Music as Auditory Enrichment in Rats and Mice: A Review of Neurobehavioral, Endocrine, and Disease-Modifying Effects

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***Abstract*—**Rodent models, particularly rats and mice, are extensively used in experimental research to investigate neurobehavioral, physiological, and disease-related mechanisms. In recent years, controlled auditory environments especially music exposure has gained attention as a form of environmental enrichment with measurable biological effects. Evidence from multiple experimental studies demonstrates that music exposure can significantly reduce anxiety- and depression-like behaviors, enhance learning and memory, and promote overall well-being in laboratory rodents. At the neurobiological level, music modulates neurotransmission, suppresses hypothalamic–pituitary–adrenal (HPA) axis activation, and enhances neuroplasticity through increased expression of markers such as brain-derived neurotrophic factor (BDNF) and glial fibrillary acidic protein (GFAP). Endocrine responses, including alterations in gonadotropins, stress hormones, leptin, and thyroid hormones, further indicate the systemic influence of auditory stimulation. Notably, specific sound frequencies and musical genres have been shown to affect reproductive behavior, cognitive recovery after stroke, blood–brain barrier permeability, and even therapeutic targeting in glioblastoma models. Collectively, these findings highlight music as a multimodal neuromodulatory stimulus capable of influencing neural, hormonal, and behavioral pathways. The growing body of evidence supports the integration of music-based auditory enrichment in laboratory settings, not only to improve animal welfare but also to serve as a scientifically valid, non-invasive intervention with translational relevance for neuroscience, endocrinology, and therapeutic research.

***Index Terms*—** Music therapy, Auditory enrichment, Rat, Mice, Neuroplasticity, HPA axis, Cognitive Behavior, Endocrine Regulation.

I. Introduction

Music is a universal auditory stimulus which is capable of influencing emotional, cognitive, and physiological processes. In the modern context, sound is often perceived mainly as a form of entertainment; however, the therapeutic use of sound has deep historical roots (Jeevan and Sandhya, 2025). Ancient traditions, particularly within the Indian Vedic system, have long incorporated sound-based practices such as mantra recitation and Nada Yoga, recognizing the potential of structured sound vibrations to influence mental and physiological states. Contemporary scientific research increasingly supports these traditional concepts, demonstrating that music and auditory stimuli can produce measurable biological effects on the nervous and endocrine systems (Koelsch, 2014; Chanda and Levitin, 2013). In recent decades, music therapy has emerged as a promising complementary and non-invasive intervention with potential applications in stress reduction, cognitive enhancement, and emotional regulation (Bradt *et al.*, 2013; Thoma *et al.*, 2013). Numerous studies in humans have demonstrated that music can modulate mood, improve attention and memory, and promote psychological well-being, suggesting that auditory stimuli may influence complex neurobiological pathways (Särkämö *et al.*, 2008).

In modern society, rapid technological advancement and increasingly demanding lifestyles have contributed to elevated levels of psychological stress. Chronic stress is now recognized as a major risk factor for a wide range of health disorders, including cardiovascular diseases, neurological dysfunction, immune imbalance, and metabolic disturbances (Montgomery *et al.*, 2024). Persistent activation of the stress response can disrupt hormonal homeostasis and negatively affect brain function, ultimately impairing both physical and mental health (McEwen, 2007). Because many of these stressors are inherent to contemporary life and cannot be completely avoided, there is growing interest in non-pharmacological and non-invasive approaches that can help regulate stress responses and maintain physiological balance (Thoma *et al.*, 2013).

Animal models play a critical role in advancing our understanding of the biological mechanisms underlying such interventions. Among these, rodents particularly rats and mic are widely used in biomedical research due to their well-characterized neurophysiology, genetic similarity to humans, and suitability for controlled experimental studies. Research using rodent models has shown that environmental factors, including auditory stimulation, can significantly influence neural activity, behavioral responses, and endocrine regulation (Kühlmann *et al*. 2018). These models therefore provide an effective platform for investigating the physiological effects of music exposure under controlled laboratory conditions.

Recent experimental studies have provided compelling evidence that music exposure can modulate behavioral, cognitive, and neurobiological processes in rodents. For instance, exposure to different musical genres, including classical, country, Latin, and rock music, has been shown to significantly reduce anxiety- and depression-like behaviors in mice subjected to chronic stress. Exposure to different musical

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genres such as classical, country, Latin, and rock music has been shown to reduce depression- and anxiety-like behaviors in mice subjected to chronic stress. These behavioral improvements were accompanied by reduced inflammatory responses, decreased oxidative stress, and protection against neuronal damage, suggesting potential neuroprotective effects of music exposure (Fu *et al.*, 2023). Similarly, experimental studies in rats have demonstrated that exposure to Mozart compositions can enhance learning and memory performance, indicating that structured auditory stimulation may positively influence cognitive function (Korsós *et al.*, 2018).

