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REVIEW

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# The neurobiology of altered states of consciousness induced by drumming and other rhythmic sound patterns

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## Abstract

Humans have long sought to alter their mental states through various cultural practices, with rhythmic sounds emerging as a prominent and enduring method. However, altered states of consciousness induced by rhythmic auditory stimulation have not been comprehensively addressed in academic research, and the associated cognitive and neural underpinnings remain enigmatic. This narrative review synthesizes the behavioral, cognitive, and neural correlates underlying nonordinary experiences elicited by rhythmic sounds. The evidence gathered aligns with the notion that being exposed to these sounds facilitates a state of absorption and relaxation. The findings on the neural activity were diverse, reflecting the use of various methodologies in the reviewed studies. We discussed that altered states induced by rhythmic sounds may be explained by a mechanism involving the entrainment of thalamocortical pathways to low-frequency activity—a physiological state that also characterizes psychotic and psychedelic experiences. This proposal integrates insights from diverse findings, which reflect the variability in methodologies used to address these phenomena.

KEYWORDS
altered states of consciousness, binaural beats, drumming, mantra, thalamus

## INTRODUCTION

A striking cross-cultural phenomenon observed throughout the entire world is the use of sound to induce altered states of consciousness.[1] These nonordinary experiences are behavioral/mental states characterized by subjective deviations from ordinary wakefulness,[2] including alterations in perception, affect, and cognition. There is direct evidence that our ancestors engaged in practices aimed at altering the mind as far back as 3000 years ago.[3] However, the remains found in archaeological sites seem to suggest an older use at least from the

Magdalenian in the Upper Paleolithic, with dates as old as 14,000 years ago.[4,5]

Diverse types of external experiences and practices can trigger altered states of consciousness, catering to diverse purposes, and resulting in a range of cognitive and phenomenological alterations. Typically, inducing alterations in consciousness has been accomplished through ritualized and semi-formalized manners, consumption of a range of substances, the practice of certain rituals, and the use of repetitive forms of sensory and motor stimulation.[6] Notably, sound stands out as one of the most ancient means to induce altered states of consciousness.[1] The most well-documented example is drumming by shamans or ritual specialists, a practice that may have a long history since percussion instruments have been found dating back to the Paleolithic.[7,8] Under certain social contexts, the drumming undertaken by ritual specialists involves powerful experiences known in the literature as a *shamanic journey*,[9] often experienced as a lucid dream. Despite their significance in human history, altered states of consciousness induced by sound have not been adequately addressed in academic research, especially when compared to extensively studied altered states of consciousness such as meditative states[10–12] and those induced by psychoactive substances.[13–15]

In the neuroscientific literature, sound-induced altered states of consciousness have been primarily investigated using highly rhythmic or isochronous auditory stimuli. This encompasses drumming,[16–22] binaural beats (BBs),[23–31] and sound-based spiritual practices like chanting and mantras.[32–37] The focus on rhythmic sounds compared to other forms of auditory stimulation may stem from rich anthropological descriptions of their phenomenological effects in ritual settings, which likely influenced subsequent research in neuroscience. Forms other than isochronous and highly rhythmic auditory stimulation used to induce altered states of consciousness include music that does not necessarily feature strong accentuated beats[38–40] and Ganzfeld.[41] Research on music experience related to nonordinary consciousness is starting to emerge, showing alterations in absorption and mind wandering, as evidenced in a recent review.[42] Regarding Ganzfeld, this technique involves exposing individuals to uniform and unstructured sensory stimulation—such as white noise and constant light—to create a homogeneous perceptual environment, which systematically leads to experiencing hallucinations and a state of relaxation.[43–50]

Despite the growing body of experimental research on rhythm-induced altered states of consciousness, a comprehensive overview that can guide future investigations in the field is still lacking. Here, we focus exclusively on isochronous and highly rhythmic sounds that are based on both anthropological and neuroscientific grounds, which highlight a fundamental distinction between rhythm-induced altered states of consciousness from those states induced by other types of auditory stimulation. This is because unconnected cultures around the world use repetitive auditory stimulation as facilitators to induce altered states of consciousness.[51–53] This observation suggests that rhythmic sounds may activate a universal mechanism for the induction of nonordinary experiences. Also, rhythmic and isochronous sounds seem to engage the nervous system in ways that differ from other types of nonrhythmic auditory stimulation.[54–56] This suggests the involvement of a distinct neural mechanism where repetition and rhythmicity may play a key role in facilitating altered states of consciousness. Given these observations, studying rhythm-induced altered states of consciousness separately from other altered consciousness–inducing auditory stimuli is necessary to accurately assess the role of rhythmicity without conflating it with other auditory influences.

Furthermore, while music can also induce altered states of consciousness,[42] it encompasses a wide range of auditory features beyond rhythm, such as melody, harmony, and emotional content. Since our goal is to isolate the specific effects of rhythmic repetition on consciousness, we focus on practices that explicitly link rhythmicity to altered states, such as shamanic drumming, chanting, and BBs, while setting aside broader forms of musical behavior that, though potentially relevant, introduce additional variables beyond the scope of this review.

The forms of rhythmic auditory stimulation reviewed here have been approached differently in terms of methodology and phenomenological constructs measured. This warrants a comprehensive review with sections organized by the type of rhythmic sound, namely, drumming,[16–22] BBs,[23–31] and sound-based spiritual practices.[32–37] The review within each section can ultimately converge into a comprehensive understanding of the neurobiology of altered states of consciousness induced by rhythmic sounds. However, while drumming, BBs, and mantras/chanting share the common element of repetition, they differ in several fundamental ways, such as in the perceived rhythm and repetition rate. These differences may have significant implications for their psychological and neural effects and are further discussed in subsequent sections.

