

Paper Type: Original Article

Binaural Beats at the Crossroads of Computer Science and Ethics: From Audio Processing to Digital Drugs

Eman Sayed ^{1,*} 

¹ Department of Decision Support, Faculty of Computers and Informatics, Zagazig University, Harayah Raznah, Zagazig 44519, Sharqiyah, Egypt; essayed@fci.zu.edu.eg.

Received: 05 Dec 2024

Revised: 03 Feb 2025

Accepted: 12 Jun 2025

Published: 16 Jun 2025

Abstract

The emergence of digital drugs, particularly in the form of binaural beats, has drawn increasing attention across neuroscience, psychology, and computer science. These auditory stimuli are marketed for their potential to modulate mood, enhance cognition, and support non-pharmacological therapeutic interventions. While some empirical studies suggest effects on brainwave activity and emotional regulation, the scientific evidence remains inconsistent, and the sociotechnical implications are not yet well understood. Binaural beats occupy a unique position at the intersection of algorithmic audio processing, consumer wellness, and digital media environments, where their use is often promoted without adequate regulatory oversight or ethical guidance. This survey brings together interdisciplinary perspectives to examine the current state of research on binaural beats and their classification as digital drugs. It reviews technical foundations in audio synthesis and neural entrainment, analyzes psychological and clinical studies, and explores usage trends across cultural and digital contexts. In doing so, it identifies key gaps in empirical validation, demographic profiling, and content moderation practices. The paper also discusses the role of algorithmic recommendation systems in shaping user exposure and proposes directions for ethical decision-support mechanisms. By integrating insights from computer science, cognitive neuroscience, and digital policy, this survey provides a comprehensive foundation for understanding both the potential and the risks of binaural beats in contemporary digital ecosystems.

Keywords: Digital Drugs; Binaural Beat Consumers; i-dosing; Neural Entrainment; Recreational Simulated Experience; Binaural Innovation and Auditory Stimulation; Neuroscience.

1 | Introduction

Binaural beats are auditory perceptual phenomena that occur when two pure tones with slightly different frequencies are presented separately to each ear [20, 21]. The listener perceives a rhythmic third tone equal to the frequency difference between them, which is generated through neural integration in the auditory pathway. While originally studied within psychoacoustics and cognitive neuroscience, binaural beats have become increasingly prominent in consumer-facing digital products marketed for focus, relaxation, sleep enhancement, and emotional regulation. This commercial and cultural repurposing has led to the term "digital drugs," a label used to describe non-pharmacological, audio-based methods aimed at producing altered psychological states. Though the term lacks clinical precision, it reflects a growing public perception of binaural beats as tools capable of simulating some of the effects associated with psychoactive substances.



Corresponding Author: essayed@fci.zu.edu.eg



<https://doi.org/10.61356/j.mawa.2025.7562>



Licensee **Multicriteria Algorithms with Applications**. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0>).

The popularity of binaural beats has surged due to their accessibility on digital platforms [5], including wellness apps, streaming services, and social media. This surge has drawn attention from multiple research communities. Neuroscientists investigate how binaural beats affect brainwave patterns through mechanisms such as entrainment [10, 16]. Psychologists explore their potential to influence attention, anxiety, or mood [6]. Computer scientists analyze the algorithms and synthesis techniques used to generate beat signals, as well as the recommender systems that surface such content to users. At the same time, ethicists and digital policy researchers are beginning to examine the unregulated dissemination of binaural beat content, particularly as it relates to platform accountability, vulnerable users, and evidence-informed health communication.

Despite this cross-disciplinary interest, the literature on binaural beats remains fragmented across domains [13]. Studies vary widely in methodological rigor, target outcomes, and interpretation of results. There is a lack of standardization in how binaural beats are synthesized, delivered, and tested, and a noticeable gap in reviewing how such technologies intersect with digital recommendation systems and behavioral exposure. No existing survey to date provides a comprehensive overview that integrates the technical underpinnings of binaural beats with their clinical claims, user behaviors, and ethical risks in a unified framework.

This survey addresses that gap by synthesizing peer-reviewed research across neuroscience, computer science, and digital ethics. It explores the technical foundations of binaural beat synthesis, reviews empirical evidence of their cognitive and psychological effects, and examines their diffusion through algorithmically mediated platforms. The remainder of the paper is structured as follows. Section 2 introduces the technical background of binaural beats, including their audio generation and neural basis. Section 3 provides a literature review organized thematically across conceptual, therapeutic, and usage-related domains. Section 4 explores real-world applications in mental health and self-guided wellness. Section 5 presents theoretical frameworks explaining their cultural and psychological impact. Section 6 reviews empirical findings in greater depth. Section 7 discusses policy and ethical implications, and Section 8 concludes with a synthesis of insights and future directions for research and decision support.

2 | Technical Foundations of Binaural Beats

Binaural beats are an auditory phenomenon that occurs when two pure tones with slightly different frequencies are presented separately to each ear through stereo headphones. The listener perceives a third, rhythmic beat corresponding to the frequency difference between the two tones, a percept that does not exist in the physical signal but is generated within the auditory system. This phenomenon was first documented by Heinrich Wilhelm Dove [9] and later explored by Thompson in 1877 [24] laying the groundwork for subsequent studies in auditory neuroscience laying the groundwork for subsequent studies in auditory neuroscience [20].

The neural basis of binaural beat perception involves the integration of auditory input from both ears within binaurally sensitive neural circuits. According to [20], this integration begins in the brainstem and continues along the ascending auditory pathway to the auditory cortex. Neuroimaging studies using magnetoencephalography (MEG) have shown that binaural beats elicit steady-state auditory responses in various regions of the cerebral cortex, particularly in the auditory cortex, as well as in frontal and parietal areas [16]. These cortical activations support the notion that binaural beats are processed in higher-order brain regions associated with sound perception and cognitive integration.

In addition to cortical involvement, subcortical structures also contribute to binaural beat generation. Evidence suggests that the medial superior olive and the inferior colliculus play roles in the early phase-locking of auditory signals from each ear, which is essential for the perception of the binaural beat [10]. This highlights the complexity of auditory signal processing, wherein both subcortical and cortical structures are engaged in decoding and integrating interaural differences.

