrates that musicians show enhanced phase-locking in auditory brainstem responses, which supports superior rhythm perception and temporal prediction (Colverson et al. 2024; Wong et al. 2007). This neural synchronization not only enables rhythmic accuracy in music but also facilitates speech processing in noisy environments, underscoring the close relationship between music training and broader auditory cognition.

Another line of evidence highlights cortical tuning to pitch and timbre, which becomes increasingly refined through musical training. Functional imaging studies demonstrate that musicians exhibit sharper frequency tuning in auditory cortex as well as stronger engagement of auditory–motor networks, reflecting the integration of perceptual processing with motor planning (Schlaug et al. 2009; Hyde et al. 2009). These findings underscore the brain's remarkable capacity for plasticity: intensive auditory practice reshapes cortical representations, yielding long-lasting improvements not only in musical performance but also in language-related auditory tasks. This plasticity provides a biological rationale for uniting sound, cognition, and training within a single framework, thereby grounding pedagogical interventions in well-documented neurophysiological processes. Practically, it can be understood as the brain's readiness to reconfigure itself by applying previously acquired knowledge to novel auditory models. At the same time, it must be acknowledged that networks shaped through repetitive pattern training are not easily generalized to new contexts. *CETra* therefore emphasizes a dual approach: stepwise reinforcement that strengthens neural coding through repeated exposure, combined with opportunities for flexible transfer that encourage learners to reapply and reorganize neural resources in unfamiliar auditory environments.

Decades of neuroscientific work show that both structural predispositions and training shape the auditory cortex. A seminal study demonstrated that morphology of Heschl's gyrus is associated with enhanced activation in musicians compared to non-musicians (Schneider et al. 2002). Later, structural and functional asymmetries in the lateral Heschl's gyrus were shown to correlate with pitch perception preferences, such as fundamental versus overtone dominance (Schneider et al. 2005). More recently, a 12-year longitudinal study confirmed that musicians exhibit distinct neuroanatomical dispositions, maturational changes, and robust training-induced plasticity compared to non-musicians (Schneider et al. 2023). Complementary evidence indicates that even short-term active listening training can elicit measurable neuroplastic changes in auditory processing (Schneider et al. 2022).

CETra translates these mechanisms into training tasks such as rhythm oddball paradigms, which require learners to detect deviations in expected rhythmic patterns; beat prediction tasks under tempo jitter, which strengthen predictive coding mechanisms; and polyrhythm switching spatial exercises, which engage both auditory and motor systems in managing complex temporal structures. Evaluation relies on metrics including prediction error rates (how often learners miss deviations), synchronization stability (variability in entrainment to a beat), and switch costs (time or accuracy penalties when changing between rhythmic patterns). By embedding training in tasks that directly engage neural prediction and motor coupling, the neurophysiological spotlight ensures that *CETra* not only develops perceptual skills but also harnesses the brain's biological substrates for lasting auditory and cognitive benefits.

6. Physical Spotlight: Auditory–Motor Integration and Rhythmic Entrainment

The physical spotlight underscores the fundamental role of the body in shaping auditory learning, with pitch and rhythm serving as primary media for bodily activation. These auditory parameters are not merely abstract musical constructs, but dynamic triggers for movement and neural coordination – enabling learners to transform sound directly into embodied experience. Importantly, this spotlight interrogates how rapidly individuals can perceive acoustic information and translate it into movement, as speed of auditory–motor integration critically determines the alignment of perception, prediction, and action.

These embodied processes extend into real-world contexts: bodily engagement with rhythm enhances attention, prediction, and adaptability, contributing to speech segmentation and coordination in social settings. Gerry et al. (2012) found that children who engaged in rhythmic movement while listening show stronger retention of melodies and rhythms. Similarly, adult studies reveal that coordinated movement stabilizes beat perception and improves tempo adaptation (Phillips-Silver and Trainor 2005).

Recent studies add depth to this understanding. For example, low-pitched rhythms significantly stabilize spontaneous movement entrainment compared to high-pitched alternatives, a finding supported by evidence that both pitch and tempo systematically affect the strength and stability of movement synchronization with auditory rhythms (Varlet et al. 2020). Meanwhile, pitch influences the timing of sensorimotor synchronization – suggesting pitch can adjust the perceived timing structure of rhythm itself (Pazdera et al. 2025). Additional evidence shows that entrainment capacity varies across individuals, with some demonstrating more precise auditory–motor synchronization than others – a variability that Mares et al. (2023) trace to both individual traits and acoustic features of the stimuli.