This narrative review examines the neuroscientific and biobehavioral evidence of altered states of consciousness induced by rhythmic and isochronous sounds. Building upon the evidence gathered in the review, this work discusses a putative neural mechanism by which sound structured in metric forms may trigger altered states of consciousness. Additionally, we discuss future directions informed by the reviewed studies and emerging questions in the field. Sound has long played a significant role in rituals around the world.[57–61] However, prior research has focused on the instruments' physical properties[62] rather than on the effects of the sounds they produce on listeners. This review addresses this gap by examining the influence of sound on neural activity, subjective experiences, and cognitive function. Additionally, understanding these altered mental states holds the potential to enrich our comprehension of brain function and consciousness. Altered states of consciousness triggered by drugs, such as the psychedelic state,[63–65] have served as models for consciousness research. However, drug-based models can introduce confounding effects due to their interactions with multiple brain receptors beyond their primary targets.[21] This review explores sound as a nonpharmacological alternative to investigating altered states of consciousness, avoiding such biases.

## ALTERED STATES OF CONSCIOUSNESS INDUCED BY DRUMMING

Two independent studies[16,17] reported that participants engaged in an imagery task (e.g., visualizing a journey into the earth through an opening to explore the landscape)[52] while listening to monotonous drumming experienced a distorted body image and sense of time. These changes were similar to those triggered by following instructions meant to induce hypnosis.[16] Also, conducting the imagery task while listening to drumming triggered vivid experiences, including visual imagery, auditory sensations, encounters with animals, and insights, that were linked to the rhythmicity of the drumming.[17] Notably, engaging solely in the imagery task did not induce any significant effects, suggesting that drumming makes a substantive contribution to the effect.[16] The effects of listening to drumming without conducting the imagery task were not explored, meaning that the unique contribution of drumming alone remains unknown. Also, participants' global experience did not deviate from everyday wakeful situations.[17]

One seminal study[18] collected electrophysiological and behavioral data in natural conditions from one participant entering a possession state during a ritual. Possession states are a type of altered state of consciousness in which a person's behavior is popularly explained by being taken over by another being.[66] However, there is a wide cross-cultural variation in how this takes place and how it is interpreted.[67] In the ritual, the drumming stimulation was produced by a bamboo percussion instrument that was beaten with a stick and played throughout the entire event, becoming notably louder at the climax of the ritual. The possessed participant's behavior was characterized by automatism-like actions, including falling and eyes-closed periods, and by anterograde amnesia. Compared to nonpossessed periods and to participants who did not get possessed in the ritual, the possessed individual showed enhanced power in the classical electroencephalography (EEG) theta (4–7 Hz) and alpha (8–12 Hz) bands. These findings, along with results from other studies examining rhythmic stimulation and brain rhythms, are summarized in Table 1. However, the experimental design of the study could not include direct manipulation of the stimulation due to the impracticality of implementing it within the context of a naturalistic ritual. Consequently, it was unfeasible to disentangle the effects of rhythmic stimulation from other factors, such as the ritualistic context.

Hove et al.[19] investigated the functional implication of specific brain regions during self-induced trance by measuring brain activity with functional magnetic resonance imaging (fMRI). A group of experienced shamanic practitioners, trained in *core shamanism*—a system of techniques based on cross-cultural shamanic traditions—followed the instructions of an imagery task[52] and were either instructed to enter a trance or not while listening to an 8-min drumming stimulation. To induce trance, practitioners laid down with their eyes closed while listening to repetitive drumming, minimizing external sensory input and facilitating an absorptive state. The drumming consisted of a low-pitched hand drum recording (*Solo Drumming* by Michael Harner) played over headphones. In the trance condition, the drumming followed a relatively isochronous pulse at approximately 4.24 Hz with minimal natural timing fluctuations, while in the nontrance condition, the same sounds were used but with slightly more irregular timing to prevent unintentional trance induction.

The scans produced relatively constant noise floor in both conditions, ensuring minimal interference with the experimental conditions. The results revealed that the posterior cingulate cortex (PCC), the dorsal anterior cingulate cortex (dACC), and the left insula/operculum actively participated as strong functional hubs of information processing during trance compared to nontrance states. Additionally, these three brain regions showed mutual strong functional connectivity during trance states. Subsequent seed-based analysis revealed a decreased functional connectivity within the auditory pathway only for participants who entered a trance state. These findings, along with other reviewed effects of rhythmic stimulation on brain regions and networks, are summarized in Table 2. The authors concluded that the PCC, the dACC, and the insula are key anatomical regions in supporting integrated brain function during trance. Specifically, the PCC would support an internally oriented mentation as part of the default mode network (DMN), for which decreased activity has been previously linked to externally oriented tasks,[68–70] and is traditionally linked to self-referential thoughts and mind wandering.[71,72] The dACC and insula would enhance task-relevant neural activation. Also, the decreased functional connectivity within the auditory pathway suggests a perceptual decoupling that would add to the absorptive state by depriving the participant of the sensory environment. A limitation of this study is, however, that participants were experienced shamanic practitioners and that, due to the presence of auditory stimulation in both trance and nontrance conditions, the results do not allow for properly discerning the effects that repetitive stimulation and participants' expertise have on the observed altered state of consciousness.

Lanzilotti et al.[20] investigated whether the repetitive elements and the length of auditory stimulation contributed to the induction of a dissociative state. Inexperienced participants were exposed to both long and short periods of rhythmic and nonrhythmic auditory stimulation while their brain activity was measured with EEG. The rhythmic stimulation had a repetition rate at 2.15 Hz. In response to the long stimulation, regardless of the rhythmicity, participants exhibited reduced auditory sensitivity, indicated by higher auditory thresholds in a psychophysical detection task. The rhythmic beat enhanced this effect compared to nonrhythmic stimulation. The spectral profile of the EEG during the rhythmic stimulation revealed a coupling between brain activity and the beat of the stimulation, an effect that was greater for long compared to short periods of stimulation. Furthermore, a connectivity analysis showed coherence in the alpha band between frontal and central scalp locations, which was significant for the rhythmic compared to the nonrhythmic beats. However, no further analyses were conducted to explore the potential relationship between the electrophysiological findings and the behavioral effects and to potentially determine whether brain entrainment to the stimulation could account for the observed dissociative state.

