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The Role of Neurostimulation and Audio Stimulation in Improving Deep Sleep Phases

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Abstract: ***This article presents an analysis of the role of neurostimulation and auditory stimulation as mechanisms for enhancing deep-sleep phases. The importance of the topic arises from the fact that deep-sleep disturbances and chronic insomnia affect up to 30 % of the adult population, impairing cognitive and emotional functions and increasing the risk of somatic diseases. The methodological framework was based on a comparative analysis of results reported by other researchers in theoretical and experimental studies. The integration of these technologies into premium products (e.g., Royal Therapy), wearable devices (Oura, WHOOP), and multimodal sensors highlights the potential for establishing a "smart" sleep ecosystem. The findings confirm the effectiveness of combined auditory and neurostimulation in augmenting deep sleep and underscore the need for further large-scale controlled studies incorporating objective neurophysiological and biochemical markers. The information presented will interest specialists in sleep medicine and neurophysiology who investigate mechanisms of structural and functional plasticity in brain networks during deep sleep. These findings will also have practical significance for clinical neurologists and psychiatrists, as well as for biomedical engineers involved in the development and implementation of non-pharmacological sleep-modulation technologies and cognitive-optimization strategies.***

Keywords: Sound stimulation of the brain, binaural rhythms, isochronous tones, deep sleep, closed-loop EEG stimulation, ecosystem of health improvement during sleep, wearable biofeedback.

1. Introduction

Sleep is an essential physiological process that ensures the restoration of cognitive, emotional, and somatic functions. Deep sleep deprivation and chronic insomnia lead to memory impairment, reduced concentration, and increased anxiety, and are also associated with a heightened risk of cardiovascular disease and metabolic disorders. Estimates of insomnia prevalence among adults range from 10 % to 30 %. Traditional treatments—cognitive-behavioral therapy for insomnia (CBT-I) and pharmacotherapy- although proven effective, are often constrained by accessibility issues, low patient adherence, and adverse effects [1, 2].

The literature on the role of neurostimulation and auditory stimulation in enhancing deep-sleep phases can be grouped into several main approaches, distinguished by the type of stimulating intervention, the mechanisms under investigation, and the protocols applied.

First, precision auditory stimulation of deep sleep as a technique for fine-tuning brain rhythms during slow-wave sleep has been developed in studies where acoustic pulses are synchronized with endogenous brain oscillations. Dogan U. [1] introduced the concept of Deep Brain Sound Stimulation, in which stimuli are delivered via implanted and external sound sources while accounting for the phase position of slow waves. A similar approach received empirical validation in the study by Sousouri G. et al. [7], where phase-locked auditory stimulation enhanced the amplitude of slow oscillations and improved functional connectivity between cortical areas during the N3 sleep stage. Both studies emphasize the need for precise timing of stimulus delivery based on online EEG analysis; however, the algorithmic synchronization methods differ in complexity and computational demands.

Second, a wide range of investigations has examined the effects of acoustic neurostimulation on somatic and cognitive parameters comparable with the properties of pharmacological interventions. In a clinical study, Kanzler S. A. et al. [2] showed that daily auditory stimulation for six weeks improves sleep quality on the PSQI scale and reduces anxiety and depressive symptoms in healthy adults. Lustenberger C. [3] demonstrated that closed-loop auditory stimulation increases slow-wave activity power and favorably influences heart-rate variability, indicating elevated parasympathetic activity during sleep. Kim D. et al. [5] developed a digital therapeutic protocol in which sound patterns evoke cortical activation comparable with non-pharmacological interventions and demonstrated the potential to replace pharmacological agents for sleep disorders. Engelbregt H. et al. [6] compared the effects of binaural and monaural beat stimulation on cognitive performance as a function of participants' emotionality and found that binaural beats are more effective for enhancing attention, whereas monaural beats exert a mild but stable effect. In a fundamental study, Cabral-Calderin Y. and Henry M. J. [9] showed that the reliability of neuronal entrainment in the auditory analyzer varies across individuals, underscoring the need for personalized stimulus selection and rigorous control of EEG recording conformity.

Third, methodological innovations aimed at developing flexible cross-species stimulation systems are presented in the article by Attokaren M. K. et al. [4], which proposes the BrainWAVE framework for non-invasive modulation of brain rhythms in various laboratory animals and in humans.

Non-auditory neurostimulation studies also deserve attention. Su Y. J., Yi P. L., and Chang F. C. [8] applied transcranial direct-current stimulation (tDCS) to restore sleep disrupted by stress and showed that targeting the infralimbic area and ventrolateral prefrontal cortex activates projections that facilitate the transition to deep sleep.