Beyond behavioral outcomes, music exposure has also been shown to influence endocrine responses and molecular signaling pathways. Experimental findings indicate that auditory stimulation can alter levels of several hormones involved in reproductive and metabolic regulation, including follicle-stimulating hormone (FSH), luteinizing hormone (LH), leptin, and thyroid-stimulating hormone (TSH) (El-Etreby *et al.*, 2016). In addition, changes in gene expression related to stress regulation and reproductive function have been observed following music exposure, suggesting that auditory stimuli may affect neuroendocrine signaling at the molecular level (Nazdikbin Yamchi *et al.*, 2022).

Interestingly, emerging evidence also suggests that music may influence disease-related mechanisms. One particularly intriguing finding is the ability of certain musical stimuli to modulate blood–brain barrier (BBB) permeability. For example, exposure to a rock ballad has been reported to increase BBB permeability in rats, thereby enhancing the delivery of therapeutic agents in experimental glioblastoma models (Semyachkina-Glushkovskaya *et al.*, 2022). Such findings highlight the possibility that auditory stimulation could play a role not only in behavioral regulation but also in facilitating novel therapeutic strategies for neurological diseases.

Taken together, these observations suggest that music functions as a multifaceted environmental stimulus capable of influencing neural, hormonal, and physiological systems. As a form of auditory environmental enrichment, music may represent a valuable tool for both improving laboratory animal welfare and providing insights into the biological mechanisms underlying music-induced neuromodulation. Therefore, the present review aims to synthesize and critically evaluate existing experimental studies investigating the effects of music exposure in rats and mice, with particular emphasis on neurobehavioral outcomes, endocrine regulation, and disease-modifying mechanisms.

II. Neurobehavioral Effects of Music

Several experimental studies have demonstrated that music exposure can influence behavioral responses and cognitive performance in rodents. One of the most significant findings is the ability of music to reduce stress-related behaviors. Mice exposed to different genres of music showed reduced anxiety- and depression-like behaviors along with decreased inflammatory markers and oxidative stress, suggesting that music may act as a protective factor against chronic stress (Fu *et al.*, 2023).

Music exposure has also been shown to improve cognitive performance. Rats exposed to adapted Mozart music demonstrated enhanced learning and memory performance, indicating that auditory stimulation can positively influence cognitive processes (Korsós *et al.*, 2018). Similar findings have been reported in studies examining classical music exposure, where improvements in passive avoidance learning and reductions in stress hormones were observed (Zhang *et al.*, 2022).

Neuroplasticity appears to be one of the key mechanisms underlying these cognitive improvements. Exposure to Mozart music has been shown to increase BDNF expression in the brain, a factor known to promote synaptic plasticity and neuronal survival (Chen *et al.*, 2019). In addition, music exposure has been associated with improved motor recovery following stroke in rats, further supporting the role of music in promoting neural repair and functional recovery (Chen *et al.*, 2021).

III. Endocrine Effects of Music

Music exposure can also influence endocrine regulation. Hormonal responses are essential indicators of physiological stress and metabolic balance. Studies examining the hormonal effects of music exposure have reported significant changes in reproductive and metabolic hormones.

For example, exposure to light music resulted in significant decreases in follicle-stimulating hormone (FSH) and increases in leptin levels in rats, indicating that music may influence reproductive and metabolic regulation (El-Etreby *et al.*, 2016). Similarly, exposure to Mozart music has been associated with changes in reproductive hormone expression and stress-related gene regulation (Nazdikbin Yamchi *et al.*, 2022).

Music may also influence lipid metabolism and stress hormones. Exposure to Indian classical raga music resulted in reduced cortisol levels and improvements in lipid parameters including LDL, VLDL, and triglycerides (Sharma and Sharma, 2013). These findings suggest that auditory stimulation may have broader metabolic and endocrine effects