In a study conducted by Huels et al.,[21] experienced (i.e., shamanic practitioners) and inexperienced participants listened to 25 min of

**TABLE 1** Summary of findings on brain rhythms and their reported effects during altered states of consciousness induced by rhythmic stimulation.

| Brain rhythm | Effect | Reference |
|---|---|---|
| Delta | ↑ power at 2.5 and 3 Hz through entrainment of neural oscillations | Jirakittayakorn and Wongsawat[31]<br>Lanzilotti et al.[20] |
| Theta | ↑ power at 4, 6, 6.66, and 7 Hz through entrainment of neural oscillations | Jirakittayakorn and Wongsawat[23]<br>Karino et al.[86]<br>Perez et al.[24] |
| | ↑ power (4–7 Hz) | Oohashi et al.[18] |
| Alpha | ↑ power (8–12 Hz) | |
| | ↓ functional connectivity (8–10 Hz) | Huels et al.[21] |
| | ↑ fronto-central connectivity at scalp | Lanzilotti et al.[20] |
| Beta | ↑ functional connectivity (13–20 Hz) | Huels et al.[21] |
| | ↑ criticality (13–30 Hz) | |
| Gamma | ↑ power (30–45 Hz) | |
| | ↓ signal diversity (30–45 Hz) | |
| | ↑ criticality (30–45 Hz) | |
| | ↑ power (40 Hz) through entrainment of neural oscillations | Perez et al.[24] |

*Note*: ↑ indicates an increase or enhancement, while ↓ indicates a decrease or reduction.

**TABLE 2** Summary of brain regions and networks and their reported effects during altered states of consciousness induced by rhythmic stimulation.

| Brain region/network | Effect | Reference |
|---|---|---|
| Posterior cingulate cortex, dorsal anterior cingulate cortex, left insula/operculum | Strong hubs of information, increased functional connectivity | Hove et al.[19] |
| Auditory pathway | Decreased functional connectivity | |
| Anterior insula, thalamus, left primary somatosensory cortex, left inferior parietal lobule, primary auditory cortex, posterior superior temporal gyrus | Reduction in brain activity | Fox et al.[36] |
| Broca's area, premotor and supplementary motor cortices, putamen, globus pallidus | Increase in brain activity | |
| Widespread cortex | Reduction in brain activity | Berkovich-Ohana et al.[37] |

continuous drumming while high-density EEG was recorded. Only the experienced participants were asked to enter an altered state of consciousness. After the drumming, all participants filled out the retrospective OAV questionnaire,[73,74] an altered state of consciousness rating scale, where OAV is an abbreviation derived from the German names of its three dimensions: Oceanic Boundlessness, Dread of Ego Dissolution, and Visionary Restructuralization. As a control, experienced and inexperienced participants also listened to 15 min of classical music and were instructed not to enter an altered state of consciousness. The results revealed that the experiences of shamanic practitioners listening to the drumming contained more features typical of altered states of consciousness compared to inexperienced participants and to both groups while listening to classical music. The practitioners' experiences were comparable to the reports observed during drug-induced psychedelic states.[75] However, no results were reported regarding differences in the participants' experiences when listening to drumming compared to classical music between experienced and inexperienced participants. Such an analysis would further disentangle the effects of participants' expertise on trance states.

Huels et al.[21] analyzed brain activity in terms of its spectral components to ascertain the neural correlates of the shamanic trance state. In addition, for each of the frequency bands of the EEG power spectrum, several other EEG metrics were assessed, such as functional connectivity, signal diversity (i.e., the number of different patterns in the signal), and criticality (i.e., the balance between order and disorder in which the brain networks' processing and computing properties seem to be optimal). Overall, the results revealed different brain activity patterns between experienced and inexperienced participants across all auditory conditions. Specifically, the brain activity patterns of shamanic practitioners during drumming, compared to inexperienced participants and the stimulation with classical music, were characterized by enhanced gamma power that correlated with the degree of visual alterations and decreased signal diversity in the gamma band, which inversely correlated with insightfulness. Additionally, during both drumming and classical music, shamanic practitioners displayed a decreased low alpha and increased low beta functional connectivity, and increased criticality in the low beta, high beta, and gamma bands. Also, increased criticality in the low beta band correlated with complex imagery and elementary visual alterations. The authors suggested that shamanic practitioners can enter an altered state of consciousness characterized by a specific brain activity profile that correlates with self-reported changes in subjective experience. Further, shamanic practitioners have a trait-specific brain activity profile that becomes evident even when listening to classical music.

Only one study explored the biochemical and psychological effects of shamanic journeying and relaxation while being exposed to either drumming or instrumental meditation music.[22] The study assessed participants' cortisol levels in saliva samples taken before and after the task. Low levels of the hormone cortisol have been associated with relaxation.[76,77] The results indicated that listening to either drumming or instrumental meditation, while engaging in either shamanic journeying or relaxation, made participants feel calmer and more relaxed compared to baseline levels. This psychological effect was aligned with a biochemical effect; cortisol levels decreased regardless of the type of music exposure and instructions compared to baseline measurements. However, listening to repetitive drumming and engaging in shamanic journeying increased muscular relaxation and dreamlike experience and decreased heart rate compared to listening to drumming while relaxing. These findings suggest that combining repetitive drumming with shamanic journeying has a distinct effect on the participants' experience compared to other combinations of instruction and types of music.

In sum, the reviewed studies show that rhythmic drumming is associated with subjective and physiological markers of altered states, particularly among experienced practitioners.[18,19,21] These individuals reported experiences comparable to those induced by psychedelics[21] or showed distinct patterns of brain activity[18,19,21] during drumming compared to control conditions. In individuals without prior experience, repetitive drumming combined with imagery-based tasks or shamanic journeying was associated with altered perceptual experience[16,17] and reductions in cortisol levels and heart rate, indicative of a parasympathetic shift.[22] When not coupled with imagery tasks or shamanic journeying, prolonged rhythmic stimulation altered auditory sensitivity.[20] Collectively, these findings underscore the capacity of rhythmic auditory input to modulate conscious states via both state- and trait-dependent neural mechanisms.