A useful distinction can be made between binaural beats and acoustic beats. While binaural beats are created within the auditory system and require separate tones delivered to each ear, acoustic beats result from the physical interference of two tones combined in the same channel. Acoustic beats are processed much earlier

in the auditory pathway, with detectable neural responses beginning in the cochlear nuclei, the first auditory relay station in the brainstem [10]. Interestingly, despite their different origins, electroencephalographic (EEG) studies have shown that both binaural and acoustic beats produce similar patterns of cortical activation, suggesting shared mechanisms in their neural processing [10].

In practical applications, open-source audio libraries such as Librosa and PyDub have made binaural beat synthesis more accessible to researchers and developers. Librosa, a Python-based signal processing toolkit, enables detailed manipulation of waveform data, frequency generation, and time-domain transformations. PyDub facilitates stereo channel control and supports real-time audio rendering, making it suitable for creating beat-based auditory experiences. Together, these tools allow for the controlled generation of binaural signals, including phase-offset sine waves tailored for specific cognitive or emotional outcomes. Their widespread use has contributed to the expansion of do-it-yourself platforms, mobile wellness applications, and audio experiments that simulate therapeutic or psychoactive effects.

This increasing accessibility underscores the need for standardized protocols and quality control, particularly as binaural beat content moves beyond laboratory settings into unregulated commercial and recreational domains. Together, the neurophysiological findings and the technological enablers illustrate that binaural beat perception emerges from a complex interaction between peripheral auditory input, brainstem integration, and cortical interpretation. This layered architecture supports both the scientific exploration of neural entrainment and the growing interest in binaural beats as foundations for digital drug applications.

3 | Literature Review

Binaural beats have been explored across a wide spectrum of disciplines, from auditory neuroscience and psychology to digital wellness and recreational technology. This section provides a thematic synthesis of the existing scholarly literature, highlighting key conceptualizations, reported neuropsychological effects, usage patterns, and current research limitations.

3.1 | Conceptualization of Digital Drugs

The term “digital drugs” typically refers to the use of auditory or visual stimuli delivered via digital platforms with the intent of altering mental or emotional states. Binaural beats represent one of the most prominent examples in this domain. They are often marketed as tools capable of simulating effects similar to pharmacological substances without the use of chemicals, a claim that has fueled their informal classification as “digital drugs” or “i-doses” [12, 14, 23]. Academic discourse generally defines them more conservatively, describing them as auditory illusions resulting from interaural frequency differences that may entrain neural oscillations.

3.2 | Neuropsychological Effects

Numerous studies have examined the psychological and cognitive outcomes associated with binaural beat exposure. Reported benefits include improvements in mood, attention, anxiety reduction, and memory performance [6-7, 25]. For instance, Lane et al. [17] found that exposure to beta-frequency binaural beats was associated with enhanced vigilance and reduced fatigue. However, these findings are not universally replicated. Several studies have reported only marginal improvements or null results, particularly when accounting for placebo conditions and individual variability [4].

These psychological effects are often attributed to brainwave entrainment, a neurophysiological phenomenon wherein auditory stimuli are believed to synchronize neural oscillations to the frequency of the beat. Electroencephalography (EEG) studies have investigated this mechanism with mixed results. Some have demonstrated measurable changes in neural activity aligned with the presented frequency. For example, [8] found that binaural beats could induce EEG shifts corresponding to the auditory stimulus, suggesting a direct neural modulation effect.

Further EEG research supports these findings in controlled settings. Ecsy et al., [11] reported elevated alpha power in participants exposed to 10 Hz binaural beats, consistent with the hypothesized entrainment of relaxation-associated rhythms. However, these effects are not consistently observed across studies. Several investigations have highlighted the influence of psychological context, user expectations, and placebo responses on outcomes. López-Caballero and Escera [19] emphasized that while binaural beats can modulate neural rhythms linked to relaxation and attention, such mechanisms are increasingly exploited by unregulated commercial applications marketed as digital drugs. This raises important concerns regarding scientific reproducibility and the potential for misuse in non-clinical environments.

Taken together, current evidence suggests that binaural beats may provide modest cognitive or mood-related benefits in certain contexts, yet methodological variability and possible expectancy effects limit firm conclusions. More rigorous and standardized protocols, especially those that use double-blind controls and include long-term follow-up, are needed to determine when and for whom binaural beats exert reliable neuropsychological influence.

3.3 | Usage Patterns and Cultural Trends

Large-scale survey research provides the clearest window into who engages with binaural beats as so-called digital drugs and why they do so. Data from the Global Drug Survey 2021, which included more than thirty thousand respondents across twenty-two countries, showed that 5.3 percent had used binaural beats to experience an altered state [5]. National rates varied, with higher prevalence in the United States, Mexico, and Brazil. The median age of users was twenty-seven, and use correlated with recent consumption of cannabis, psychedelics, or novel psychoactive substances. Relaxation and sleep enhancement were the most frequently cited goals, followed by mood change and curiosity about simulating drug effects.

Digital media platforms play a central role in the distribution and normalization of binaural beats. Video-sharing sites and music-streaming services host thousands of freely accessible tracks that carry titles such as deep focus, lucid dreaming, or legal high. Algorithms that recommend content based on viewing history and engagement can quickly channel users from mainstream wellness material toward more experimental audio marketed for euphoria or dissociation. Because these algorithms rarely screen for mental health status or age, adolescents and individuals with anxiety or sleep difficulties are disproportionately exposed to unverified claims.

Cultural framing further shapes usage. In many wellness communities, binaural beats are embedded in guided meditation podcasts, productivity playlists, and sleep hygiene routines. Influencer narratives often present them as self-help tools that require no professional oversight. Conversely, media outlets have periodically sensationalized binaural beats as digital substances, raising concerns about a gateway effect to actual drug use. Although evidence for such a gateway remains limited, qualitative studies from Gulf-country regions have reported public anxiety about so-called electronic drugs and called for regulatory attention [3].

