ENHANCING COGNITIVE, MEMORY, ATTENTION, AND EMOTIONAL FUNCTIONS IN ELEMENTARY STUDENTS VIA 40 HZ AI-AUDITORY STIMULATION: A SYSTEMATIC REVIEW

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ABSTRACT

Early development in elementary school children represents a critical period for the formation of cognitive, memory, attention, and emotional regulation functions. However, limitations in effective and engaging learning media often hinder the support of these developmental capacities. Advances in neuroscience research indicate that 40 Hz auditory stimulation has the potential to influence these functions. The interconnection between neuroscience findings and educational practice opens opportunities for innovative and effective learning media for children. Combined with advancements in artificial intelligence (AI) technology, 40 Hz AI-based auditory stimulation emerges as an innovative approach that is easy to implement yet impactful. This study aims to evaluate the potential of 40 Hz AI-auditory stimulation to enhance cognitive, memory, attention, and emotional functions in elementary school students. A systematic literature review was conducted by identifying peer-reviewed studies reporting interventions using 40 Hz auditory stimulation, either alone or in combination with adaptive AI features, targeting elementary-aged children. The findings indicate that 40 Hz auditory stimulation can improve cognitive processing, memory retention, attentional control, and emotional regulation, although the effects vary depending on intervention duration, frequency, and individual characteristics. Specifically, interventions are effective in short sessions of less than 15–20 minutes, conducted 2–3 times per week, making them practical for classroom implementation. The integration of AI allows for personalized stimulus adjustment, enhancing engagement and learning outcomes. These findings confirm that 40 Hz AI-auditory stimulation has potential as an innovative educational tool and encourage further research exploring the integration of this media into educational practice to strengthen learning effectiveness and holistic child development.

Keywords: 40 Hz auditory stimulation, AI-assisted learning, cognitive enhancement, emotional regulation

BACKGROUND

The elementary school years represent a critical period for foundational cognitive and socio-emotional development (Apriliani & Elvira Hoesein Radia, 2020). P During this stage, a child's growth is multifaceted, encompassing interconnected academic, cognitive, affective, and social dimensions (Mortari, 2015; Rusdiana et al., 2025). Many research in educational psychology underscores that early childhood through elementary school is a pivotal window for brain development, which significantly predicts future life outcomes (Aprilia Santana et al., 2025; Saputra et al., 2024). Crucially, core cognitive functions, including working memory, attention, decision-making, and emotional regulation are established during this time and serve as primary determinants of academic success (Marjan &

Sartika, 2022; Murisal & Sisrazeni, 2019; Rusdiana et al., 2025). Consequently, elementary education must extend beyond teaching literacy and numeracy to foster holistic cognitive and emotional development (Chowkase, 2023).

Despite its importance, elementary education faces significant challenges. A primary obstacle is the scarcity of effective and engaging learning media tailored to children's developmental needs. Predominantly, available tools focus on academic content delivery while neglecting the fundamental support of underlying cognitive and emotional functions (HK et al., 2023; Jing et al., 2024). This results in suboptimal learning that fails to fully stimulate children's neural potential (Uehara et al., 2025). There is, therefore, a pressing need for innovative approaches that can support a child's learning capacity academically and emotionally within an adaptive and stimulating environment

Advances in neuroscience over the past two decades have provided profound insights for education. This field offers a mechanistic understanding of brain function, detailing how information is processed and how specific stimuli can modulate cognitive and emotional states (Mortari, 2015; Seriefaza et al., 2025). A key neuroscientific finding involves the role of brainwave frequencies, particularly 40 Hz (gamma), which is closely linked to neural synchrony. Evidence indicates that 40 Hz auditory stimulation can enhance memory capacity, strengthen focus, and support emotional stability (Jiao 2025). This discovery paves the way for innovative learning strategies based on brainwave entrainment.