Finally, contextual investigations, such as the work by Mahadule A. A. et al. [10], highlight general issues of sleep quality and hygiene among medical students during the COVID-19 pandemic and reveal a high prevalence of poor sleep and low adherence to hygienic recommendations, emphasizing the importance of considering behavioral factors when planning neurostimulation.

The literature analysis reveals inconsistencies in stimulation protocols: differences in parameters (frequency, intensity, duration), target areas, and synchronization methods lead to inconsistent results. Despite encouraging data on the short-term effects on slow-wave activity and somatic indices, the mechanisms of subcortical transmission of acoustic signals during sleep, as well as the influence of inter-individual characteristics (genetics, emotional baseline) on stimulation efficacy, remain insufficiently studied. Moreover, issues pertaining to the integration of auditory and electrical neurostimulation and to the optimization of modality combinations for improving the effectiveness and sustainability of therapeutic outcomes are poorly addressed.

The **objective** of the study is to analyze the influence of neurostimulation and auditory stimulation as mechanisms for enhancing deep sleep phases.

The **scientific novelty** consists in a systematic comparative analysis of the potential application of neurostimulation and auditory stimulation to determine their effects on the enhancement of the deep sleep phase (N3) and to substantiate the need for large-scale randomized controlled trials employing objective neurophysiological and biochemical markers.

The **author's hypothesis** posits that combined neurostimulation- incorporating deep brain stimulation (DBS) and auditory entrainment using binaural beats/isochronic tones in an EEG-closed-loop format—will enhance the deep sleep phase (N3) compared with single-protocol approaches, ensure sustained improvement in sleep quality, and reduce levels of the stress hormone cortisol.

The **methodological** foundation of the work was a comparative analysis of results obtained by other researchers in both theoretical studies and practical experiments.

1) Deep neurostimulation using acoustic signals

Deep Brain Sound Stimulation (DBSS) is a non-invasive form of auditory neuromodulation designed to restore disturbed neural rhythms associated with the N3 (slow-wave) phase of deep sleep. The method delivers precisely tuned auditory pulses (30–260 Hz) that elicit a Frequency-Following Response (FFR), i.e., phase-locking of neuronal populations to an external rhythmic stimulus [1, 2]. In vivo experiments and FFR observations demonstrate that such auditory input can induce phase synchronization in the prefrontal cortex, hypothalamus, pineal gland, and related white-matter tracts, driven by theta and delta rhythm generators within the autonomic system [7, 8].

Each DBSS session lasts 22 minutes and alternates between monoaural and isochronic beats. The first 3- 5 minutes consist of an adaptive beta-modulation phase (13–30 Hz), followed by 15 minutes of core slow-wave sleep stimulation (30–260 Hz), and concluding with a return to the beta mode to facilitate emergence from the session.

Sessions are performed at home using standard headphones and the Vital Tones mobile application. The user remains in a quiet environment, and volume is set to a comfortable level (no higher than 60 dB) in accordance with the application's built-in guidelines [1, 2].

The recommended therapeutic course comprises 5–6 sessions per week over 4 weeks, which provides sustained neuroplasticity and neuromodulation through the cumulative effects of FFR [4].

The results of a retrospective observation of 358 Vital Tones users are presented in Table 1.

Table 1: The results of a retrospective observation of 358 users of the Vital Tones application [1]

Measure	Insomnia	Deep Sleep
Subjects requesting the full course of therapy	143	215
Refund requests (refund rate)	0.70%	0.47%
Satisfaction (excluding refunds)	99.30%	99.53%
Median symptom improvement	80% (95% CI 44.92–85.08%)	65% (95% CI 35.6–94.4%)

High user satisfaction (≥99%) and extremely low return rates (<1%) confirm strong adherence and the perceived therapeutic benefit. Median self-assessed improvements in sleep depth (65–80%) indicate a clinically significant effect comparable to or exceeding those of various pharmacological and behavioral interventions.

Since April 2015, Deep Brain Sound Stimulation (DBSS) has been administered over 3 million times without reports of serious adverse events; only occasional mild effects (dizziness, headache) have been noted, resolving spontaneously within 24 hours. A case report with MRI documentation of reduction in a porencephalic cystic lesion and restoration of motor function in a 24-year-old patient illustrates the potential neurotrophic component of the method [1, 5].

The observational design without a control group does not permit clear distinction of DBSS effects from placebo response or seasonal sleep variations. Randomized controlled trials with objective polysomnography and electrophysiological biomarkers, including closed-loop audio stimulation synchronized to slow-wave EEG phases, are required to establish causality [3].