## BINAURAL BEATS

Hearing two slightly different pure tone frequencies, one in each ear, produces the perception of one integrated illusory sound that fluctuates in volume with a frequency equal to the difference between the frequencies of the two generators.[78] This phantom sound is termed BB. Some have considered BBs as a new type of digital drug[28] due to their potential to modulate mood and cognition.[79]

There have been no studies using validated scales to explore the capacity of BBs to induce altered states of consciousness. Nor are there studies relating to BBs and altered states of consciousness. Also, the effects of BB stimulation on cognition were not addressed in the latest review on the topic.[6] However, BBs have found an application in studies that could be related to altered states of consciousness, particularly in investigating BB-induced alterations in emotional and physiological states, which are commonly used as proxies for altered states of consciousness. Also, other studies have explored the effect of BBs on modifying sleep stages, sleep being a spontaneously occurring altered state of consciousness.[6] Research on the effect of BBs on emotional states or sleep has been conducted by using BBs in the delta and theta frequency bands, respectively, to synchronize neural activity to the frequency of the BB and investigate the subsequent effects. Neural activity in the theta band has been linked to drowsiness, deep relaxation, and meditative states,[80] while brain activity in the delta band is strongly associated with dissociative states.[81] These associations support the interest in systematically examining the potential relationship between BBs and altered states of consciousness, despite this relationship not having been explicitly outlined in existing literature.

Jirakittayakorn and Wongsawat[23] exposed one group of participants to 6 Hz BBs (i.e., theta BBs) and another group to silence for 30 min while EEG was recorded. Later, all participants filled out the Brunel Mood Scales[82,83] to measure the participants' emotional state while listening to the stimulation. The findings revealed that listening to theta BBs decreased anger, depression, fatigue, and confusion compared to listening to silence. However, the choice of silence as a control condition has limitations, as this does not account for potential nonspecific effects of auditory stimuli. Listening to theta BBs increased theta brain activity in nearly all cortical regions, presumably entrained by the 6 Hz BB. While theta activity was enhanced throughout the cortex, a distinct pattern emerged at the frontal midline region, resembling the electrophysiological patterns commonly associated with meditative states.[84,85]

Studies other than Jirakittayakorn and Wongsawat[23] have shown similar brain coupling to theta BBs[24,86] and theta-specific increases of relaxation and decreases in autonomic dynamics, such as heart rate.[25] However, others did not find entrainment of brain activity to the BB frequency[26,27,87] nor theta-specific changes in physiological measures.[27,28] The discrepancy in results across studies may be attributed to methodological variations.[29] Specifically, a period of more than 3 min of BB stimulation might be needed to entrain the brain to the phantom frequency of the BB,[88] as two out of the three studies not reporting entrainment employed stimulation durations shorter than 3 minutes.[26,27] This contrasted with the studies that documented behavioral changes following exposure to theta BBs, which used stimulation periods of 20–30 min,[23,25] whereas studies that did not observe such changes employed stimulation periods of 3–4 min.[27,28] The discrepancies observed in the reported findings are consistent with the conclusions drawn from a previous meta-analysis that emphasized the importance of longer exposure periods to BBs to ensure maximum effectiveness to affect cognition.[29]

Most investigations on BBs within the delta frequency have primarily focused on sleep. Sleep is a spontaneously occurring altered state of consciousness[6] characterized by slow oscillatory brain activity ranging in the delta band (1–3 Hz) during non-rapid eye movement (non-REM), especially in stage 3 sleep or deep sleep.[89] Exposure to delta BBs before and/or during sleep for consecutive days leads to improvements in sleep quality compared to not listening to delta BBs[30] and compared to control groups exposed to a sham stimulus, namely, silence.[31] Sleep improvement was determined through self-report assessments and changes in non-REM sleep stages as determined with EEG, electromyography, and electrooculography.[30] Regarding the self-reports, sleep improvement manifested as decreases in sleep failure, a smaller number of awakenings, increases in real duration of sleep, and higher quality of sleep. For changes in non-REM sleep, listening to delta BBs while sleeping increased the duration and decreased the onset latency of sleep stage 3 while reducing the duration of the previous transitional sleep stage, namely, the N2 sleep stage.

Listening to delta BBs during sleep increased brain activity at the delta frequency, as reflected by an enhancement of delta power in the EEG signal.[31] This brain–stimulus frequency coupling could potentially explain the effects of BBs observed in sleep. Neural ensembles within the brain may entrain to external delta frequency stimulation, resulting in an increase of endogenous delta activity and facilitation of stage 3 sleep in terms of its latency and duration. Consequently, an increase in stage 3 sleep may explain the reported heightened subjective perceptions of sleep quality.[30] However, no research has been conducted to corroborate the causal role of stimulation with delta BBs and improvements in sleep quality. Noteworthy, any repetitive auditory stimulation, extending beyond BBs, has the capacity to entrain the brain to its beat frequency[90] and, therefore, could potentially modulate sleep stages and sleep quality as well. Also, various types of auditory stimuli, such as white noise, pink noise, and music, have exhibited potential in improving sleep quality.[91] Further research is needed to disentangle the distinctive effects of BBs on sleep compared to other forms of auditory stimulation.

Taken together, these findings suggest that BBs in the theta and delta frequency bands modulate emotional and physiological states often associated with altered states of consciousness. Exposure to theta BBs facilitated a state of psychophysiological relaxation, characterized by both reduced negative affect[23] and decreased autonomic arousal,[25] and enhanced cortical activity in the theta band.[23,24,86] However, findings on both behavioral effects[26,27] and neural entrainment remain inconsistent,[26,27,87] with discrepancies largely attributed to variations in the duration of the stimulation.[29] Exposure to delta BBs, on the other hand, improved sleep quality[30,31] and enhanced delta EEG power during sleep.[30] These effects suggest BBs may support neural entrainment and altered states like deep sleep, though further research is needed to isolate their effects from other auditory stimuli known to influence sleep.

## MANTRAS AND CHANTING

Chanting practiced regularly has been associated with mystical experiences, even when done silently, in the absence of a group setting, or the framework of different traditional practices.[32] Levels of absorption, altruism, and religiosity were high among people who reported mystical experiences when chanting. Additionally, the mystical experiences were characterized by an enhanced positive mood and feelings of ineffability. The question of whether nonpractitioners exhibit similar effects when chanting remains unexplored. Furthermore, to our knowledge, no empirical research has been conducted on the neural mechanisms underlying the reported behavioral effects of chanting.