IV. Disease-Modifying Effects of Music

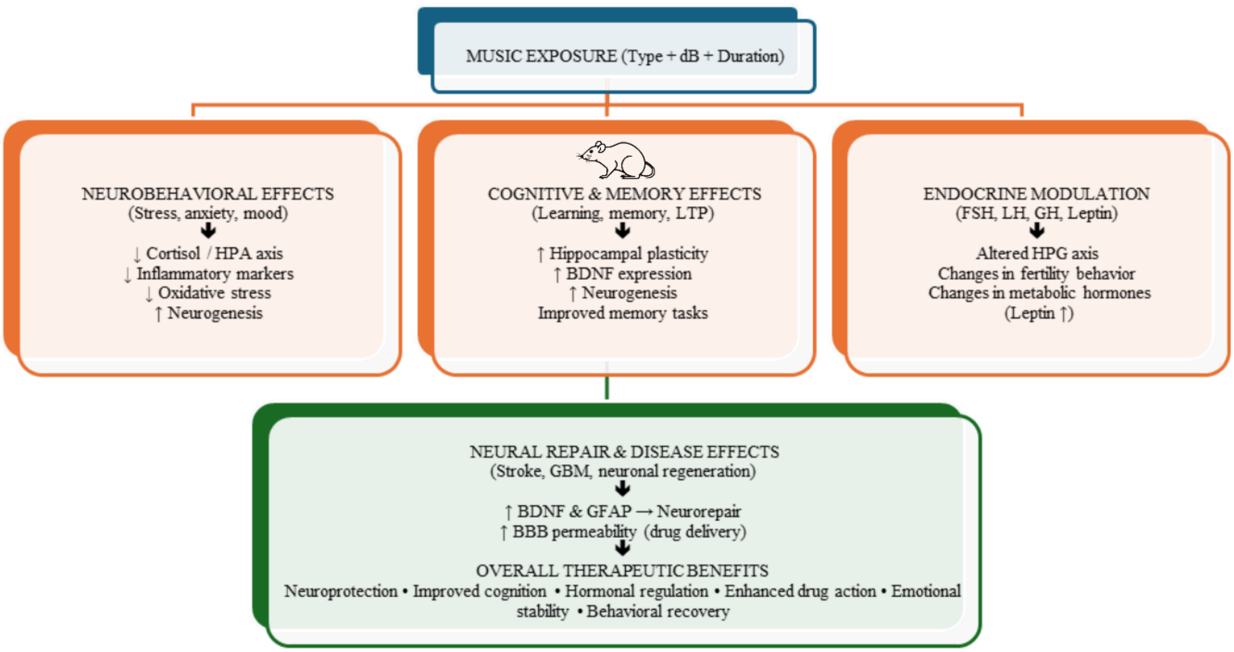
Beyond behavioral and hormonal effects, music exposure may also influence disease processes. One notable example involves its effect on the blood–brain barrier (BBB). Research has demonstrated that specific musical stimuli can increase BBB permeability, thereby enhancing the delivery of therapeutic drugs to the brain. This phenomenon has potential implications for treating neurological disorders such as glioblastoma (Semyachkina-Glushkovskaya *et al.*, 2022).

Music exposure has also been shown to improve recovery following neurological injury. Rats exposed to Mozart Sonata K.448 after stroke exhibited improved motor function along with increased expression of BDNF and GFAP, markers associated with neuronal repair and neuroplasticity (Chen *et al.*, 2021).

In addition, certain types of music have been found to influence reproductive behavior. Balinese Gamelan music increased sexual activity in female rats during the estrous cycle, suggesting that auditory stimulation may affect reproductive physiology (Herawaty *et al.*, 2022). hese findings highlight the potential role of music-based auditory stimulation in neurological rehabilitation