Binaural beats have become part of a broader trend toward self-experimentation with non-chemical methods of mood and cognition management. Their appeal lies in perceived safety, low cost, and immediate availability. At the same time, the absence of standardized content labeling, scientific validation, and usage guidelines highlights a need for clearer communication of benefits and risks. Future research should examine how platform design, cultural attitudes, and individual traits interact to shape long-term use patterns and potential dependence.

3.4 | Gaps in Current Literature

Despite growing scholarly and commercial interest in binaural beats, the literature remains limited in several important respects. A major issue is the absence of standardized experimental protocols. Studies often vary in terms of beat frequency, duration of exposure, control conditions, and outcome measures, making comparisons across findings difficult and replication unreliable. Additionally, many studies rely on small

sample sizes or one-time interventions, which restricts statistical power and weakens the generalizability of observed effects.

Another underdeveloped area is the exploration of demographic and cultural factors. Few studies examine how variables such as age, gender, cultural background, or psychological traits influence the perception or impact of binaural beats. Similarly, there is a lack of longitudinal research assessing whether repeated or prolonged use yields cumulative cognitive or emotional effects, or if tolerance and desensitization emerge over time.

Ethical and regulatory issues also remain insufficiently addressed. While binaural beats are marketed as tools for cognitive enhancement, stress relief, and mood regulation, their promotion often occurs without scientific validation or oversight. Questions surrounding informed consent, age-appropriate exposure, and the psychological claims made by commercial platforms have received limited attention in academic discourse. As binaural beats continue to blur the line between therapeutic technology and recreational simulation, future research must confront these challenges to support responsible development and application.

4 | Therapeutic Applications

The potential of binaural beats to support non-pharmacological treatment strategies has attracted interest from clinical researchers, music therapists, and digital health developers. Although evidence remains inconclusive, a growing number of studies have explored the use of binaural beats for anxiety reduction, pain management, attention modulation, and cognitive enhancement. This section outlines their application in both structured clinical protocols and commercial wellness tools.

4.1 | Clinical Protocols in Music Therapy

Binaural beats have been integrated into music therapy frameworks aimed at improving patient well-being in both medical and mental health contexts. Controlled studies have investigated their effects on anxiety, stress, and physiological responses in preoperative and therapeutic settings. For example, a research found out that listening to theta-frequency binaural beats prior to surgery significantly reduced patient-reported anxiety scores and heart rate [2]. Similarly, another research reported lowered anxiety levels and stabilized vital signs in patients exposed to binaural beats during treatment .

In neurodevelopmental contexts, binaural beats have also been evaluated for attention-deficit/hyperactivity disorder (ADHD). Preliminary studies suggest that stimulation at beta frequencies may enhance focus and sustained attention in individuals with attentional deficits, though most findings stem from small-scale or pilot interventions [1]. Larger randomized trials are needed to establish efficacy and dosing guidelines.

While these results are promising, methodological limitations persist. Many studies lack active placebo controls, blinding, or long-term follow-up, which limits their reliability. Nonetheless, music therapy programs increasingly incorporate binaural audio as part of individualized treatment plans, especially in settings emphasizing relaxation, mindfulness, and anxiety regulation.

4.2 | Consumer Mental Health Applications

Beyond clinical environments, binaural beats have gained widespread popularity in consumer wellness platforms, where they are marketed as non-invasive tools for improving sleep, reducing stress, enhancing mood, and boosting cognitive performance. These applications typically offer customizable audio tracks designed to target specific mental states, drawing on the premise that different frequencies can entrain distinct brainwave patterns.

Most commercial offerings allow users to select tracks based on intended psychological outcomes, such as deep relaxation, increased alertness, or emotional balance. These selections are based on established associations between brainwave frequencies and mental states [19]. Delta waves (1 to 4 Hz) are linked to deep sleep, theta waves (4 to 8 Hz) to meditation and creativity, alpha waves (8 to 13 Hz) to relaxed wakefulness,

beta waves (13 to 30 Hz) to active thinking and alertness, and gamma waves (above 30 Hz) to higher-order cognitive functions. The perceived binaural beat is thought to promote a corresponding brain state. For instance, a 6 Hz binaural beat may enhance theta activity and support introspective or meditative experiences.

Research into these applications has examined their effectiveness in improving mood, anxiety levels, sleep quality, and cognitive function. A systematic review by García-Argibay et al. [13] concluded that binaural beats in the theta and alpha ranges can reduce anxiety and induce relaxation. Wahbeh et al. [25] similarly found that exposure to theta-frequency binaural beats significantly reduced anxiety among participants compared to control conditions. However, other studies, such as Basu and Banerjee [6], note that outcomes can vary significantly across individuals, suggesting that listener expectations, psychological profiles, and environmental context may moderate results.

Binaural beats have also been investigated as tools for enhancing sleep. A proof-of-concept study by Lee et al. [18] used dynamic binaural beat stimulation in the delta range (0 to 3 Hz) and observed improvements in sleep quality and reductions in sleep latency. Earlier research published in *Sleep* also suggested that delta-frequency beats may increase the duration of deep sleep stages, reinforcing their relevance to sleep architecture [1, 7].

Cognitive performance is another target of consumer interest, though findings are less consistent. An early research by [7, 15] reported improvements in attention and verbal memory tasks following exposure to beta-frequency beats. However, another systematic review by Ingendoh et al. [14] highlighted significant variability in study designs, participant characteristics, and cognitive metrics. The research concluded that although some effects are promising, methodological heterogeneity prevents definitive conclusions and calls for more standardized research protocols.

While binaural beat applications have attracted widespread user engagement and commercial interest, most remain unsupported by clinical validation. Many platforms present frequency-based claims without disclosing the underlying scientific uncertainty or offering health disclaimers. Furthermore, these tools rarely adapt their content to account for user-specific factors such as mental health status, age, or sensitivity to auditory stimuli. This disconnection between scientific evidence and commercial practice raises important ethical concerns, particularly in cases where vulnerable users engage with binaural beats for self-treatment.

To ensure the responsible development of neuroacoustic technologies, greater collaboration is needed between researchers, healthcare professionals, and application developers. Establishing clear standards for evidence-based design, transparent labeling, and user safety will help distinguish credible tools from those based on unverified or overstated claims. As interest in non-pharmacological mental health interventions grows, such safeguards will be essential in supporting both user well-being and scientific integrity.