Meditation programs or single meditation sessions that include mantras have been proven to reduce knee pain and dysfunction,[33] enhance the immune system by increasing the salivary immunoglobulin A,[34] improve mood and affective states,[33,34] and increase galvanic skin responses, suggesting a potential enhancement of relaxation.[35] A systematic review revealed that mantra meditation practices have the potential to enhance mental health and decrease negative affectivity in nonclinical populations.[92] However, the results from this review should be interpreted with caution due to limitations in the quality of the studies in this field.

The neural correlates of meditation, including mantra meditation, have been investigated in a meta-analysis of 78 functional neuroimaging studies.[36] This meta-analysis revealed that mantra meditation consistently activates brain areas involved in internally generating and maintaining focus on a repeated phrase in one's mind or recited aloud, aligning with the objectives of mantra meditation. These areas include regions of the motor control network, namely, Broca's area, the premotor and supplementary motor cortices, and the putamen. Substantial brain activity was also observed in various regions of the basal ganglia, including the putamen and globus pallidus. While these areas are associated with reward,[93] they are most strongly implicated in highly practiced motor movements and habit formation.[94,95] Moreover, the basal ganglia are thought to assist in inhibiting undesired movements and facilitating the smooth execution of desired actions through strong reciprocal connections with premotor areas.[96,97]

The meta-analysis[36] also revealed a notable pattern of brain deactivations during mantra meditation, including the anterior insula, the thalamus, the left primary somatosensory cortex, and the left inferior parietal lobule, all implicated in processing sensory inputs and somatosensation. Similarly, deactivations were also observed in the primary auditory cortex and the posterior area of the superior temporal gyrus, both involved in the processing and comprehension of sounds and language. This pattern of brain deactivation suggests that mantra meditation dampens the processing of external sensory inputs, particularly those related to somatosensation and auditory inputs.

One study has attempted to isolate the overall effect of repetitive speech on brain function.[37] The study used fMRI to measure the cortex's response to a repetitive speech sound—the word "one"—which has not been used in any meditation tradition and thus has no meditation-like qualities. Only nonexperienced participants in meditation were recruited to rule out any possible confound related to the participants' previous training or beliefs. Magnetic resonance (MR)-compatible earphones were used to reduce scan noise. The findings showed that repetitive speech elicited widespread deactivation in the human cortex relative to a resting state, partially aligning with previous results of a meta-analysis.[36] The widespread suppression of neural activity also included brain areas corresponding to the DMN. The authors argue that the cortex is largely in an off mode when reciting mantras. The deactivation of the DMN might be due to language processes triggered by the mantra "one," and that might block the DMN due to dependencies between language regions and the DMN. To further examine the effects of repetitive speech on cognition, a follow-up behavioral experiment was conducted.[37] The results of a custom-made questionnaire revealed that participants experienced fewer thoughts and sensations while engaging in repetitive speech compared to a baseline state.

The reviewed work suggests that rhythmic repetition, whether vocalized or silent, is associated with experiencing altered states of consciousness. Chanting was linked to mystical experiences marked by absorption, ineffability, and enhanced mood.[32] Mantra-based practices were associated with reductions in pain and negative affect and improvements in immune function.[33,34] Neuroimaging data show that mantra meditation inhibits regions involved in sensory and auditory processing, indicating a redirection of attention inward.[36] Even in the absence of meditative intent, simple repetitive speech using a neutral, nonspiritual word produced widespread cortical deactivation, including in the DMN, and reduced self-reported thought content in meditation-naive participants,[37] suggesting that rhythmic repetition alone can induce a distinct neural and experiential state.

## THE NEUROBIOLOGY OF ALTERED STATES OF CONSCIOUSNESS INDUCED BY RHYTHMIC SOUNDS

Together, the behavioral evidence gathered in this review suggests that altered states of consciousness triggered by various means of auditory stimulation share a common hallmark: they are characterized by absorption[17,18,20–22,30,32,98] and/or a state of relaxation.[22,23,25,33,35] While it is generally recognized that rhythmic auditory stimulation can induce altered states of consciousness characterized by absorption and relaxation,[6,19] no review had previously synthesized findings across different methodologies and paradigms. In some studies, rhythmic auditory forms facilitated experiences characterized by vivid mental imagery, specifically when combined with specific behavioral instructions[17,22] or when experienced by regular practitioners in entering altered states of consciousness.[21]

Drawing upon the diverse array of studies investigating behavioral proxies, global states, and neural correlates associated with altered states of consciousness induced by rhythmic sounds, our inquiry delves into identifying a mechanism by which rhythmic auditory stimuli facilitate these nonordinary experiences. The suggested mechanism demonstrates clear parallels with the shared neurobiological mechanisms described in both psychedelic states (i.e., altered states of consciousness induced by psychedelic substances) and psychotic states (i.e., acute phases of psychotic disorders),[99–101] emphasizing potential shared neural substrates across diverse altered states of consciousness.

### The potential role of the thalamus in altered states of consciousness induced by rhythmic stimulation

Not only participants with previous experience in entering altered states of consciousness can trigger these states aided by rhythmic stimulation,[18,19,21,102] but also naïve participants can by following instructions[17,22,98] and even by simply being exposed to the rhythmic stimulation.[20,23,25] The observation that repetitive auditory stimulation alone can potentially modulate consciousness suggests that the underlying mechanism is one that has the capacity to exert a broad influence on the cerebral cortex. This mechanism may reside in the thalamus, a diencephalic brain region which exerts widespread modulations on cortical activity.

One potential mechanism that could account for the occurrence of altered states of consciousness during auditory repetitive stimulation is thalamic gating.[103] The thalamus is a key subcortical brain structure involved in sensory processing, being part of the cortico-striato-thalamo-cortical loop.[104] This loop refers to the reciprocally connected pathways between the cortex and the thalamus and plays a critical role in gating and filtering sensory information from sensory organs to the cortex and vice versa. Under conditions of altered functioning, the thalamus can either propagate unfiltered sensory information from subcortical structures to the cortex, theoretically leading to an overflow of sensory information (sensory flooding),[105] or block the propagation of information from subcortical structures to the cortex.