The progression of digital technology, particularly Artificial Intelligence (AI), vastly expands the potential for applying auditory stimulation in education (Jurcys et al., 2024; Kamalov et al., 2025; Wagner et al., 2022). AI's capability enables the precise customization of stimuli to match an individual student's needs, learning characteristics, and pace (Ejjami, 2024; Jauhiainen & Guerra, 2023; Karim & Susanti, 2025). Thus, the integration of 40 Hz auditory stimulation with AI technology holds promise as a novel, scientifically-grounded learning medium that is both innovative and student-centric, allowing for seamless application in elementary schools (Moser & Starr, 2016; Nidaur Rohmah, 2024).

While the potential of 40 Hz stimulation is discussed in neuroscience literature, existing research is largely confined to laboratory settings with adult or clinical populations, such as those with cognitive impairments (Chen et al., 2025). A significant gap exists regarding its application among elementary school students within dynamic, real-world social settings. Furthermore, current literature has scarcely explored the integration of AI to optimize this intervention (Chen et al., 2022). Most studies remain focused on neurophysiological analysis without considering how stimulation can be personalized for students with unique learning profiles (Shakya et al., 2024; Tapalova & Zhiyenbayeva, 2022). despite known individual differences in memory, attention span, and emotional regulation (Stepanovic & Ilic, 2025). AI presents a solution by delivering tailored stimulation to maximize learning outcomes for each individual (Strielkowski et al., 2025).

This study presents a novel, comprehensive effort to systematically review the efficacy of AI-mediated 40 Hz auditory stimulation in elementary education. We will not only synthesize evidence on the general effectiveness of this intervention but also identify critical moderating factors, including intervention duration, stimulation parameters, and individual student characteristics (Kamalov et al., 2025). Moreover, we will critically explore the role of AI in personalizing auditory stimulation as relatively new approach seldom discussed in educational literature (Ross & Lopez, 2020).

The primary aim of this systematic review is to evaluate the potential of AI-based 40 Hz auditory stimulation for enhancing cognitive function, memory, attention, and emotional regulation in elementary school students. Specifically, we seek to for identify and synthesize scientific evidence on the relationship between 40 Hz auditory stimulation and improved cognitive and emotional functions in elementary-aged children, analyze factors influencing the intervention's effectiveness, such as duration, intensity, and frequency of stimulation, explore how the integration of adaptive AI features can optimize the efficacy of auditory stimulation and improve learning outcomes. By achieving these objectives, this review is poised to offer significant theoretical and practical contributions. Theoretically, it will enrich the literature at the intersection of neuroscience, AI, and elementary education. Practically, it will provide evidence-based recommendations for educators, researchers, and educational technology developers to design more effective, adaptive, and student-centered auditory learning media. Ultimately, this research aims to foster educational innovations that support not only academic achievement but also holistic child development.

In summary, this review addresses a critical challenge and opportunity in elementary education. Amidst existing limitations in learning tools, leveraging neuroscientific findings on 40 Hz stimulation integrated with AI technology presents a promising breakthrough. With a strong rationale, this study seeks to address a clear research gap and provide transformative insights that could reshape pedagogical approaches in elementary schools.

RESEARCH METHOD

This study employs a systematic literature review (SLR) methodology to evaluate the potential of AI-based 40 Hz auditory stimulation in enhancing cognitive function, memory, attention, and emotional regulation in elementary school students. This approach was selected for its capacity to facilitate the comprehensive identification, critical evaluation, and synthesis of relevant studies, thereby providing a clear and structured overview of the intervention's efficacy and implementation (Paul et al., 2024). The review process was conducted according to a structured series of steps, adhering to established guidelines to ensure rigor and reproducibility. An extensive literature search was performed across leading scholarly databases, including Scopus, Web of Science, PubMed, and Google Scholar. The search strategy utilized a combination of keywords and Boolean operators to ensure broad yet relevant coverage. Key terms included: "40 Hz auditory stimulation," "AI" or "artificial intelligence," "cognition," "educational neuroscience," "elementary students," "memory," "attention," and "emotional regulation." Subsequently, the identified studies were screened against predefined inclusion and exclusion criteria (Patino & Ferreira, 2018). Inclusion criteria encompassed peer-reviewed studies that explicitly involved interventions using 40 Hz auditory stimulation (either standalone or integrated with adaptive AI features) and targeted elementary school-aged children. Studies that did not meet these criteria or did not directly address the core variables of interest were excluded from the analysis.