5 | Algorithmic Exposure and Platform Mediation

The increasing availability of binaural beats through digital platforms has shifted their use from specialized therapeutic tools to easily accessible consumer experiences. Platforms such as streaming services, wellness apps, and video-sharing sites frequently deliver binaural beat content using recommendation algorithms. These algorithms often optimize for engagement rather than well-being, leading to unintended exposure and reinforcing usage patterns. Understanding how these systems mediate access to binaural beats is critical, particularly given their potential neuropsychological effects. This section examines the role of recommender systems, the lack of filtering based on user vulnerability, and the broader issue of platform transparency and responsibility.

5.1 | Role of Recommender Systems

As binaural beats have moved from clinical and experimental settings into the mainstream, their discovery and consumption are increasingly mediated by algorithm-driven platforms. Recommender systems embedded within services such as YouTube, Spotify, wellness apps, and digital marketplaces play a central role in

surfacing binaural beat content to users. These algorithms typically optimize for engagement rather than safety, guiding users toward content similar to their previous selections without accounting for psychological vulnerability or intent of use.

On video-sharing platforms like YouTube, users who begin with innocuous searches such as “study music” or “relaxing meditation audio” can quickly be directed toward more suggestively labeled tracks promoting “euphoria,” “psychedelic effects,” or “legal highs.” These recommendations are generated through behavioral similarity, watch time, and click-through rates, which reinforces exposure to more intense or recreational interpretations of binaural beats. This can lead to an unintended drift into content marketed with quasi-pharmacological claims, despite the absence of scientific verification.

Wellness apps and streaming services similarly categorize binaural beats into playlists like “focus,” “deep sleep,” or “boost your mood.” Although many of these tools present themselves as therapeutic, they often lack clear evidence standards or professional oversight. Algorithms that curate or auto-generate content within these platforms may further blur the line between science-informed interventions and recreational audio. Some apps personalize suggestions based on mood tags or time of day, but very few include clinical disclaimers or restrict access based on age or mental health history.

This uncritical algorithmic exposure creates a feedback loop where users are continuously nudged toward content that reinforces certain cognitive or emotional states. While such personalization may enhance perceived relevance, it also raises the risk of overexposure, dependency, or misinformed self-treatment. As binaural beats gain traction as digital tools for mental enhancement or escapism, the recommender systems that shape their reach warrant critical examination from both computational and ethical perspectives.

5.2 | Personalization and Risk of Unfiltered Access

While personalization is often framed as a benefit of digital media, its application in the context of binaural beat exposure introduces significant ethical and psychological concerns. Most platforms that deliver binaural beat content personalize recommendations based on surface-level behavioral data, such as search history, listening duration, or general engagement patterns, without accounting for deeper user characteristics that are crucial in mental health contexts.

This lack of individualized psychological profiling means that users experiencing anxiety, depression, sleep disorders, or emotional dysregulation may be guided toward audio content claiming to support these conditions, even though such content is rarely clinically validated. Unlike therapeutic interventions administered by healthcare professionals, binaural beats on consumer platforms are presented without proper context, dosage guidelines, or screening mechanisms. Users are therefore left to self-diagnose and self-administer auditory interventions that may or may not be appropriate for their mental state.

The situation is further complicated by the fact that many of these platforms offer “mood-based” navigation interfaces. These allow users to select emotional states like “calm,” “energized,” or “blissful,” which then trigger audio suggestions. While such systems offer a sense of autonomy, they do not adjust content based on risk factors such as a user’s age, psychiatric history, or sensitivity to dissociative experiences. As a result, individuals with heightened psychological vulnerability may encounter content that either fails to address their needs or, worse, exacerbates symptoms.

From a computational standpoint, this form of personalization is largely unregulated and lacks safeguards typically found in clinical recommendation systems. There is no mechanism for monitoring adverse reactions or limiting continued exposure to ineffective or misleading audio programs. The absence of such filters represents a structural blind spot in the current design of wellness and audio platforms.

As digital health tools continue to integrate AI-based personalization, it becomes critical to develop frameworks that distinguish between benign entertainment recommendations and those with potential psychological impact. In the case of binaural beats, which are increasingly marketed for their mental and

emotional effects, unfiltered personalization raises the risk of misuse, overdependence, and unmet user expectations.

5.3 | Platform Responsibility and Opaqueness

Although digital platforms play a central role in distributing binaural beat content, most do so without transparency or mechanisms for ethical accountability. Unlike pharmaceutical products or licensed mental health interventions, binaural beats are typically classified as entertainment or wellness media. This classification allows them to bypass formal regulations, even when they are marketed with therapeutic language or cognitive claims.

Most applications and streaming services fail to provide disclaimers that clarify the unverified nature of binaural beats as mental health tools. Audio tracks are frequently labeled with terms such as brain enhancement, theta healing, or digital high, but rarely provide sources or explain the scientific foundations behind these labels. In many cases, users are exposed to emotionally charged or neuropsychological terminology without understanding its relevance or limitations. This contributes to confusion and can lead users to overestimate the efficacy of these tools for self-regulation or psychological support.

The absence of transparent content labeling and user guidance has further implications for individuals seeking relief from stress, anxiety, or sleep disturbances. These users may engage with binaural beat content as a substitute for clinical intervention, unaware of its limited empirical validation. In doing so, they may delay or avoid evidence-based care, particularly if platform design reinforces repeated exposure without critical reflection.

Content curation algorithms and recommendation systems are also typically opaque. Users are not informed about how playlists are generated or why specific tracks are promoted based on their listening history. This lack of disclosure allows pseudoscientific content to circulate freely and creates an environment in which marketing claims go unchallenged. Unlike mental health platforms that follow data protection standards and clinical guidelines, wellness applications offering binaural beats operate with few checks on accuracy, safety, or target audience.

Currently, there are no industry standards or third-party bodies that audit binaural beat content for its health implications. Platforms are not required to verify therapeutic claims, evaluate user outcomes, or implement protective measures for vulnerable groups. As a result, binaural beats exist within a regulatory vacuum in which marketing, distribution, and consumption proceed without safeguards.