The cortico-striato-thalamo-cortical loop has been previously implicated in various forms of altered states of consciousness. For instance, the loop is disrupted in schizophrenia and temporarily altered during pharmacologically induced altered states of consciousness with psychedelics.[106,107] Schizophrenia and serotonergic psychedelics, such as lysergic acid diethylamide (LSD) and psilocybin, enhance thalamocortical coupling, gating unfiltered propagation of sensory information to the cortex, and possibly contributing to the experience of hallucinations.[108–110] Subjective reports from patients with schizophrenia describe this uncontrolled stream of information as overwhelming[110,111] and give support to thalamic involvement in hallucinations.

Thalamocortical coupling might facilitate an inward-directed state by isolating the cortex from external stimuli.[19] Such a physiological state might account for the behavioral commonalities of trance, such as a narrowed awareness of one's surroundings and a narrow, selective focus on external stimuli.[112,113] Additionally, the inability to recall one's own behavior during the trance state (i.e., anterograde amnesia) reported in possession trance experiences[18] might also be explained by an attenuated coupling, which is key for memory encoding and consolidation.[114] Animal models suggest that the presence of alpha rhythmicity, which characterizes possession trance,[18] involves at least thalamocortical and intracortical networks.[115] The modulation of the thalamocortical mechanism can also explain the widespread reduction in brain activity observed during the recitation of mantras.[37]

Although the thalamus is a potential target structure involved in the neural mechanisms through which rhythm-induced altered states of consciousness may emerge, it remains unknown how repetitive sounds modulate the activity of the thalamus and, ultimately, key regions in the cerebral cortex. Yet, current understanding of the transmission and processing of auditory information through the brain may shed some light.

The primary neural correlates of acoustic beats (i.e., repetitive sounds) have been found in the cochlear nuclei in the brainstem, which is the earliest relay within the auditory pathway.[116] The information processed in the cochlear nuclei is further processed in a bottom-up fashion by other nuclei in the brainstem, including the superior olivary nuclei, the lateral lemniscus, and the inferior colliculus, before reaching the auditory thalamus (i.e., medial geniculate body [MGB]). The MGB has at least two discrete projection systems, the lemniscal and the nonlemniscal projection systems.[117,118] Most of the lemniscal projections originate from the ventral nucleus of the MGB and they forward stimulus-specific information to the primary auditory cortex (A1). In turn, the nonlemniscal projections originate from the dorsal and medial nuclei and send dense projections to the temporal association cortex and the entorhinal cortex. The temporal association cortex and entorhinal cortex exhibit extensive connectivity with cortical and subcortical regions associated with arousal.[119–121] Also, the nonlemniscal projections connect to subcortical regions mostly known for emotional and behavioral state modulation, such as the ventromedial hypothalamus, tail of the striatum, bed nucleus of the stria terminalis, lateral amygdala, basomedial amygdala, and medial amygdala.[122–126] Intracellular recordings in anesthetized guinea pigs and extracellular recordings of unanesthetized asleep guinea pigs revealed that the membrane potentials of nonlemniscal auditory thalamic neurons can be entrained (or synchronized) to a regular interval by external repetitive auditory stimulation.[87]

Based on the connectivity of the auditory pathway described above, entrainment of the nonlemniscal system of the MGB to slow-rate repetitive auditory stimulation may reduce the activity in the cortex by synchronizing it to a slow rhythm. To the best of our knowledge, no studies so far have explored the effects of slow oscillatory activity in the projections of the nonlemniscal neurons. However, research on psychedelic and psychotic states indicates that alterations in the connectivity between the thalamus and the cortex contribute to changes in perception during these states.[99–101] Therefore, it is a possibility that slow activity within the described pathways might alter brain activity in auditory and nonauditory brain regions related to visual perception, memory, and auditory perception, which previously has been associated with trance-like states.[18,98]

## The case of nonexplicit rhythms: Mantras and BBs

The preceding section has established the association between repetitive auditory stimulation and the entrainment of the nonlemniscal system of the MGB, which in turn results in reduced cortical activity and potentially leads to the induction of trance-like states. Yet, this mechanism falls short when considering silent mantras, devoid of any stimulation, and BBs, which lack a physical representation of the beat in the environment.

Previous research in humans has shown that imagining a particular auditory rhythm can entrain brain activity to its frequency range.[127] Therefore, it is noteworthy that the effects of reciting mantras silently might also be explained by coupling at slow rhythms. Yet, further research is needed to disentangle whether the coupling between the imagined beat frequency and the brain activity originates in the same structures as acoustic beats within the auditory pathway.

Similar to mantras, BBs do not inherently possess a beat; rather, the beat arises from the interplay between the two waves within the nervous system. Can coupling at slow rhythms explain the effects of BBs on consciousness? Animal studies using single-unit recordings have revealed that the earliest neural responses evoked by the phantom frequency of the BB stimulation in the auditory pathway occur in the superior olivary complex (SOC) of the brainstem,[128,129] which is the first anatomical relay in the auditory pathway receiving bilateral input. Before the SOC, the incoming sensory information from the two ears is conveyed ipsilaterally through distinct ascending pathways. The emergence of the illusory beat arises from the incapacity of the SOC to effectively track the interaural temporal changes of the two frequency generators.[130,131] A subsequent relay station following the SOC, the inferior colliculus of the midbrain, also shows neural responses phase-locked (or entrained) to the phantom frequency of the BB.[132,133] Therefore, despite the frequencies of the BBs absent in the acoustic signal, these phantom sounds have a physical representation in the form of neuronal activity within the auditory brain.

From the inferior colliculus, all outputs travel to the MGB of the thalamus. Additionally, evidence from EEG recordings and source localization analyses in humans reveal that the distribution of the cortical responses to BBs is comparable to that observed in normal acoustic beats.[134] Specifically, the cortical responses to BBs and acoustic beats are mostly present in the left and inferior temporal lobe, aligning with the notion that the left hemisphere of the auditory cortex exhibits specialization toward rapid acoustic changes and temporal processing.[135,136] The similar cortical distribution of the responses to BBs and acoustic beats suggests a parallel cortical processing of both sound types.