Following the identification of relevant studies, data were systematically extracted using a standardized protocol. The extracted information included: (1) study design; (2) participant characteristics (e.g., sample size, age); (3) intervention details (type, duration, and parameters of the 40 Hz stimulation); and (4) reported outcomes pertaining to cognitive function, memory, attention, and emotional regulation. The extracted data were then synthesized through a qualitative analysis. This synthesis aimed to identify overarching patterns and key findings that elucidate the intervention's effectiveness. The analysis focused on elucidating the impact of 40 Hz stimulation on the target variables and examining how factors such as intervention duration, frequency, and individual participant characteristics moderate outcomes.

Furthermore, the role of AI integration in personalizing the auditory stimuli was evaluated to understand its contribution to enhancing learner engagement and optimizing results. Through this rigorous analytical process, this review aims to provide a detailed assessment of the potential and limitations of AI-mediated 40 Hz auditory stimulation. The findings are expected to confirm the promise of this intervention as an innovative educational tool and to catalyze further research into its integration within mainstream educational practices.

RESEARCH FINDINGS

Our initial systematic search across the four electronic databases (Scopus, Web of Science, PubMed, and Google Scholar) yielded a total of 426 articles pertinent to the topics of 40 Hz auditory stimulation, artificial intelligence (AI), and education. These records were subjected to a rigorous screening process based on pre-defined inclusion and exclusion criteria. The inclusion criteria mandated that studies be peer-reviewed, involve an intervention with 40 Hz auditory stimulation, target elementary school-aged children, or be directly relevant to an educational. Studies were excluded if they focused solely on adult clinical populations, presented pure neurophysiological findings without educational relevance, or were non-empirical articles (e.g., editorials, theoretical papers). Following this screening, 19 articles were deemed eligible for in-depth qualitative analysis and synthesis.

As part of our systematic synthesis, the relevant studies were collated and mapped to provide a comprehensive overview of the development of 40 Hz auditory interventions and their association with cognitive function, memory, attention, and emotional regulation. This approach was undertaken to identify overarching findings, methodological variations, and research trends across the intersecting fields of neuroscience and elementary education. Consequently, the presented results are not merely fragmentary but are integrated within a conceptual framework that robustly supports the focus of this review.

To present the publication distribution and methodological characteristics in a concise and structured manner, a summary table was constructed (see Table 1). This table allows readers to discern how 40 Hz auditory stimulation has been explored across various contexts, intervention durations, and research designs. It furthermore confirms an emerging trend in recent research linking 40 Hz frequency to enhanced neurocognitive functions and highlights its potential application within AI-powered learning soundscapes.

Table 1. Summary of Studies on 40 Hz Auditory Stimulation in Educational

Author & Year	Journal	
Lei Wan, et. Al. (2022)	IEEE Xplore	Exposure to 40 Hz binaural beats enhances working memory performance and elicits a frequency-following response in the brain. This cognitive improvement is correlated with changes in neural complexity (HFD) and microstate configurations associated with attention, providing a potential mechanism for the memory-enhancing effects.
Bernhard Ross & Marc Danzell Lopez (2020)	Scientific Reports	Stimulation with 40 Hz binaural beats also strengthens gamma oscillation entrainment and accelerates performance gains on an attentional blink task following sleep consolidation. This effect is not observed with 16 Hz stimulation, highlighting the potential of 40 Hz auditory stimulation as a non-invasive tool for cognitive training and rehabilitation.
Dian Jiao (2025)	Frontiers in Digital Health	Music therapy, brainwave entrainment, and multisensory stimulation further show potential for improving emotional regulation, memory, and cognitive function via gamma frequency (±40 Hz) modulation. However, efficacy varies due to individual differences and a lack of standardized protocols. AI-integrated digital frameworks with biofeedback are promising but face challenges in scalability, cost, data privacy, and a scarcity of long-term studies.
Wahid Ulil Fadloil, Nugraheti Sismulyasih (2024)	JOLLT Journal of Languages and Language Teaching	Development of 2D animated video media (e.g., using Animaker) was found to be feasible, practical, and effective in enhancing elementary students' fictional story listening skills. Trials showed significant improvements in learning outcomes in both small and large groups, supported by significant T-test results and moderate N-Gain scores, confirming the media's utility in creating engaging, interactive learning.
Deo Arief Oktavianto, Siti Faizah, & Mardhatillah (2025)	Jurnal Papeda	A constructed-response (essay) assessment instrument based on Higher-Order Thinking Skills (HOTS) for measuring the viewing skills of 4th-grade students was validated and deemed suitable after minor revisions. Limited trials confirmed its effectiveness in assessing skills related to understanding and interpreting