In practical terms, *CETra* operationalizes these insights through tasks such as body-percussion polyrhythms, gait-clapped synchronization, and sensorimotor timing exercises of increasing complexity. These activities not only engage working memory – as learners juggle multiple rhythmic layers – but also accelerate auditory–motor mapping via pitch-guided gesture (e.g., contour-driven movement). Performance is assessed through metrics like movement-beat asynchrony, variability in synchronization consistency, and endurance across challenging tempi.

By weaving physical movement into auditory learning, the physical spotlight ensures that *CETra* leverages embodied cognition – reinforcing auditory precision through motor integration and embedding abstract listening skills in the lived experience of the body.

7. Pedagogical Spotlight: Integrating Cognitive, Emotional, and Social Dimensions in Ear Training

The pedagogical spotlight highlights how *CETra* principles can be systematically embedded into curriculum design, ensuring that the benefits of acoustic, social, behavioural, psychoemotional, neurophysiological, and physical training are integrated into structured educational pathways. Unlike the other spotlights, this one encompasses all eight cognitive domains, since teaching design inherently requires balancing perception, attention, memory, prediction, creativity, decision-making, timing, and motor engagement. Research in adaptive curricula demonstrates that individualized pacing and scaffolded learning pathways yield stronger outcomes than uniform, one-size-fits-all models, aligning with evidence that musical training confers cognitive benefits across the lifespan (Román-Caballero 2023). Within this context, adaptive technologies provide one powerful means of implementation: digital platforms and AI-driven systems enable teachers to calibrate task difficulty dynamically, maintaining learners in an optimal challenge zone that fosters both motivation and measurable growth (Reis et al. 2021).

Evidence also underscores the importance of early sensitive periods in musical training. Longitudinal studies reveal that structured music education in early childhood not only accelerates auditory discrimination but also confers lasting benefits for language development, working memory, and attentional control (Schlaug et al. 2009; Moreno et al. 2009). This suggests that *CETra*-informed curricula should strategically embed auditory-cognitive training from the earliest stages of education. Beyond childhood, curricula remain crucial for older learners and professionals, as spiral models of instruction – where concepts such as rhythm, timbre, and auditory scene analysis are revisited at progressively deeper levels – promote long-term mastery and transfer (Bruner 1960, 12–13, 141). Recent studies in music education reinforce this approach: Fautley and Daubney describe a spiral-based curriculum structured around interconnected strands such as singing, composing, improvising, playing, and critical engagement, all of which are revisited with increasing complexity to support experiential learning (Fautley and Daubney 2019). Similarly, models such as the Swanwick–Tillman spiral emphasize developmental transformations through the repeated revisiting of musical concepts within a growth trajectory (Leveridge 2022; Philpott 2022). Empirical evaluations further show that spiral curriculum designs enhance retention and deepen understanding, with students reporting stronger consolidation and fewer misconceptions when prior knowledge is revisited in structured, layered ways. A spiral curriculum for rhythm, timbre, and auditory analysis ensures recurring engagement with core auditory domains, reinforcing and expanding skills over time. Classroom group entrainment games integrate social and rhythmic learning while supporting attentional and behavioural development. Emerging VR-based spatial listening labs provide immersive environments where learners can train auditory scene analysis and spatial perception in realistic yet controllable contexts (Han et al. 2024).

Longitudinal and cross-sectional research indicates that auditory cortex size and synchronization predict not only musical skills but also literacy and attentional abilities in children (Schneider et al. 2014). The AMseL longitudinal findings (Schneider et al. 2023) support *CETra*'s spiral-curriculum approach, integrating perception, cognition, and emotion across development. Moreover, short-term training studies (Schneider et al. 2022) show how adaptive, individualized methods can quickly enhance auditory discrimination and attention, making the case for personalized ear-training design.

Going one step further, *CETra* can also function as a tool for balancing cognitive resources for learners across diverse fields who face high levels of stress and performance pressure. Research shows that musical engagement reduces stress and enhances resilience, with structured music training lowering performance anxiety and perceived stress in student populations (Nwokenna et al. 2022). These effects are not merely emotional but also cognitive: by strengthening self-regulation, attentional control, and working memory under challenging conditions, musical practice equips learners to maintain cognitive efficiency when demands are high.

CETra can incorporate evidence-based self-control techniques for optimizing cognitive resources under stress. Controlled breathing and rhythmic entrainment have been shown to stabilize physiological arousal (Pozzato et al. 2025) and improve attentional focus (Jha et al. 2007). Mental rehearsal and imagery, widely used in performance psychology, reduce cognitive load by pre-activating relevant neural networks before execution (Lotze et al. 2006). Metacognitive strategies such as self-monitoring and reflective journaling enhance awareness of attentional lapses and support adaptive allocation of effort (Efklides 2011). Cognitive reappraisal – reframing stress as challenge rather than threat – promotes greater working memory efficiency and resilience during demanding tasks (Jamieson et al. 2013).

