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The Sound of Sleep: How Auditory Stimuli Influence Sleep Quality and Brainwave Activity

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Abstract

Sleep's multifaceted contribution to physical, cognitive, and emotional health is discussed in this paper, emphasizing the indispensable roles beyond basic rest. The paper synthesizes the present understanding of how sleep enables memory consolidation, immune function, metabolic homeostasis, and emotional stability. The review also examines the impact of sound and music on sleep quality, separating the disruptive effects of noise from the therapeutic effects of auditory stimuli like white noise, pink noise, binaural beats, and slow-tempo music. Objective approaches using polysomnography and newer wearable technologies are assessed to quantify sleep quality. The dynamic interplay between auditory input and neural entrainment in the control of sleep is considered. The paper highlights interpersonal differences in sound response and refers to the potential of personalized audio interventions for enhancing sleep and mental well-being.

SLEEP

"Sleep" is a term that might be familiar to everyone. However, what exactly is "sleep", and what really defines a "good" or "bad" sleep? According to Mohinur et al. (2025) , sleep is necessary for the human body. It's essential for maintaining both physical and mental health, such as supporting basic cognitive functions and the immune systems. Beyond these fundamental roles, sleep also holds many other essential benefits to our human body. Cognitively, it helps our memory system organize and store new information, and also supports long-term memory formation (especially during deep NREM sleep). It also enhances our learning, problem-solving, creativity, attention, and decision-making abilities. Physically, sleep helps our body produce cytokines (proteins that fight infections and inflammation), release hormones that support cellular repair and muscle growth, and, most importantly, strengthen immune response (reduces susceptibility to illnesses). It also assists in regulating blood pressure (reducing risk of hypertension, heart disease, and stroke), balancing hunger hormones, ghrelin, and leptin (preventing overreacting and obesity), and lowering the risk of insulin resistance and type 2 diabetes. Emotionally, sleep helps regulate our emotions. For example, reducing stress, anxiety, and mood swings can lower the risk of mental health disorders like depression and anxiety. Therefore, improving our emotional resilience and psychological well-being. Moreover, it has been shown that productivity and performance are associated with sleep as well. For example, it improves reaction times and cognitive flexibility, and enhances alertness, concentration, creativity, and work/school performance.

Considering all the advantages of sleep, naturally some individuals ask themselves what makes a "good sleep" versus a "bad sleep." Healthy and restorative sleep, according to the National Sleep Foundation (NSF), is usually characterized by 4 main factors such as sleep efficiency, sleep latency, sleep duration, and wake after sleep onset. For example, healthy adult sleep is characterized by high sleep efficiency (more than 85 percent of bed time actually sleeping), short sleep latency (asleep within 30 minutes), low wake after sleep onset (wakening 1 time or less during the course of the night), and sufficient sleep duration (usually 7 to 8 hours) (Menzies et al.; Öktem). Scientists primarily quantify the determinants of a good night's sleep using polysomnography (PSG), a sleeping test conducted in the laboratory extensively used in research and clinical practice, which records brain activity, heart rate, respiration, and muscle activity (Menzies et al.; Richards and Hammond). New technology has also made it possible to do home sleep tests that capture many of the same features as a PSG. Other technologies, such as wearables, nearables, and airables, can capture similar sleep data with varying mechanisms. Wearables are devices like watches, rings, or headbands that track activity, heart rate, and temperature. Nearables are on-bed or bedside devices that monitor movement and breathing, while airables monitor sleep with wireless signals like radar or sound without contacting the

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sleeper (Richards and Hammond). However, most sleep studies rely on self-reports, which are susceptible to recall bias because individuals fail to remember or rate their sleep properly. Therefore, understanding objective and subjective indicators, made possible by valid measurement tools, is a prerequisite for proper definition and improvement of sleep quality (Menzies et al.).

SOUND

Sound is a mechanical vibration propagating through air, liquids, or solids and is defined by frequency, in hertz, amplitude, in decibels, and waveform (Richards and Hammond; Gosine and Tabi). The frequency determines the pitch of a sound, varying between low and high pitch, while amplitude is its perceived intensity (Gosine and Tabi). During sleep, sound has two main roles to play: it can disturb or it can be therapeutic (Feld and Born; Killgore et al.). On the one hand, sudden, loud, or random sounds will disturb the sleep cycle by causing micro-wakings and lowering sleep efficiency, while persistent and patterned sounds will do the opposite by covering up extraneous noise or entraining in coincidence with brainwave patterns for restful sleep (Feld and Born; Gupta and Johns). Among sound categories typically studied for their effect on sleep are white noise, pink noise, and binaural beats (Richards and Hammond; Feld and Born). White noise is equally powerful across all frequencies, which masks disruptive background sounds. Pink noise, which focuses on lower frequencies and drops off more gradually at higher frequencies, is said to be less jarring and more suited to natural brainwave frequencies (Menzies et al.; Killgore et al.). Binaural beats are a unique kind of sound stimulation produced when two tones slightly differing in frequency are played individually into each ear (Gupta and Johns). A third tone, referred to as a binaural beat, is experienced by the brain with a frequency equal to the difference between the initial two tones, even though this tone is not present outside (Feld and Born).