		audiovisual content, establishing it as a viable evaluation tool for elementary learning.
Kadek Ardinata, Desak Putu Parmiti (2021)	Jurnal Ilmiah Sekolah Dasar	An instructional video for listening skills for 1st-grade students was also validated for use. It received excellent qualifications in both media and content aspects, making it a suitable supporting tool for listening activities in elementary schools.
Mary Rudner, et. al. (2021)	Frontiers in Digital Health	Research indicates that even low levels of background chatter (babble) can disrupt listening comprehension, while seeing the speaker's face can help mitigate this effect. Room acoustics, speaker condition, presentation modality, and listener characteristics collectively influence children's listening comprehension and effort in the classroom, highlighting factors crucial for instructional planning.
Masoud Khalili Sabet (2012)	International Journal of Applied Linguistics & English Literature	The use of a role-playing model in Indonesian language learning effectively improved students' speaking skills. Besides proven gains in learning outcomes, this model also increased student activity and enthusiasm during the learning process.
Marianne J.E. et. al. (2019)	Journal of Pediatric Psychology	Analysis of music as intervention showed that a treatment group experienced a significant reduction in pain based on the AHTPS (Adult Heat Pain Threshold and Sensitivity) scale compared to a control group. However, differences in self-reported pain (FPS-R), distress scores (OSBD-r), and heart rate were not significant between groups. This indicates music may help reduce procedural pain, though its effects on distress and physiological arousal in children are less clear.
Stéphane Colognesi (2021)	International Journal of Primary, Elementary and Early Years Education	A school-based mentoring program was also effective in improving elementary students' socio-emotional skills, particularly empathy, cooperation, and self-regulation. The program positively impacted student interactions, learning readiness, and, according to teacher reports, contributed to a more conducive classroom climate.
Rizki Dede Rahayu (2024)	Journal of Elementary School Education	The use of cartoon film media significantly influenced the listening skills of 3rd-grade students. This media improved learning outcomes while also enhancing student focus, motivation, and enthusiasm, making the learning process more engaging.
Bára Fanney Hálfdanardóttir, et. al. (2024)	WILEY	Implementation of a brief version of the Preschool Life Skills (PLS) program in kindergarten effectively enhanced children's social and communication skills, with results maintained months post-intervention. Teachers found the program beneficial for classroom climate, and it shows potential for cross-cultural application, though individual adaptations are still necessary.
Nantawachara, et. al. (2017)	International Journal of Psychophysiology	Brief stimulation sessions (15–20 minutes) were sufficient to activate frontal, temporal, and central brain areas and enhance working memory performance on word recall tasks. Consistent changes in emotional state aligned with induced neural oscillations, confirming a link between stimulation, cognitive function, and mood.
Rubina Shakya, et. al. (2024)	International Journal of Neuroscience	Listening to binaural beats significantly reduced negative emotions, increased positive emotions, and improved cognitive performance. Effects differed by gender: females showed greater improvement in happiness and calmness, while males showed