Success in pedagogical spotlight interventions can be measured using metrics such as course-level mastery paths, which track longitudinal progression across competencies, and standardized listening transfer tests, which assess the extent to which classroom training generalizes to authentic musical and communicative contexts. By uniting evidence-based strategies with scalable instructional design, the pedagogical spotlight ensures that *CETra* is not only a set of isolated practices but a coherent, progressive, and transformative approach to music and cognitive education. These results align with the pedagogical case for explicitly integrating psychosocial skills into music curricula. While traditional programs rarely teach these skills, emerging evidence suggests that systematically cultivating them may substantially support musical giftedness education (Voitova et al. 2025).

Within the pedagogical spotlight, these considerations underscore that *CETra* is not intended as a catalogue of prescriptive exercises but as a conceptual framework. Detailed examples and training protocols are intentionally reserved for future work directed at practitioners and specific learner groups. Here, the aim has been to articulate principles that allow readers and instructors to critically reflect on their current practice, to recognize where traditional approaches converge with *CETra*, and to identify points of divergence.

Illustrative directions highlight this interface. Solmization systems – whether perfect or relative – can be complemented, or in some cases reoriented, toward interval-based labelling, enabling learners to internalize absolute intervallic structures rather than anchoring them solely within a tonal framework. Research suggests that interval-focused encoding fosters more durable auditory schemas and enhances transpositional flexibility (Halpern 1989). Similarly, memorization strategies may shift from reproduction to generative activity: learners might be invited to compose and retain their own melodic material within multi-voice textures, a process shown to deepen memory consolidation and strengthen transfer (Fiorella et al. 2015). Finally, the balance between harmonic and non-harmonic material can be calibrated to the learner's level of experience, consistent with evidence that graded exposure to increasing complexity supports perceptual acuity and cognitive resilience (Bigand et al. 2006).

In this way, the pedagogical spotlight brings *CETra* into dialogue with established practice, while also extending beyond it. This provides a natural bridge to the conclusion, where the broader implications of *CETra* – as both a framework and a reorientation of ear training – can be articulated.

CONCLUSION

Taken together, the spotlight framework illustrates that ear training is not a narrow technical exercise but a multifaceted process grounded in cognitive, emotional, social, and physiological dimensions. It is important to broaden and enrich ear training by respecting all of these perspectives. For example, beginners benefit from being given time to explore the qualities of sound in diverse musical contexts, fostering curiosity and perceptual sensitivity before more advanced technical demands are introduced. Psychoacoustic training sharpens attention to detail, while social and behavioural approaches cultivate adaptability, collaboration, and reflective practice. Psychoemotional strategies ensure that motivation and affect remain central to sustained engagement, whereas neurophysiological and physical spotlights remind us that listening is embodied, predictive, and deeply rooted in brain–body networks. Finally, the pedagogical spotlight highlights the importance of curriculum design in weaving these strands together across developmental stages, from early childhood through professional musicianship.

The philosophy that emerges from this framework is that ear training must balance structure with exploration, discipline with creativity, and technical precision with emotional resonance. At its core, the most important element is the circulation between gaining knowledge and experiencing pleasure: progress in auditory skills should generate aesthetic enjoyment, and that enjoyment, in turn, fuels further learning. Effective practice strategies should therefore target not only measurable outcomes such as accuracy or memory retention but also the cultivation of joy, attentional flexibility, resilience, and cooperative listening. By uniting evidence-based methods with an openness to cultural diversity, embodied practice, and evolving technologies, *CETra* establishes a holistic model of ear training – one that prepares learners not only to master musical repertoire but also to listen, interact, and create with greater depth, imagination, and satisfaction throughout their lives.

Ultimately, *CETra* demonstrates that ear training is not merely a narrow exercise in technical listening, but a gateway to broader cognitive development and enriched communication. It reframes ear training from a specialized drill into a dynamic, integrative model of human learning. By aligning knowledge with pleasure, precision with creativity, and discipline with social and emotional engagement, *CETra* outlines a path for twenty-first-century music education. As research continues to refine its methods and document transfer effects, *CETra* is positioned to play a pivotal role in bridging music, neuroscience, and education – ensuring that ear training produces not only skilled musicians but also more attentive, adaptive, and connected human beings. Above all, *CETra* remains inherently open to interdisciplinarity, inviting dialogue across fields and reaffirming music education as a site of innovation, integration, and cognitive growth.

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