Summary of Studies on Music Exposure in Rodent Models

S. No.	Animal Model	Type of Music	dB Level	Parameter Studied	Key Findings	Reference
1	Mice	Classical, Country, Latin, Rock	Not specified	Stress and depression indicators	• ↓depression and anxiety-like behavior under chronic stress • ↓inflammatory markers (blood and brain) • Protection against oxidative stress • Prevention of neuronal cell death; enhanced neurogenesis • Suppression of HPA axis activation	Fu *et al.*, 2023
2	Rat	Adapted Mozart music	Not specified	Learning and memory	• Improved cognitive performance • Enhanced learning and memory task outcomes	Korsós *et al.*, 2018
3	Rat	Gentle (Javanese), Moderate (Balinese Gamelan), Intense (Dangdut Tekno)	20 dB	Sexual behavior	• ↑ Sexual activity in female rats during estrous cycleunder Balinese Gamelan music	Herawaty*et al.*, 2022
4	Rat	"Still Loving You" (Rock ballad, Scorpions)	100 dB	Glioblastoma progression and BBB permeability	• ↑ BBB permeability • Enhanced delivery and drainage of BZM drug • Improved therapeutic targeting in GBM	Semyachkina-Glushkovskaya*et al.*, 2022
5	Rat	Mozart Sonata (K.448)	65–75 dB	Motor recovery post-stroke	• Improved motor function • ↑ BDNF and GFAP expression leading to neuronal repair	Chen *et al.*, 2021
6	Rat	Mozart Sonata (K.488)	65–75 dB	Anxiety and neuroplasticity	• ↓anxiety behaviors • Promoted fear extinction • ↑BDNF in anterior cingulate cortex	Chen *et al.*, 2019
7	Rat	Classical and Rock	50–70 dB	Spatial memory	• Energetic rock music showed slight memory enhancement	Psyrdellis *et al.*, 2017
8	Rat	Hard Rock, Classical, Rap	65–70 dB	Learning, memory, stress hormones	• Classical music improved learning and memory in passive avoidance task • ↓ stress hormones and adrenal weight • Anxiolytic effects	Zhang *et al.*, 2022
9	Rat	Light music	60 dB	Endocrine hormones (GH, Gonadotropins, Prolactin, TSH, Leptin)	• ↓FSH significant • ↓LH insignificant • ↑ TSH insignificant • GH = no change • ↑Leptin significant	El-Etreby*et al.*, 2016
10	Rat	Mozart Sonata (K.448)	65–70 dB	FSH, LH, E2; histology; Ntrk2, Crh, Pomc expression	• ↓FSH significant • ↑LH insignificant • ↓E2 insignificant • Altered expression of stress- and reproduction-related genes	NazdikbinYamchi*et al.*, 2022
11	Rat	Indian Raga	Not specified	Adrenalin, Cholesterol, Cortisol, TG, HDL, LDL, VLDL	• ↓ Cortisol, LDL, VLDL, TG • Adrenalin Non significant	Sharam and Sharma (2013)



Effects of Music on Rat/Mice

V. Discussion

The studies summarized in this review collectively demonstrate that music exposure functions as a complex environmental stimulus capable of influencing multiple physiological and behavioral systems in rodents. Evidence from the reviewed literature suggests that auditory enrichment through music can modulate neurobehavioral responses, regulate endocrine function, and even influence disease-related mechanisms. These findings highlight the multidimensional role of auditory stimulation and support the growing recognition of music as a biologically active environmental factor.

One of the most consistent findings across studies is the effect of music on stress-related behaviors and emotional regulation. Chronic stress is known to activate the hypothalamic–pituitary–adrenal (HPA) axis, resulting in elevated glucocorticoid levels and subsequent behavioral and physiological changes. Music exposure appears to attenuate this stress response. For instance, Fu *et al.* (2023) demonstrated that exposure to different musical genres significantly reduced depression-like and anxiety-like behaviors in mice subjected to chronic stress. These behavioral improvements were accompanied by reductions in inflammatory markers and oxidative stress, suggesting that music may exert neuroprotective effects through anti-inflammatory and antioxidant pathways. The suppression of HPA axis activation observed in this study further supports the hypothesis that auditory stimuli can regulate neuroendocrine stress pathways.

Another important mechanism underlying the beneficial effects of music involves neuroplasticity. Neuroplasticity refers to the ability of the brain to reorganize its structure and function in response to environmental stimuli. Several studies have reported increased expression of brain-derived neurotrophic factor (BDNF) following music exposure. BDNF plays a crucial role in neuronal survival, synaptic plasticity, and memory formation. In experiments involving Mozart music exposure, increased BDNF expression has been observed in brain regions associated with cognitive processing and emotional regulation (Chen *et al.*, 2019). These findings suggest that music may enhance neural connectivity and promote synaptic remodeling.

The role of music in cognitive enhancement is also supported by behavioral studies. Rats exposed to Mozart music demonstrated improved performance in learning and memory tasks (Korsós *et al.*, 2018). Similarly, Zhang *et al.* (2022) reported that classical music improved learning outcomes in passive avoidance tasks while also reducing stress hormone levels. These observations align with the concept of the "Mozart effect," which proposes that certain musical structures may enhance spatial and cognitive performance. Experimental studies in rodents provide valuable insights into the potential neural mechanisms through which musical and auditory stimuli may influence cognitive and behavioral functions. Music exposure has also been associated with improvements in neurological recovery following injury. Chen *et al.* (2021) reported that rats exposed to Mozart Sonata K.448 following stroke showed significant improvements in motor function compared to control animals. This improvement was accompanied by increased expression of both BDNF and glial fibrillary acidic protein (GFAP), markers associated with neuronal repair and astrocyte activation. These findings suggest that music may facilitate recovery processes by promoting neuroplastic changes and enhancing neuronal survival.