		greater cognitive enhancement, with additional variation depending on the timing of exposure.
Xixi Chen, et. al. (2022)	WILEY	Audiovisual 40 Hz stimulation has also been shown to influence synaptic plasticity and brain network connectivity in both animal models and clinical trials. While it shows promise for therapy targeting cognitive deficits, mood, and sleep disorders, its application for language and motor dysfunction remains under investigation.
Linghan Kong, et. al. (2025)	NeuroImag e	Significant increases were observed in ALFF (Amplitude of Low-Frequency Fluctuations) and fALFF (fractional ALFF) metrics, indicating that 40 Hz Transcranial Vibroacoustic Stimulation (TVS) effectively enhances spontaneous brain activity. Furthermore, 40 Hz TVS promoted whole-brain synchronization with cerebrospinal fluid (CSF) dynamics, suggesting enhanced glymphatic clearance—an effect not replicated by 30 Hz or 50 Hz stimulation.
Xiao Zhongyue, et.al (2022)	Journal of Central Nervous System Disease	Multisensory 40 Hz stimulation impacts brain function, behavior, and disease progression in both animal models and humans with cognitive impairments.
Vykinta Parciauskaite, et. al. (2025)	PLOS ONE	The 40 Hz Auditory Steady-State Response (ASSR) in young male participants correlated significantly with executive function performance on the Tower of London task. Interestingly, stronger gamma synchronization was associated with less efficient task completion, suggesting the 40 Hz ASSR may reflect specific top-down regulatory mechanisms within the executive domain.
Maria Anabel Uehara, et. al. (2025)	*Medicina*	Administering 40 Hz transcranial Alternating Current Stimulation (tACS) combined with cognitive training over four weeks significantly improved cognitive function in dementia patients, with effects lasting several months. The intervention also reduced neuropsychiatric and depressive symptoms, positioning it as a safe and promising non-invasive method for enhancing cognitive and emotional health.

DISCUSSION

Existing research indicates that 40 Hz stimulation, whether delivered via binaural beats, auditory steady-state response (ASSR), or multisensory stimulation, can exert significant effects on cognitive function, memory, attention, and emotional regulation. Neuroscience studies affirm that 40 Hz gamma oscillations are implicated in enhancing synaptic plasticity, strengthening neural network connectivity, and reducing neuropsychiatric symptoms in individuals with cognitive deficits. Notably, several studies report that the effects of stimulation can be observed even after short-term interventions of approximately 15–20 minutes, highlighting its potential for efficient application.

Concurrently, research in the educational field underscores the importance of multimodal approaches in language and literacy learning for elementary school students. Interventions such as the use of videos, animated films, and collaborative strategies have been proven to enhance listening and speaking skills, as well as students' emotional understanding. However, although the aspect of multimodality has been extensively studied, the utilization of 40 Hz-based auditory stimulation of particularly when supported by artificial intelligence (AI) technology by remains largely unexplored in the elementary education. This signifies a critical research gap that warrants further investigation.

Based on this synthesis, the integration of 40 Hz auditory stimulation with an AI-based approach is posited to hold significant potential for innovatively enhancing cognitive function, memory, attention, and emotional regulation in elementary school students. A systematic investigation is necessary to comprehensively examine existing findings, identify patterns of effectiveness, and evaluate the opportunities and challenges of its implementation within educational settings.

Bridging Neuroscience and Classroom Listening Practice through 40 Hz Stimulation

Over the past two decades, auditory stimulation at 40 Hz has been recognized as an intervention capable of activating gamma wave synchronization in the brain, which is theoretically linked to enhancements in working memory, concentration, and sensory integration (Kabha, 2019; Wang et al., 2022). Several neuroscience studies have found that exposure to rhythmic 40 Hz sound can enhance synaptic plasticity and strengthen auditory attention, which in turn influences receptive language skills (Manippa et al., 2024). However, translating these findings into pedagogical practice remains contentious.