Therefore, Deep Brain Sound Stimulation (DBSS) represents a safe and highly effective noninvasive method for correcting disrupted deep-sleep (N3) phases by inducing a frequency-following response (FFR) to monaural and isochronic auditory beats in the 30–260 Hz range. Application of a 22-minute protocol- comprising adaptive β-modulation followed by primary stimulation- over 20–24 home sessions yields median improvements in sleep depth of 65- 80%, with user satisfaction ≥99% and minimal side effects. Although retrospective observation of 358 patients and over 3 million sessions confirms the cumulative neuromodulatory and potentially neurotrophic effects of the method, randomized controlled studies with objective polysomnography and electrophysiological markers, including closed-loop audio stimulation aligned with slow-wave EEG phases, are critically needed to definitively establish causal efficacy and optimize stimulation parameters

2) Modulation of brain rhythms using binaural beats and isochronic tones

Audio entrainment (brainwave entrainment, BWE) is a phenomenon whereby periodic auditory stimuli synchronize the brain's endogenous neuronal oscillations. The following methods of BWE are presented for illustration.

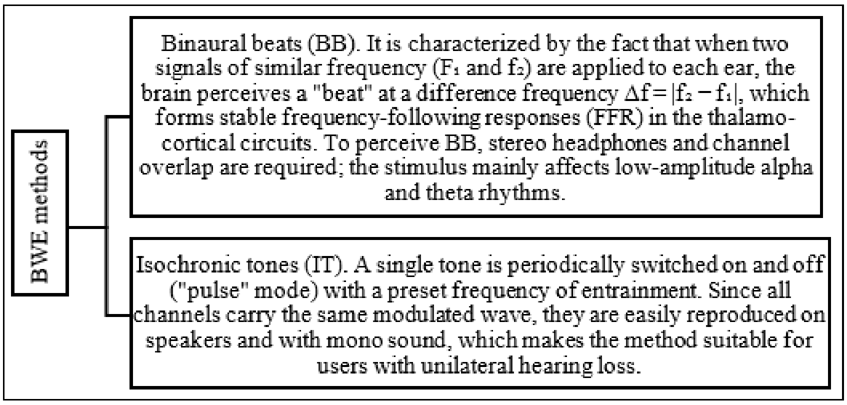

Figure 1: BWE methods (compiled by the author based on the analysis: [2, 6])

Neural entrainment is achieved via the resonant amplification of EEG frequency components: the alpha band (8–13 Hz) is associated with relaxed wakefulness, the theta band (4–8 Hz) with presleep and early sleep stages, and the delta band (1–4 Hz) with deep N3 sleep. Periodic auditory stimuli induce phase and amplitude modulation of neural oscillations through thalamo-cortical loops, thereby enhancing the synchronization of networks responsible for sleep–wake regulation.

Kanzler S. A. et al. [2] conducted a randomized, single-blind, parallel-group study involving 37 healthy adult volunteers (aged 18–70 years, 35 % male) who underwent daily 20-minute sessions over a 21-day period. Participants were assigned to one of four groups: a control group exposed to white noise, a group receiving 10 Hz binaural beats (BB), a group receiving isochronic tones (IT) at the same frequency, and a combined group receiving BB and IT against a white noise background. Randomization was performed using a random number method, and blinding was maintained for both participants and the outcome assessor. EEG recordings were obtained using a MUSE™ headset with electrodes positioned at TP9, TP10, AF7, and AF8; power spectral density in the principal frequency bands was calculated via fast Fourier transform during stimulation and post-stimulation. Psycho-emotional state was evaluated using the abbreviated Depression Anxiety Stress Scales (DASS-21) at baseline (T0) and at study completion (T1). Sleep quality was assessed with the Pittsburgh Sleep Quality Index, and salivary free cortisol concentrations were determined from samples collected before and after the three-week intervention [1, 2].

The results demonstrating the effects of BB and IT are presented in Table 2.

Table 2: Effects of BB, IT and their combination on EEG power spectrum [2]

Group	Alpha (8–13 Hz), TP region	Theta (4–8 Hz), TP region	Delta (1–4 Hz), TP region	Beta (13–30 Hz), FC region
BB	$p = 0.075$	$p = 0.021$	↑ $p = 0.046$	n.s.
IT	n.s.	n.s.	n.s.	$p = 0.031$
BB + IT	$p = 0.098$	n.s.	n.s.	n.s.

Note. TP – temporoparietal region; FC – frontal cortex; n.s. – not significant.