Addressing these gaps will require coordinated responses at the level of platform governance and digital health policy. This includes requiring apps and media services to distinguish entertainment content from tools claiming cognitive or emotional effects. It also involves promoting transparency in how content is categorized, recommended, and framed. Without such measures, the ethical risks associated with the unregulated spread of binaural beat content are likely to grow alongside its popularity.

6 | Ethical and Policy Challenges

As binaural beats gain popularity as non-invasive tools for mood enhancement, sleep improvement, or even recreational alteration of consciousness, new ethical concerns have emerged. Unlike regulated pharmaceuticals, binaural beat content is largely unmonitored and disseminated without medical oversight or informed consent protocols. This raises important questions regarding misuse, especially among impressionable or vulnerable users such as adolescents. Ethical frameworks and policy guidelines have yet to keep pace with these developments. This section outlines key challenges in digital consent, equitable access, risk of misuse, and the need for governance models that reflect both technological complexity and human-centered safety.

6.1 | Risk of Recreational Simulated Experiences

The framing of binaural beats as digital drugs introduces ethical risks related to recreational misuse, psychological suggestibility, and unsupervised experimentation. While many users seek these audio tracks for relaxation, focus, or sleep enhancement, others are drawn to their perceived ability to simulate altered states of consciousness. This practice, often referred to as i-dosing, reflects the belief that specific binaural frequencies can induce experiences comparable to those produced by psychoactive substances.

Although scientific evidence does not support equivalence between binaural beats and pharmacological agents, suggestive labeling and anecdotal reporting have amplified this perception. Tracks with titles like “simulate LSD,” “mind expansion,” or “legal high” can create expectations that influence user experience through placebo effects or psychological priming. Users who are highly suggestible may report altered mood or dissociation, even in the absence of measurable neurophysiological changes. These outcomes raise concerns about unintended cognitive or emotional responses, particularly among impressionable or inexperienced users.

The risk is heightened when binaural beat content is consumed without medical or psychological insight. Unlike guided therapeutic protocols, recreational listening often occurs in private, with no external monitoring or safety boundaries. Users may self-administer binaural beats with the hope of managing anxiety, depression, or sleep disturbances, yet without understanding the mechanisms, limitations, or appropriate conditions of use. In some cases, repeated or excessive exposure may reinforce unrealistic expectations, reduce trust in conventional care, or lead to emotional discomfort if effects fail to materialize.

The simulation of drug-like experiences through audio alone presents an additional regulatory challenge. While i-dosing does not involve substance ingestion, it evokes questions similar to those raised by digital therapeutics or neuromodulation technologies. The boundary between entertainment and intervention becomes blurred, particularly when users seek out binaural beats to replace or replicate the effects of restricted substances. This context calls for clearer communication about what binaural beats can and cannot do, as well as ethical guidelines for how they are labeled and recommended in digital spaces.

The recreational use of binaural beats highlights the ethical complexity of audio-based neuromodulation when it occurs outside formal therapeutic or research contexts. As the accessibility and appeal of these tools continue to grow, it becomes increasingly important to consider how specific populations may be uniquely affected. Ethical concerns are especially pronounced for users who lack the knowledge, maturity, or clinical support to assess the risks and boundaries of self-directed use.

6.2 | Vulnerable Populations and Consent Concerns

Among the most pressing ethical concerns in the diffusion of binaural beats are the implications for vulnerable populations, particularly adolescents, individuals with pre-existing mental health conditions, and users who rely on digital media for emotional regulation. These groups may be drawn to binaural beat content through targeted wellness messaging, social recommendations, or casual browsing, yet may lack the critical insight required to assess its appropriateness for their psychological state.

Adolescents are especially susceptible due to their ongoing cognitive and emotional development. Emerging research in media psychology shows that younger users are more likely to experiment with tools that promise stimulation, escape, or emotional enhancement, often without understanding the underlying mechanisms or verifying safety claims. The use of suggestive labels such as “get high naturally” or “alter your state” can reinforce unrealistic expectations and encourage self-experimentation without oversight.

Individuals with anxiety, depression, or trauma-related symptoms may also be at risk. These users often seek immediate and accessible coping strategies, making them more likely to try binaural beats as a form of self-treatment. However, without guidance, they may misinterpret transient mood shifts as evidence of therapeutic

efficacy or, conversely, may feel discouraged if effects do not align with marketed outcomes. In either case, the lack of professional support undermines informed consent and exposes users to emotional risk.

The structure of most digital platforms compounds these concerns. Platforms do not currently screen for user age, psychological vulnerability, or mental health status when recommending binaural beat content. Consent is assumed through interaction, even when the content is positioned as having psychological or cognitive effects. This undermines the ethical principle of informed use, which requires that users are fully aware of what a tool is designed to do, how it works, and what risks it might entail.

Addressing these issues calls for stronger safeguards, including age-aware platform design, content disclaimers, and the integration of educational cues that help users differentiate between wellness entertainment and empirically supported interventions. Without such measures, vulnerable populations remain exposed to unregulated practices that may appear therapeutic but lack the protections of formal care environments.

6.3 | Regulation and Governance

The increasing use of binaural beats as tools for mental enhancement, emotional regulation, and recreational simulation presents a challenge for existing regulatory frameworks. Unlike pharmaceutical interventions or certified digital therapeutics, binaural beats occupy a legal and conceptual grey area. They are distributed through wellness apps, streaming platforms, and social media, often without being subject to health-specific oversight, safety standards, or disclosure requirements.

At present, no centralized body is responsible for reviewing the scientific claims made by content creators or app developers who promote binaural beats for therapeutic or cognitive benefits. This stands in contrast to digital therapeutics and medical apps, which in some jurisdictions must be evaluated by regulatory authorities such as the United States Food and Drug Administration or the European Medicines Agency. The absence of such governance mechanisms allows binaural beat content to proliferate without formal validation, even when it mimics clinical interventions in language and framing.

This regulatory gap is further complicated by the variability in how binaural beats are classified. Some platforms treat them as entertainment or ambient media, while others categorize them under health and wellness. As a result, they are not held to consistent standards for efficacy, user protection, or ethical distribution. This lack of clarity prevents the development of cross-sector guidelines and limits the ability of policymakers to respond to emerging risks.