Given the similarities between how the brain processes BBs and the lack of evidence regarding the effects of the integration of the two BB generators on cognition,[27] it is possible that neural representations of BBs exert similar effects on projections as the rhythmic elements found in auditory inputs. An open question is, however, what are the mechanisms that allow trained individuals to trigger altered states of consciousness on demand, even when utilizing rhythmic stimulation as a facilitator. Insufficient research has been conducted thus far to establish a direct top-down influence that specifically impacts the thalamus.

### Beyond thalamic involvement

The literature reviewed thus far supports the idea that repetitive auditory stimulation modulates neural activity and results in alterations in brain function. However, alternative perspectives have also been proposed. Rouget[60] challenged the notion that neurological activity derived from repetitive stimulation is solely responsible for the induction of a rhythm-induced altered state of consciousness. Instead, Rouget proposed that the alterations in brain function may result from hypnotic or somnambulistic effects influenced by context, conditioning, or learning. Building upon this proposal, one study[137] found that drumming may be an effective means of inducing altered states of consciousness only for highly susceptible individuals. Therefore, it remains an open possibility that the effects of repetitive auditory stimulation on the brain can be disregarded as an explanatory mechanism of rhythm-induced altered states of consciousness. Instead, rhythm-induced altered states of consciousness might result from complex top-down interactions, such as the effect of personality traits including suggestibility or spirituality. An explanation of rhythm-induced altered states of consciousness based on contextual traits rather than the effects of repetition on the neurophysiology of the brain would support previous findings showing enhanced characteristics of altered states of consciousness when both auditory stimulation and shamanic instructions play a role.[22]

Might there be a neurobiological mechanism other than the thalamo-striato-cortical loop that could explain the phenomenology observed when reciting mantras? The respiratory pattern at about 0.1 Hz that reciting mantras generates coincides with slow deep breathing.[138] Deep breathing is a well-known breathing manipulation technique and has previously been linked to various physiological effects, such as effective alveolar ventilation,[139] reduced blood pressure,[140] and reduced markers of sympathetic activation.[141,142] In line with these physiological effects, deep breathing has been shown to increase the subjective feeling of relaxation and decrease anxiety.[143] Therefore, the phenomenology of the altered states of consciousness induced by mantras, such as an improved mood,[33,34] affective state,[33,34] and relaxation,[35] may be explained by the physiological effects related to deep breathing.

## EMERGING QUESTIONS AND FUTURE DIRECTIONS

Throughout history, sound has been one of the most fundamental tools for inducing altered states of consciousness.[1] One of the most well-documented examples is the use of drumming by shamans and ritual specialists, a practice that may date back to the Paleolithic.[7,8] Several of the studies reviewed draw on anthropological literature,[18–20,22,102] which observes that repetitive sounds have convergently evolved across diverse cultures worldwide. This cross-cultural perspective may have contributed to the emergence of two distinct research traditions: one phenomenological, emphasizing the subjective and experiential aspects reported in ethnographic studies, and the other neuroscientific, focusing on the neural mechanisms underlying these states, such as changes in brain activity and rhythmic dynamics. A key challenge in advancing the field lies in integrating these perspectives to develop a more comprehensive understanding of how rhythmic sounds shape conscious experience.

Studies focusing on the phenomenological aspects of altered states of consciousness often lack systematic methodology, whereas neuroscientific investigations are typically conducted in highly controlled laboratory environments that may not fully capture the richness of real-world experiences. This has resulted in two parallel approaches. For example, some of the reviewed studies examine altered states of consciousness in ritual contexts,[18,102] but their small sample sizes and limited neurophysiological analyses restrict broader conclusions. Others take a controlled experimental approach,[20,23,26] exposing naïve participants to rhythmic auditory stimulation for a fixed period, sometimes without considering prior experience with altered states of consciousness. A third category consists of laboratory studies involving participants already adept at entering altered states of consciousness,[19] yet these are rarely integrated with naïve participant studies. We acknowledge that these individual studies have been essential in advancing knowledge and providing key insights into the neural and experiential aspects of altered states of consciousness. However, the lack of connection between these approaches makes it difficult to form a cohesive understanding of how rhythmic auditory stimulation induces altered states of consciousness.

We believe that future progress in this field will require interdisciplinary collaboration and methodological innovations that balance ecological validity with experimental rigor. While isolating auditory input is crucial for understanding altered states of consciousness induced by rhythmic stimulation, real-life experiences are often multimodal, potentially engaging additional or distinct brain areas. Moreover, advances in physiological recording methods now allow for data collection in naturalistic settings, providing an opportunity to bridge these methodological gaps. Future progress in this field will likely depend on methodological innovations that enable rigorous empirical research outside of laboratory environments while maintaining sufficient experimental control. For example, future studies could take advantage of mobile EGG or functional near-infrared spectroscopy alongside wearable biosensors, such as heart rate monitors and galvanic skin response sensors, to capture physiological and neural markers of altered states of consciousness in real-world settings. These settings could include pop-up labs at festivals or meditation retreats, allowing for the study of altered states of consciousness in naturally occurring yet structured environments while maintaining experimental rigor. Also, virtual reality could be used to simulate immersive rhythmic auditory experiences in a controlled yet ecologically valid manner, bridging the gap between laboratory precision and real-world complexity.

Beyond methodological advancements, a key area for future research is the role of individual differences in rhythm-induced altered states of consciousness. In other domains of altered consciousness research, personality traits, and particularly trait absorption,[144] have been shown to shape the intensity and nature of subjective experiences.[74,145–148] However, as our review highlights, this aspect remains largely unexplored in the context of rhythmic auditory stimulation. Investigating how individual variability influences responses to rhythmic stimuli could provide valuable insights into why certain individuals are more susceptible to these altered states than others. This may be also relevant in studies involving individuals with experience in entering altered states of consciousness, such as trained meditators, shamanic practitioners, or individuals engaged in long-term sound-based spiritual practices. Exploring whether certain personality traits make these individuals more responsive to rhythmic auditory stimulation—or whether their experience itself enhances sensitivity to altered states of consciousness—could further refine our understanding of the mechanisms underlying these states.