In the biofeedback group (BF) the total score on the Depression Anxiety Stress Scales-21 (DASS-21) fell from 21.78 ± … to 7.67 ± … ($p = 0.008$), indicating a pronounced clinical effect. The cognitive-behavioural intervention (CBI) produced a comparable change, with scores decreasing from 15.29 ± … to 4.00 ± … ($p = 0.028$). Concurrent administration of both approaches (BF + CBI) did not yield statistically significant alterations in the composite score.

Analysis of the DASS-21 subscales using the Friedman test confirmed that each procedure selectively reduced distinct affective components. In the BF group significant decreases were observed for anxiety ($p = 0.028$), depression ($p = 0.035$) and stress ($p = 0.012$). The CBI group showed a trend toward lower depression scores ($p = 0.068$) and a significant reduction in stress ($p = 0.027$), suggesting that the two therapeutic mechanisms modulate emotional regulation through different pathways.

The global Pittsburgh Sleep Quality Index (PSQI) improved after CBI ($p = 0.041$) and in the combined BF + CBI cohort ($p = 0.075$), whereas no such change emerged in the stand-alone BF group. All three cohorts reported a subjective enhancement of sleep quality; BF chiefly shortened sleep-onset latency and prolonged total sleep time, while the BF + CBI combination additionally reduced daytime sleepiness, pointing to distinct intervention targets within circadian regulation.

Salivary cortisol secretion displayed only a non-significant downward trend among participants receiving CBI ($p = 0.121$), and no reliable shifts were detected in the remaining groups [2]. The absence of a marked endocrine response in the presence of substantial psychometric improvement implies that the clinical benefits are mediated primarily by cognitive-affective rather than hormonal mechanisms.

In summary, BF amplifies delta, theta and alpha activity in the parietotemporal region, whereas CBI affects frontal beta activity. Both techniques markedly attenuate symptoms of anxiety, depression and stress and enhance subjective sleep quality. Their combination produces intermediate effects, underscoring the need to optimise stimulation parameters for specific therapeutic objectives.

3) Integrating innovation into consumer products and health ecosystems

Royal Therapy, a subsidiary of Pharmonis USA LLC, was founded on the conviction that every individual deserves quality sleep, luxury, and enhanced well-being. Engineering excellence and premium design are embodied in its range of orthopedic pillows, mattresses, and bedding, which have garnered more than 18 000 five-star reviews on Amazon owing to their capacity to alleviate neck and back pain, reduce anxiety, and improve sleep quality.

According to company projections, Royal Therapy’s sales volume will exceed USD 6 million in 2025, reflecting the brand’s growing popularity, customer trust, and the pronounced impact of its products on users’ lifestyles. Royal Therapy’s mission- to deliver aesthetically appealing, high-quality health-oriented products- has been transforming both the e-commerce industry and the wellness sector, establishing a new standard of “functional luxury” in sleep health.

Contemporary wearable devices have progressed beyond simple counts of steps and calories, shaping habits, encouraging healthy behaviors, and increasing user accountability for personal health status.

The prospects for multimodal sensory systems are exemplified by the emergence of digital technologies for the delivery of aromatic stimuli that, according to a predetermined schedule or in response to recorded biosignals, can discretely release either calming or cognitively activating compositions. Such digital scent delivery creates an adaptive olfactory environment, shifting the focus from passive odor perception to active therapeutic application and opening a new niche in neurosensory modulation of behavioral states.

Non-invasive glucose monitoring based on optical sensors and artificial-intelligence algorithms demonstrates comparable transformative potential. By eliminating the need for skin puncture, it enables continuous glycemic tracking, thereby expanding the horizons of personalized nutrition and metabolic management. Integration of such systems into everyday wearable electronics promises an evolution toward a preventive health model in which dietary and physical-activity adjustments are made in real time on the basis of objective biodata.

The convergence of these sensors with data-analytics applications and platforms makes it possible to create an ecosystem in which hardware solutions (sleep products, wearables) are complemented by digital services, forming closed-loop feedback cycles capable of continuously assessing and adjusting sleep conditions and physiological parameters [9, 10].

Royal Therapy illustrates how premium sleep products can become the nucleus of a health ecosystem that unites

1) Orthopedic equipment (pillows, mattresses) for optimizing sleep physiology,
2) Wearables and biosensors for monitoring and motivating the user,
3) Digital services (mobile applications, AI algorithms) for personalized recommendations, and
4) Additional multimodal interfaces (aroma- and light stimulation, non-invasive biomonitoring).

Table 3 illustrates the key components of this ecosystem.

Table 3: Key components of the sleep-health ecosystem (compiled by the author based on the analysis: [1, 2]).