From a public health perspective, this absence of regulation raises questions about user safety, misinformation, and the normalization of self-directed neurostimulation. Users often engage with binaural beats based on implicit trust in platform visibility or peer endorsement, not on clinical evidence or guidance. In the absence of official evaluation, misleading or exaggerated claims may influence individuals to substitute binaural beats for appropriate clinical care.

To address these concerns, policymakers and health authorities may consider extending aspects of digital health regulation to cover high-risk uses of binaural beats. This could include clearer content labeling requirements, standardized disclaimers, and a mechanism for evaluating apps or services that make therapeutic claims. Moreover, collaborative efforts between neuroscientists, digital ethicists, and platform designers could support the development of voluntary certification systems, offering users better tools to evaluate what is safe, effective, or potentially misleading.

6.4 | Need for Ethical AI and Digital Content Moderation

As digital platforms increasingly rely on artificial intelligence to personalize user experiences, there is a growing need to integrate ethical principles into the design and deployment of these systems. In the context of binaural beats, AI-powered recommendation engines shape what content users encounter, how frequently

it is presented, and under what contextual framing. However, these systems are rarely optimized to account for user well-being, psychological risk, or medical appropriateness.

Most content moderation frameworks on mainstream platforms prioritize issues such as copyright, hate speech, or explicit content. Wellness-oriented audio, including binaural beats, typically falls outside these categories and is therefore subject to little or no scrutiny. Yet, when such content is labeled with therapeutic or psychoactive claims, it intersects with health communication and requires a more nuanced approach. Without intervention, AI systems may continue to promote binaural beat tracks based solely on engagement metrics, unintentionally amplifying misleading or manipulative content.

Ethical AI in this context involves more than transparency or explainability. It requires deliberate constraints on how health-related audio content is classified, recommended, and distributed. For instance, recommendation systems could be programmed to prioritize verified information, flag unsupported claims, and avoid directing vulnerable users to content that may be psychologically inappropriate. Additionally, moderation tools could prompt users with disclaimers or reflective questions when they engage with audio labeled as therapeutic or consciousness-altering.

The integration of ethical AI design principles is particularly urgent in mobile apps that promise mood enhancement, focus improvement, or anxiety relief through binaural stimulation. These apps often feature automated playlists, adaptive interfaces, and behavioral tracking without clinical oversight or mental health safeguards. Embedding digital content moderation into these ecosystems is essential for minimizing harm and ensuring that AI systems do not replace professional judgment with algorithmic suggestion.

To move forward, platforms offering binaural beat content should collaborate with interdisciplinary experts to develop content classification standards and ethical recommendation practices. This may include the adoption of red-flagging systems for high-risk claims, opt-in health disclaimers, and informed usage models that educate users about limitations and uncertainties. By doing so, platforms can align innovation with responsibility, supporting both access and safety in the digital delivery of auditory wellness tools.

The ethical and policy challenges surrounding binaural beats reflect a broader tension between innovation and regulation in the digital wellness landscape. As users increasingly engage with these audio tools outside formal therapeutic contexts, the absence of scientific validation, user protection measures, and platform accountability raises concerns about safety, equity, and informed consent. Addressing these issues will require more than clinical insight or content moderation. It calls for intelligent systems capable of supporting ethical decision-making, anticipating user needs, and balancing personalization with harm reduction. This opens a new avenue for computer science research, where decision support technologies can help operationalize ethical principles and guide the responsible evolution of binaural beat platforms.

The next section explores how decision support frameworks can be applied to this emerging domain. It outlines opportunities for using computational models to assess user risk, inform content exposure, and simulate policy interventions that protect users while enabling innovation.

7 | Decision Support Opportunities

The growing diffusion of binaural beats across digital platforms raises the need for robust, interdisciplinary frameworks to assess and mitigate potential risks. While previous sections have examined the psychological, therapeutic, and regulatory dimensions of binaural beat consumption, this section turns to the strategic role of decision support systems in guiding responsible innovation. Situated at the intersection of computer science, digital health, and public policy, decision support offers a toolkit for embedding ethical reasoning, safety constraints, and user-centered intelligence into the ecosystem of audio-based neurotechnology. Drawing on techniques from artificial intelligence, operations research, and adaptive systems design, the subsections that follow present key opportunities for modeling user risk, improving content filtering logic, and simulating the public health impact of unregulated digital drug dissemination. These approaches not only

align with emerging standards in ethical AI but also offer practical mechanisms for platform accountability and harm reduction.

7.1 | Risk Modeling and User Profiling

One of the most immediate decision support applications in the context of binaural beat exposure is the development of risk modeling frameworks that account for individual variability in psychological and physiological states. While current content delivery systems operate with minimal user differentiation, research in mental health informatics has demonstrated that personalization based on mood, cognitive baseline, and clinical history can significantly improve outcomes and reduce adverse effects. In the case of binaural beats, user profiling could involve lightweight psychological self-assessments, history of mental health symptoms, or inferred behavioral patterns to determine whether exposure to certain frequency ranges may be supportive, neutral, or potentially harmful.

This type of profiling aligns with established practices in decision support systems for digital therapeutics, where algorithms dynamically adjust interventions based on ongoing user feedback and risk markers. For instance, decision rules might flag users with elevated anxiety scores as unsuitable for certain theta-inducing tracks, or suggest alternatives with clinically validated relaxation outcomes. Machine learning models could further enhance profiling by identifying latent subgroups of users who are more likely to report negative reactions or placebo-driven expectations.

Importantly, risk modeling must be grounded in privacy-preserving data practices and informed consent. While profiling enhances decision-making, it also raises ethical considerations about autonomy, data ownership, and potential misuse. Therefore, transparent design, opt-in mechanisms, and alignment with health data governance standards are critical. By integrating psychological screening and contextual metadata into content delivery decisions, platforms can move toward more responsible personalization strategies that respect user wellbeing and avoid blanket exposure to emotionally impactful audio content.