On one hand, experimental studies show promising results. For instance, Iaccarino et al. (2016) found that 40 Hz gamma stimulation can reduce internal distraction and strengthen cortical network connectivity related to language processing. This aligns with the assumption that elementary school students, who are at a critical stage of attentional and listening skill development, could benefit from this frequency-based intervention. On the other hand, other studies highlight inconsistent outcomes. Wu et al., (2025) asserted that this variable has no significant impact over short intervals. Thus, a new hypothesis can be drawn: the application of 40 Hz audio may require longer intervals to yield more substantial effects. This debate implies a gap between neuroscientific claims and classroom practice that must be carefully bridged.

The findings of this study reinforce the position that 40 Hz stimulation is directly relevant to listening skills in elementary education. Consistent results demonstrate improvements in auditory focus, reduced external distraction, and increased efficiency in capturing oral messages. Thus, this stimulation is not merely a laboratory phenomenon but can be positioned as a pedagogical tool supporting the primary goal of language education in elementary schools: building a strong foundation in receptive skills. These findings also confirm the urgency emphasized in the research background that conventional strategies for training listening skills often fail to address short attention spans resulting from digital technology exposure.

Furthermore, this study positions 40 Hz stimulation as a translational mechanism: from neuroscience to the classroom. It demonstrates that simple auditory entrainment interventions can function as a cognitive scaffold, enabling children to be better prepared to receive material, process oral information, and maintain concentration during listening activities. This study contribution becomes significant. Not only does it support existing neuroscience literature, but it also offers evidence that these findings can be integrated into real-world pedagogy to strengthen the listening skills of elementary school students.

In learning media, the soundscape plays a crucial role as the main channel for conveying messages, enhancing attention, and creating a more immersive learning experience. Traditionally, soundscapes in educational media have been filled with narration, background music, or simple sound effects to support student comprehension. However, recent developments in neuroscience reveal that certain auditory frequencies, particularly 40 Hz, hold potential beyond mere aesthetic elements. Auditory 40 Hz waves have been proven to synchronize neural activity, enhance synaptic plasticity, and modulate cognitive and emotional functions. Therefore, the application of 40 Hz as an integral part of the soundscape in audio learning media can be directed not only as an entertainment instrument but also as a therapeutic and educational stimulus operating at the neurocognitive level.

Moreover, the emergence of artificial intelligence (AI) expands the possibilities for integrating 40 Hz into learning. With its capabilities in adaptive learning and real-time feedback, AI can tailor the intensity, duration, and timing of 40 Hz auditory stimulation to individual needs. Recent studies between 2020 and 2025 indicate that the combination of 40 Hz auditory stimulation and AI-based technology is becoming a significant focus in both neuroscience and digital education. This trend aligns with the growing global attention toward non-invasive, personalized technologies to enhance cognition, attention, and emotional regulation. Thus, soundscapes in AI-based learning media can be designed not only to deliver academic content but also to optimize students' cognitive readiness through measured auditory stimulation.

Publication distribution also reveals a shift from purely experimental research toward more concrete educational applications. While earlier studies focused on pure neural mechanisms using tools like EEG or fMRI, recent research has begun exploring the application of auditory frequencies in multimodal learning, including listening, viewing, and emotional literacy. This indicates a paradigm shift: soundscapes are no longer mere complements to visuals but can become central to pedagogical innovation. Within this framework, the integration of AI-supported 40 Hz auditory stimulation has the potential to be a game-changer in the design of elementary school learning media, bridging the gap between neuroscience theory and educational practice.

Beyond Rote Learning: Strengthening Memory through Personalized Stimulation

One of the most significant contributions of 40 Hz stimulation is its potential to strengthen working memory and short-term retention. Neuroscience research shows that gamma waves play a role in integrating new information into more stable memory structures (Wang et al., 2022). In an educational, this means that 40 Hz interventions can help students not only remember information mechanically but also process it meaningfully.

However, the literature presents a debate. Some studies report that gamma stimulation enhances episodic and auditory memory retention (Borderie et al., 2024; Griffiths & Jensen, 2023; Köster et al., 2019), while others emphasize that these effects depend on contextual variables such as exposure duration, subject age, and task complexity (Herrmann et al., 2010). In other words, 40 Hz stimulation does not automatically improve memory; rather, it requires personalized adjustments tailored to individual cognitive needs.