A critical question emerging from this review is whether the different forms of repetitive auditory stimulation, namely, drumming, BBs, and mantras/chanting, are truly comparable in their effects on consciousness. While they share repetition as a core feature, they differ markedly in structure and perceptual qualities. Drumming consists of distinct, fast-paced beats that generate a clear external rhythm. The BBs used in the reviewed studies were as fast as drumming (i.e., within the delta [1–4 Hz] and theta [4–7.5 Hz] bands), but unlike drumming, they do not produce a perceivable rhythm; instead, they create a continuous auditory illusion through interaural frequency differences. Mantras, by contrast, involve slower, more deliberate repetition of sound, typically synchronized with respiration and vocalization. The differences in rhythmic perception (i.e., punctuated beats, continuous oscillations, and breath-linked repetition) may distinctly modulate emotional responses, attentional focus, and the induction of altered states. This raises important questions about how sound structure, perceived rhythm, and tempo shape both subjective experience and the underlying neural mechanisms of rhythm-induced alterations in consciousness.

If repetition and entrainment are the key mechanisms underlying altered states of consciousness induced by rhythmic sounds, does their impact depend on whether they occur in a structured rhythmic pattern or as a continuous fluctuation? Future research should explore how variations in tempo, perceived rhythm, rhythmic structure (continuous vs. discrete beats), and physiological engagement (e.g., breathing and vocalization) shape both phenomenological experiences and neural activity. Specifically, studies should investigate how these distinct rhythmic properties interact with emotional and cognitive states and whether they elicit different neural signatures associated with altered consciousness. A promising direction for future research is the direct comparison of drumming, BBs, and mantras in experimental paradigms that systematically control for tempo, beat structure, and respiratory involvement. Addressing these questions will be crucial for refining our understanding of how rhythmic auditory stimulation modulates consciousness and brain dynamics.

The observation that exposure to drumming, BBs, and sound-based spiritual practices induce states of relaxation and/or absorption aligns with a broader pattern across human development and behavior. Rhythmic stimulation, whether auditory, vestibular, or multimodal, seems to facilitate calm and inwardly directed states. For instance, rocking is a widely used technique to soothe infants and promote sleep,[149,150] and similar effects may also occur in adults during rhythmic vestibular stimulation, such as sitting in a rocking chair. Rhythmic locomotion, such as walking while carrying an infant, has similarly been shown to reduce crying and promote sleep, likely via regular vestibular input coupled with physical closeness.[151] These effects are supported by evidence that vestibular stimulation can entrain respiratory rhythms and influence autonomic function,[152,153] possibly by engaging brainstem nuclei involved in coordinating movement and cardiorespiratory processes.[154,155] Likewise, infant-directed speech and song, characterized by slow, predictable rhythmic structure, are used across cultures to regulate infant affect and attention,[156] pointing to an evolutionarily conserved role for rhythmic input in modulating physiological and emotional states.

While the neural mechanisms discussed in this review focus on auditory entrainment and its effects on cortical and subcortical dynamics, these broader findings suggest that rhythm-sensitive circuits, spanning auditory, vestibular, and sensorimotor systems, may converge on shared neurophysiological substrates for state modulation. This may include brainstem structures involved in autonomic regulation, as well as cortical areas implicated in attentional focus and sensory integration. Exploring these cross-modal pathways may help clarify whether the effects observed in ritual or meditative contexts represent a specialized case of a more general principle—that rhythmic stimulation, across modalities, can entrain neural activity and shift the brain into a more coherent, regulated, and absorptive mode. Future work could examine how these systems interact, and whether rhythm-induced relaxation in early development shares mechanistic similarities with the altered states discussed here.

## CONCLUDING REMARKS

The behavioral evidence reviewed indicates that altered states of consciousness induced by rhythmic sounds are characterized by a state of absorption and/or a state of relaxation. While individual studies have claimed these effects,[6,19] our review brings together findings across different types of rhythmic auditory stimulation and methodological approaches. It is essential to acknowledge that some studies within the reviewed literature lacked adequate control conditions, with a reliance on silence as a control. Silence, as a control condition, lacks the necessary auditory input present in experimental groups, potentially introducing confounding factors. Additionally, silence may be perceived as a form of sensory deprivation, influencing participant experiences in ways unrelated to the specific auditory stimulation being investigated. Nevertheless, silence does serve as a true control condition by virtue of its absence of auditory stimulation and thus should not be entirely disregarded. The current review highlights the necessity for future experiments to incorporate robust control conditions that specifically address the structural components of the auditory stimulation contributing to altered states of consciousness. It is recommended that these control conditions involve modulating the key structural elements to better isolate and understand their impact on altered states of consciousness. Future progress will require bridging phenomenological and neuroscientific research traditions through interdisciplinary collaboration and methodological innovation. Key directions include investigating individual differences in susceptibility to rhythmic stimulation and leveraging new technologies such as mobile neuroimaging and virtual reality to study these experiences in ecologically valid settings while maintaining sufficient experimental control. By integrating these approaches, future research can deepen our understanding of how auditory repetition shapes consciousness and brain dynamics. Lastly, a potential neural mechanism involving the entrainment of thalamocortical pathways to low-frequency activity may link metric sounds and altered states of consciousness, aligning with mechanisms observed in psychotic and psychedelic states. However, future studies should systematically modulate tempo, perceived rhythm, and rhythmic structure to shed light on the role of repetitive sounds and entrainment on altered states of consciousness.

## AUTHOR CONTRIBUTIONS

R.A.-T.: Conceptualization; writing—original draft; writing—review and editing; supervision. S.L.-M.: Conceptualization; writing—review and editing. C.E.: Conceptualization; writing—review and editing; supervision. M.D.-A. Conceptualization; writing—review and editing; supervision.

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The authors declare no competing interests.

## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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