7.2 | Content Screening and Filtering Mechanisms

While risk modeling focuses on the user, an equally important component of decision support lies in evaluating the content itself. Binaural beat recordings vary widely in quality, target frequency ranges, and claimed outcomes, yet platforms often lack any standardized method for assessing the potential neural or psychological impact of this content. Decision support systems can address this gap through intelligent filtering mechanisms that evaluate and label binaural beat content according to evidence-based criteria.

A promising direction involves the development of **neural impact scores**, which could be derived from audio feature extraction (e.g., frequency accuracy, duration, amplitude consistency) combined with metadata tags on intended effects (e.g., relaxation, focus, stimulation). These scores can then inform platform-level content moderation systems, either as standalone metrics or integrated into recommender system algorithms. For instance, content with unclear auditory characteristics or unsubstantiated therapeutic claims could be downranked, while clinically validated tracks could be surfaced more prominently to users with compatible profiles.

Such filtering could also include warning signals based on risk categories—similar to those used in video game or pharmaceutical labeling. Content intended for inducing strong affective or dissociative states might be flagged as requiring caution, especially for underage users or those with flagged psychological sensitivity. To make these mechanisms interpretable and actionable, the scoring framework should be transparent and auditable, incorporating input from domain experts in neuroscience, music therapy, and psychiatry.

Advancements in content classification using deep learning (e.g., convolutional neural networks trained on spectrograms) can further automate this process, allowing for scalable, real-time filtering of newly uploaded or streamed content. The challenge remains to balance openness with safeguards—preserving innovation in digital wellness while enforcing boundaries that prevent harm or misuse. As binaural beat platforms continue

to grow in popularity, embedding intelligent screening systems will be critical to maintaining ethical, user-centered ecosystems.

7.3 | Policy Simulation and Operations Research Models

Beyond individual risk assessment and content filtering, broader systemic insights are required to guide platform governance and public health strategy. Operations research (OR) and policy simulation techniques provide a powerful, underutilized toolkit for modeling the social and behavioral dynamics of binaural beat dissemination. These models can support regulators, platform designers, and clinical stakeholders in anticipating misuse scenarios, optimizing moderation strategies, and testing the effects of potential interventions before real-world deployment.

A key opportunity lies in network contagion modeling. Given that binaural beat content often spreads virally through social platforms, OR methods such as agent-based models (ABMs) and epidemiological diffusion models can be repurposed to simulate how i-dosing trends might propagate across different user segments. These models can incorporate variables such as content virality, user susceptibility (e.g., based on age, anxiety scores), and influence from digital peer groups or influencers. By simulating these dynamics, researchers can identify high-risk clusters, tipping points in trend escalation, and optimal points for targeted intervention.

In addition, queueing theory and resource allocation models can be applied to optimize platform moderation pipelines. These models help allocate moderation efforts proportionally to the volume and risk profile of binaural content being uploaded, enabling scalable responses even as content volume increases. Scenario analysis using stochastic modeling or Monte Carlo simulations can also aid in evaluating the long-term societal effects of lax versus strict regulatory policies, including metrics like exposure prevalence, incidence of adverse reactions, or public trust.

Lastly, multi-objective optimization frameworks could help stakeholders balance competing goals such as maximizing user autonomy while minimizing harm. These models allow platforms to simulate trade-offs in recommender system design, such as the impact of narrowing suggestions to only clinically validated content versus preserving the diversity of user-generated audio. By formalizing these decisions within operations research frameworks, developers and regulators can move toward more transparent, data-informed governance of digital wellness tools.

This need for structured decision models becomes even more critical in light of current gaps in international regulatory oversight. In the United States, the Food and Drug Administration (FDA) oversees neurological devices, yet many consumer-facing binaural beat applications fall outside regulatory scrutiny due to their general wellness labeling and absence of formal medical claims. The FDA's pre-submission program offers a pathway for classification and safety review, particularly for high-risk neurological interfaces, but it remains underutilized in the auditory wellness space. Similarly, the European Union's Medical Device Regulation (EU 2017/745) mandates rigorous clinical validation for products making medical claims, yet its application to binaural beat technologies is inconsistent and often bypassed when tools are presented as entertainment or lifestyle aids.

These inconsistencies underscore the urgent need for standardized classification protocols, neural impact thresholds, and user protection frameworks. Decision support systems can help fill this regulatory void by offering computational methods for risk assessment, efficacy scoring, and policy simulation, laying the foundation for intelligent, adaptive, and ethically governed digital neurotechnology.

8 | Conclusion and Future Directions

This survey has explored the multifaceted landscape of binaural beats, highlighting their emergence as both a promising innovation and a source of ethical concern. On one hand, these auditory stimuli offer potential cognitive and emotional benefits, drawing on brainwave entrainment principles and resonating with interests in non-pharmacological mental health interventions. On the other hand, the lack of clinical validation, standardized use protocols, and effective regulation raises legitimate concerns about their uncontrolled dissemination, particularly among vulnerable users. Through a structured review of technical foundations, empirical studies, therapeutic claims, and platform mediation, this paper has shown that binaural beats occupy a unique position between science and consumer culture. Their use spans from guided relaxation apps to unverified 'digital drug' experiences, often promoted through opaque recommendation algorithms and without clinical disclaimers.

This survey contributes a novel perspective by framing the issue within the domain of decision support systems. Section 7 outlined how techniques from computer science, such as risk profiling, content filtering, and policy modeling, can be harnessed to reduce misuse and inform ethical innovation. These decision support mechanisms provide a foundation for more responsible personalization in digital wellness tools.

Future research should focus on developing standardized evaluation metrics for neural impact, implementing adaptive user safeguards within recommendation engines, and advancing simulations to test policy responses to emerging auditory trends. Longitudinal studies that track user outcomes, as well as interdisciplinary collaborations across neuroscience, ethics, and software design, will be essential for transforming binaural beats from an unregulated trend into a safe and meaningful digital tool. Ultimately, the path forward must balance the creative potential of binaural stimulation with the need for transparent, evidence-based governance that protects users while enabling innovation.

Funding

This research has no funding source.

Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

- [1] Abeln, V., Kleinert, J., Strüder, H. K., & Schneider, S. (2014). Brainwave entrainment for better sleep and post-sleep state of young elite soccer players—A pilot study. *European Journal of Sport Science*, 14(5), 393–402.
- [2] Ala, T. S., Ahmadi-Pajouh, M. A., & Nasrabadi, A. M. (2018). Cumulative effects of theta binaural beats on brain power and functional connectivity. *Biomedical Signal Processing and Control*, 42, 242–252.
- [3] Al-Tkayneh, K. M., & Ashour, S. (2025). Exploring the Impact and Prevention of Digital Drugs: Insights from the Emirati Youth Perspective. In *Handbook of Families in the Arab Gulf States* (pp. 237–250). Springer.
- [4] Atwater, F. H. (2001). Binaural beats and the regulation of arousal levels. *Proceedings of the TANS*, 11.

- [5] Barratt, M. J., Maddox, A., Smith, N., Davis, J. L., Goold, L., Winstock, A. R., & Ferris, J. A. (2022). Who uses digital drugs? An international survey of 'binaural beat' consumers. *Drug and Alcohol Review*, 41(5), 1126–1130.
- [6] Basu, S., & Banerjee, B. (2023). Potential of binaural beats intervention for improving memory and attention: insights from meta-analysis and systematic review. *Psychological Research*, 87(4), 951–963.
- [7] Borges, L. R., Arantes, A. P. B. B., & Naves, E. L. M. (2023). Influence of binaural beats stimulation of gamma frequency over memory performance and EEG spectral density. *Healthcare*, 11(6), 801.
- [8] da Silva Junior, M., de Freitas, R. C., dos Santos, W. P., da Silva, W. W. A., Rodrigues, M. C. A., & Conde, E. F. Q. (2019). Exploratory study of the effect of binaural beat stimulation on the EEG activity pattern in resting state using artificial neural networks. *Cognitive Systems Research*, 54, 1–20. <https://doi.org/https://doi.org/10.1016/j.cogsys.2018.11.002>
- [9] Dove, H. W. (1841). Über die Combination der Eindrücke beider Ohren und beider Augen zu einem Eindruck. *Monatsberichte Der Berliner Preussische Akademie Der Wissenschaften*, 41, 251–252.
- [10] Draganova, R., Ross, B., Wollbrink, A., & Pantev, C. (2008). Cortical steady-state responses to central and peripheral auditory beats. *Cerebral Cortex*, 18(5), 1193–1200.
- [11] Ecsy, K., Jones, A. K. P., & Brown, C. A. (2017). Alpha-range visual and auditory stimulation reduces the perception of pain. *European Journal of Pain*, 21(3), 562–572.
- [12] Engelbregt, H., Barmantlo, M., Keeser, D., Pogarell, O., & Deijen, J. B. (2021). Effects of binaural and monaural beat stimulation on attention and EEG. *Experimental Brain Research*, 239(9), 2781–2791.
- [13] Garcia-Argibay, M., Santed, M. A., & Reales, J. M. (2019). Efficacy of binaural auditory beats in cognition, anxiety, and pain perception: a meta-analysis. *Psychological Research*, 83, 357–372.
- [14] Ingendoh, R. M., Posny, E. S., & Heine, A. (2023a). Binaural beats to entrain the brain? A systematic review of the effects of binaural beat stimulation on brain oscillatory activity, and the implications for psychological research and intervention. *Plos One*, 18(5), e0286023.
- [15] Ingendoh, R. M., Posny, E. S., & Heine, A. (2023b). Binaural beats to entrain the brain? A systematic review of the effects of binaural beat stimulation on brain oscillatory activity, and the implications for psychological research and intervention. *PLOS ONE*, 18(5), e0286023-. <https://doi.org/10.1371/journal.pone.0286023>
- [16] Karino, S., Yumoto, M., Itoh, K., Uno, A., Yamakawa, K., Sekimoto, S., & Kaga, K. (2006). Neuromagnetic responses to binaural beat in human cerebral cortex. *Journal of Neurophysiology*, 96(4), 1927–1938.
- [17] Lane, J. D., Kasian, S. J., Owens, J. E., & Marsh, G. R. (1998). Binaural auditory beats affect vigilance performance and mood. *Physiology & Behavior*, 63(2), 249–252.
- [18] Lee, H.-A.-N., Lee, W.-J., Kim, S.-U., Kim, H., Ahn, M., Kim, J., Kim, D.-W., Yun, C.-H., & Hwang, H.-J. (2024). Effect of dynamic binaural beats on sleep quality: a proof-of-concept study with questionnaire and biosignals. *Sleep*, 47(10), zsae097.
- [19] López-Caballero, F., & Escera, C. (2017). Binaural beat: a failure to enhance EEG power and emotional arousal. *Frontiers in Human Neuroscience*, 11, 557.
- [20] Moore, B. C. J. (2012). *An introduction to the psychology of hearing*. Brill.
- [21] Oster, G. (1973). Auditory beats in the brain. *Scientific American*, 229(4), 94–103.
- [22] Pratt, H., Starr, A., Michalewski, H. J., Dimitrijevic, A., Bleich, N., & Mittelman, N. (2010). A comparison of auditory evoked potentials to acoustic beats and to binaural beats. *Hearing Research*, 262(1–2), 34–44.
- [23] Robison, M. K., Obulasetty, M., Blais, C., Wingert, K. M., & Brewer, G. A. (2022). The effect of binaural beat stimulation on sustained attention. *Psychological Research*, 86(3), 808–822.
- [24] Thompson, S. P. (1877). XXXVI. On binaural audition. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 4(25), 274–276.
- [25] Wahbeh, H., Calabrese, C., & Zwickey, H. (2007). Binaural beat technology in humans: a pilot study to assess psychologic and physiologic effects. *The Journal of Alternative and Complementary Medicine*, 13(1), 25–32.

Disclaimer/Publisher's Note: The perspectives, opinions, and data shared in all publications are the sole responsibility of the individual authors and contributors, and do not necessarily reflect the views of Sciences Force or the editorial team. Sciences Force and the editorial team disclaim any liability for potential harm to individuals or property resulting from the ideas, methods, instructions, or products referenced in the content.