In addition to neurobehavioral effects, music exposure appears to influence endocrine regulation. Hormonal responses are essential indicators of physiological homeostasis, and alterations in hormone levels can have widespread effects on metabolism, reproduction, and stress adaptation. Studies investigating the endocrine effects of music exposure have reported changes in reproductive hormones such as follicle-stimulating hormone (FSH) and luteinizing hormone (LH). For example, El-Etreby *et al.* (2016) observed a significant reduction in FSH levels and an increase in leptin levels in rats exposed to light music. These hormonal changes suggest that auditory stimuli may influence hypothalamic signaling pathways that regulate reproductive and metabolic processes.

Similarly, Nazdikbin Yamchi *et al.* (2022) demonstrated that exposure to Mozart music altered gene expression patterns associated with stress regulation and reproductive function. These findings indicate that music exposure may not only influence hormone secretion but also modulate gene expression related to neuroendocrine signaling. Such molecular changes may explain the long-term physiological effects observed in several experimental studies.

Another interesting aspect highlighted in the literature is the influence of music on metabolic parameters and cardiovascular risk markers. Sharma and Sharma (2013) reported that exposure to Indian classical raga music reduced cortisol levels and improved lipid profiles in rats, including decreases in LDL, VLDL, and triglyceride levels. Cortisol is a key stress hormone associated with metabolic dysfunction and cardiovascular disease. Therefore, reductions in cortisol following music exposure suggest that auditory stimulation may contribute to improved metabolic regulation.

Beyond behavioral and hormonal effects, some studies have reported surprising therapeutic applications of music in disease models. One of the most innovative findings involves the influence of music on blood–brain barrier (BBB) permeability. The BBB is a highly selective barrier that protects the brain from harmful substances but also limits the delivery of therapeutic drugs to the central nervous system. Semyachkina-Glushkovskaya *et al.* (2022) demonstrated that exposure to a rock ballad (“Still Loving You”) increased BBB permeability in rats, thereby enhancing the delivery of the anticancer drug BZM to brain tumors. This finding suggests that auditory stimulation may influence cerebral vascular dynamics and potentially improve drug delivery strategies for neurological diseases such as glioblastoma.

Music exposure has also been shown to influence reproductive behavior. Herawaty *et al.* (2022) reported that Balinese Gamelan music significantly increased sexual activity in female rats during the estrous cycle. This finding suggests that auditory stimulation may affect reproductive physiology through hormonal or neural mechanisms. Although the exact pathways remain unclear, these observations highlight the broad physiological impact of music.

An important consideration in interpreting these findings is the variability in musical stimuli used across studies. Differences in musical genre, intensity, frequency range, and duration of exposure may influence experimental outcomes. Classical music, particularly compositions by Mozart, has been frequently associated with cognitive enhancement and stress reduction. However, other musical forms, including rock music and traditional cultural music, have also demonstrated measurable physiological effects. This variability suggests that specific acoustic properties of music, such as rhythm, tempo, and harmonic structure, may interact with neural processing pathways.

Another factor to consider is sound intensity. Most studies reviewed here used sound levels between 50 and 75 dB, which correspond to moderate environmental noise levels. However, the study examining BBB permeability used a much higher intensity of 100 dB. Such differences in intensity may influence neural activation patterns and physiological responses. Future research should therefore investigate the dose–response relationship between sound intensity and biological effects.

From a broader perspective, the integration of music as an environmental enrichment strategy in laboratory settings may offer several advantages. Environmental enrichment is known to improve animal welfare and reduce stress-related variability in experimental results. Music exposure could serve as an accessible and non-invasive enrichment tool that enhances both animal well-being and experimental reliability.

Despite the promising findings discussed above, several limitations remain. Many studies have small sample sizes and differ in experimental design, making it difficult to compare results directly. In addition, the underlying neural mechanisms responsible for music-induced effects are not yet fully understood. Future research should focus on identifying specific neural circuits and molecular pathways involved in auditory stimulation.

Overall, the available evidence suggests that music functions as a powerful environmental stimulus capable of modulating brain function, endocrine activity, and physiological responses. Continued investigation of music-based auditory enrichment may not only improve our understanding of brain–environment interactions but also provide novel insights into therapeutic approaches for neurological and stress-related disorders

VI. Conclusion

Music exposure represents a promising form of environmental enrichment with significant neurobehavioral, endocrine, and therapeutic effects. Studies conducted on rats and mice demonstrate that music can reduce stress and anxiety, enhance cognitive performance, regulate hormonal activity, and even influence disease mechanisms.

These findings support the integration of music-based auditory enrichment in laboratory research settings. In addition to improving animal welfare, such approaches may provide valuable insights into the biological mechanisms underlying music therapy and its potential applications in human health.

Future research should focus on identifying optimal sound frequencies, exposure durations, and musical genres to better understand the mechanisms through which music influences physiological and neurological processes.

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