Component	Example product(s)	Core functions	Targeted benefit
Sleep hardware	Royal Therapy orthopedic pillows, mattresses	Optimization of neck/back support; sleep-posture adjustment	Pain reduction; improved sleep quality
Wearable tracking	Oura Ring, Garmin, WHOOP	HRV analysis; monitoring of sleep stages and body temperature	Personalized recommendations; motivation
Digital feedback	Vital Tones DBSS application	Audio stimulation; collection of user reports	Deeper sleep; high user satisfaction
Digital scent delivery	FeelReal, Vortx	Electronic generation of aromas tailored to the user profile	Reduced anxiety; enhanced concentration
Glucose monitoring	GlucoTrack, FreeStyle Libre WW	Optical/LC analysis of non-invasive glucose levels	Optimized nutrition and metabolic management

Thus, the integration of advanced technological products and services enables closed-loop systems for sleep monitoring and intervention, resulting in a synergistic effect: harmonization of sleep physiology, enhancement of psycho-emotional well-being, and improvement of overall health.

2. Conclusion

A combined approach comprising a retrospective DBSS analysis, a randomized controlled trial of BB/IT and closed-loop EEG-guided auditory stimulation demonstrated a potentiating effect on deep-sleep stages: increased delta- and theta-power, significant reductions in anxiety, depression and stress symptoms, and improved subjective sleep quality.

High user satisfaction (99.3–99.5 %) and robust effects observed in the trial confirm the methods’ applicability in home settings. Integrating the stimulators into premium sleep products (Royal Therapy), wearable trackers and multimodal sensors establishes a continuous feedback ecosystem capable of enhancing user accountability for sleep quality and overall health.

Despite these encouraging findings, the study is limited by its retrospective DBSS design and the small sample size of the trial. Large-scale, multicenter randomized studies incorporating polysomnography, closed-loop EEG stimulation and objective monitoring of cortisol levels and heart-rate variability are required.

References

[1] U. Dogan, "Deep Brain Sound Stimulation for Sleep: Precision Auditory Stimulation", pp. 9–37, 2025. DOI:10.5281/zenodo.14700257

[2] S. A. Kanzler et al., "Effects of acoustic neurostimulation in healthy adults on symptoms of depression, anxiety, stress and sleep quality: a randomized clinical study" ", *Exploration of Neuroprotective Therapy*,vol. 3, no. 6, pp. 481–496, 2023, DOI: https://doi.org/10.37349/ent.2023.00064

[3] C. Lustenberger, "Enhancing deep sleep and heart function with auditory stimulation", *Brain Stimulation: Basic, Translational, and Clinical Research in Neuromodulation*, vol. 18, no. 1, p. 233, 2025, DOI:10.1016/j.brs.2024.12.060

[4] M. K. Attokaren et al., "BrainWAVE: a flexible method for noninvasive stimulation of brain rhythms across species", *Eneuro,* vol. 10, no. 2, pp. 1–14, 2023, DOI:10.1523/ENEURO.0257-22.2022

[5] D. Kim et al., "The sound stimulation method and EEG change analysis for development of digital therapeutics that can stimulate the nervous system: Cortical activation and drug substitution potential", *CNS Neuroscience & Therapeutics*, vol. 29, no. 1, pp. 402–411, 2023, DOI: 10.1111/cns.14014

[6] H. Engelbregt et al., "The effects of binaural and monoaural beat stimulation on cognitive functioning in subjects with different levels of emotionality", *Advances in cognitive psychology*, vol. 15, no. 3, pp. 199–207, 2019, DOI: 10.5709/acp-0268-8

[7] G. Sousouri et al., "Neuromodulation by means of phase-locked auditory stimulation affects key marker of excitability and connectivity during sleep", *Sleep*, vol. 45, no. 1, pp. 1–13, 2022, DOI: 10.1093/sleep/zsab204

[8] Y. J. Su, P. L. Yi, and F. C. Chang, "Transcranial direct current stimulation (tDCS) ameliorates stress-induced sleep disruption via activating infralimbic-ventrolateral preoptic projections", *Brain Sciences*, vol. 14, no. 1, p. 105, 2024, DOI: 10.3390/brainsci14010105

[9] Y. Cabral-Calderin and M. J. Henry, "Reliability of neural entrainment in the human auditory system", *Journal of Neuroscience*, vol. 42, no. 5, pp. 894–908, 2022, DOI: 10.1523/JNEUROSCI.0514-21.2021.

[10] A. A. Mahadule et al., "Sleep quality and sleep hygiene in preclinical medical students of tertiary care center amidst COVID-19 pandemic: a cross-sectional observational study", *Journal of Rural Medicine*, vol. 17, no. 3, pp. 137–142, 2022, DOI: 10.2185/jrm.2021-048