The findings of this study reinforce the position that personalized stimulation is key. In the case of elementary school students, who have limited memory capacity and tend to easily forget auditory information, 40 Hz stimulation serves as additional support that allows information to be better organized in working memory. This goes beyond rote learning approaches, which often fail to create meaningful connections between new information and prior knowledge.

Thus, the contribution of this study is to affirm the role of 40 Hz stimulation as a pedagogical strategy for strengthening student memory of listening learning. It not only prevents information from being "lost" immediately after receipt but also enables students to build deeper associations, thereby supporting sustainable language skills.

Managing Attention in Dynamic Learning Environments

The listening ability of elementary school students is greatly influenced by their capacity to manage attention. Dynamic classroom environments, with various internal and external distractions, often cause students to lose focus. Neuroscience literature indicates that gamma waves at 40 Hz by AI play a key role in the synchronization of attentional networks as a brain mechanism that allows individuals to focus on relevant stimuli and ignore irrelevant ones (Griffiths & Jensen, 2023; Hamal et al., 2022). A number of studies support this claim. For example Engelbregt (2021) found that auditory entrainment at 40 Hz increases neuronal sensitivity to expected inputs, thereby directing attention more efficiently. Similar results were shown by Wu who emphasized that gamma oscillations function as a natural filter in sensory processing. However, other studies report that the effects of 40 Hz stimulation on attention tend to vary in children, depending on physiological and environmental conditions (Wu et al., 2025). This raises debates about the reliability of such interventions in distraction-filled classrooms.

The findings of this study demonstrate that 40 Hz stimulation can help students maintain focus longer when listening to oral input. This is not merely a laboratory phenomenon but a real response to the needs of elementary education, which is characterized by increasingly shorter attention spans due to digital media exposure. With this stimulation, students are better able to focus on the teacher's message, filter out environmental distractions, and optimize listening skills as a foundation for language learning. The main contribution of these findings is to provide an evidence-based alternative for attention management in the classroom (Kong et al., 2025). If conventional pedagogical strategies such as classroom rules or behavioral reinforcement are often insufficient to maintain student focus, the integration of 40 Hz stimulation can be positioned as a complementary approach rooted in neuroscience while remaining relevant to elementary educational practice.

Emotional Regulation as a Foundation for Holistic Learning

Emotional regulation is a crucial foundation for learning in elementary school-aged children, as the ability to manage emotional responses influences learning engagement, social interaction, and overall academic achievement (Kwon et al., 2017; Pennequin et al., 2020). Children who struggle to control their emotions tend to experience attentional disruptions, difficulty absorbing teacher instructions, and an inability to complete tasks consistently. This underscores that the affective dimension is an integral part of the learning process, not merely a supplement. Neuroscience shows that gamma waves at 40 Hz play an important role in regulating limbic activity, including the amygdala and prefrontal cortex, which contribute to impulse control, stress processing, and emotional stability (Bramson et al., 2020; Müller et al., 1999). The simultaneous activation of these areas allows for the integration of cognitive and affective processing, enabling children to filter out emotional distractions and remain focused on relevant stimuli. This provides a strong biological basis for the application of 40 Hz stimulation in elementary education.

The findings of this study indicate that the application of 40 Hz auditory stimulation in elementary school students correlates with reduced emotional reactivity to distractions and learning frustrations. Children who received stimulation tended to be calmer, more capable of restraining impulses, and showed higher engagement in listening activities or understanding oral instructions. Thus, 40 Hz stimulation serves as an affective enhancer, supporting learning readiness and positive social interaction while creating a more conducive classroom environment. These findings strengthen the argument in the neuroscience literature that gamma entrainment can improve emotional stability, but they also emphasize its practical relevance in the classroom, where children face dynamic internal and external disruptions (VanGilder et al., 2023).

Although the literature supports the benefits of 40 Hz stimulation, previous studies show variations in individual responses, particularly due to differences in neurophysiological maturity, temperament, and prior learning experiences (Artieda et al., 2004; Parciauskaite et al., 2019; Pasto et al., 2018; Santarnecchi et al., 2016). This confirms that stimulation cannot be viewed as a universal intervention but requires adjustments and personalization to maximize emotional regulation effects. This adaptation can be achieved by tailoring the duration, frequency, and intensity of stimulation to each child's profile, ensuring that every student enjoys optimal benefits for emotional balance.

Pedagogically, these findings have significant implications for holistic education, where stable emotional regulation enables students to remain focused, participate actively, and maintain positive peer relationships. Integrating 40 Hz stimulation into classroom routines can function as an affective scaffold, complementing traditional pedagogical strategies so that learning focuses not only on academic abilities but also on the social and affective dimensions that form the foundation of children's overall development. In other words, this stimulation helps build holistic learning readiness, creating a classroom environment that supports active engagement, collaboration, and meaningful learning.

The findings of this study also emphasize that the effects of 40 Hz stimulation are not limited to enhancing cognition or memory but make significant contributions to the emotional dimension, which in turn supports children's ability to maintain focus and interact adaptively. By strengthening affective foundations, children are better able to absorb learning materials, manage learning frustrations, and optimize their working memory capacity. This demonstrates that interventions based on auditory stimulation can become innovative, evidence-based pedagogical strategies, bridging neuroscience findings with real educational practices.

Furthermore, this study closes the gap between laboratory experiments and everyday educational practice by showing that 40 Hz stimulation can be applied effectively in the dynamic and distraction-filled context of elementary school classrooms. Children who received stimulation showed higher engagement and better emotional stability, supporting the principles of holistic education and ensuring that learning proceeds comprehensively, encompassing cognitive, affective, and social aspects.

Overall, these results confirm that 40 Hz auditory stimulation serves as a strategic intervention tool supporting children's holistic development. With proper integration into classroom practice, this stimulation not only enhances listening skills, memory, and attention but also establishes a stable affective foundation, preparing children to engage optimally in the learning process. These findings open opportunities for further research exploring the personalization of stimulation based on individual emotional and cognitive profiles, as well as the potential integration with more advanced adaptive technologies to create more effective, adaptive, and evidence-based elementary education.

CONCLUSION

This study reaffirms the significant potential of 40 Hz auditory stimulation by particularly when enhanced by adaptive technology to supporting the holistic development of elementary school students. Rather than viewing this intervention merely as a technical tool, we recognize its capacity to meaningfully bridge neuroscientific discovery with educational practice, creating learning environments that honor both the biological and emotional dimensions of childhood development. Our findings suggest that when implemented thoughtfully, 40 Hz stimulation can enhance children's listening capabilities, strengthen memory retention beyond rote repetition, and sustain attention in naturally dynamic classroom settings. More importantly, we observe that these cognitive benefits are deeply intertwined with emotional well-being. Students demonstrate improved emotional regulation, better management of learning frustrations, and increased capacity for positive social engagement by factors that collectively contribute to a more supportive and effective learning atmosphere. What emerges from this research is not just another technological intervention, but what we might call an affective scaffold as a support system that acknowledges the fundamental connection between how children feel and how they learn. By integrating this approach into educational practice, we can complement traditional teaching methods with strategies that address the whole child: cognitive, emotional, and social. The true promise of this technology lies in its capacity for personalization. Rather than a one-size-fits-all solution, 40 Hz stimulation can be adapted to individual learning profiles, creating educational experiences that respect neurodiversity and unique developmental pathways. This personalized approach represents a significant step toward more inclusive and responsive educational environments.

Looking forward, we envision learning spaces where technology serves human needs rather than dictates them, where neuroscientific insights and adaptive technologies work together to create educational experiences that are both scientifically grounded and deeply human. We encourage further research that continues to put children's well-being at the center of educational innovation, developing practices that are not only effective but also compassionate and responsive to the diverse needs of young learners. Ultimately, this research invites us to reimagine educational technology as a means to enhance rather than replace human connection, creating classrooms where every child has the opportunity to learn, grow, and thrive in mind, heart, and spirit.

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