MUSIC

Music is and has remained world-renowned everywhere around the globe as a tool for relaxation and management of emotions, usually used as music therapy in an effort to reduce stress, enhance cognitive and motor skills, etc. Researchers in earlier studies have found that a slower tempo, along with music of low frequency, tends to stimulate the parasympathetic nervous system, which is associated with decreasing heart rate, slower breathing, relaxed muscle tension, and much more (Killgore et al.; Barbo and Alam). Instrumental music, especially music without lyrics, is largely associated with increased relaxation as there are no language processing demands (Killgore et al.). Natural sound or ambient music built into music (e.g., rain, ocean waves) may be employed to enhance the relaxing effect by creating a soothing acoustic space (Killgore et al.; Yang). Personal preference is also important (Feld and Born). Familiar, meaningful music can enhance feelings of safety and emotional release (Feld and Born). As with the waves and frequencies mentioned above, each and every music note and pitches also have its own frequency (Killgore et al.). A lower pitch oscillates slower therefore lower frequency, and a higher pitch oscillates faster therefore higher frequency. For example, the international tuning note A above middle C (A4) under the world standard for international tuning (A440), is tuned wide to 440 Hz; that is, the sound wave has 440 oscillations per second (Killgore et al.). These movements travel through the air as sound waves, which our human ear picks up as different pitches depending on their frequency. Frequency, coupled with amplitude (loudness) and waveform (tone quality), also dictates the way we hear sound and is the foundation of music (Killgore et al.).

CORRELATIONS

Sound and music both have an exceedingly strong impact on our sleep quality, and they do so in both positive and negative manners (Feld and Born; Richards and Hammond; Barbo and Alam). In general, sound can have two important effects on sleep: disruptive or therapeutic (Menzies et al.; Richards and Hammond). For example, a sudden or break noise will disturb the sleep cycle by causing micro-awakenings, and this leads to higher levels of time in lighter stages of sleep and reduced levels of time in deep or REM sleep (Richards and Hammond). This is able to increase the stress hormones cortisol and adrenaline, increase heart rate and blood pressure, and ultimately lead to fatigue, irritability, and poor concentration throughout the day (Menzies et al.; Killgore et al.). Regular and calming sounds, on the other hand, can ensure better sleep (Feld and Born). For example, sounds such as white noise (which maintains constant power across all frequencies) or pink noise (which favors lower frequencies and decreases at the higher ones) can cover up alarming environmental sounds and stabilize the sleeping environment (Richards and Hammond). Binaural beats, created by listening to faintly different frequencies in each ear, are also believed to influence brainwave activity and guide the brain into relaxation and deeper states of sleep (Feld and Born; Gupta and Johns). Music, being a patterned and emotional form of sound, can have even deeper effects on sleep (Killgore et al.). If the right music is chosen, generally of slow tempo (around 60 to 80 beats per minute), gentle, and monotonous, it can decelerate heart rate and blood pressure, reduce stress hormones, and release the body's relaxation response (Killgore et al.; Barbo and Alam). These changes stimulate the parasympathetic nervous system so that the body can readily shift from being awake to sleeping (Killgore et al.). Aside from its physiological impact, music also has psychological advantages (Feld and Born). Soothing melodies are able to divert the mind away from anxiety, concerns, or negative thoughts, making it easier for the listener to relax (Feld and Born). Through repetition, repeatedly listening to soothing music prior to sleep can train the mind and body to link that music to sleep, establishing a useful bedtime routine (Killgore et al.; Feld and Born). But not all music enhances sleep (Killgore et al.). The loud and high-paced songs or songs with captivating lyrics may overexcite the brain and make it take longer to fall asleep (Killgore et al.). The songs that produce earworms, or the tunes that repeat unconsciously in one's head, are also likely to keep individuals awake for a longer time (Killgore et al.). Thus, how music affects sleep varies with its nature, timing, and individual response (Killgore et al.). If chosen carefully and listened to on a regular basis, music can be a natural and effective source of relaxation, stress reduction, and improved quality of sleep (Feld and Born).

METHODOLOGY

The literature reviewed in this paper were primarily selected from databases like Google Scholar and PubMed. Key words and phrases like "Music therapy", "Sound frequencies", "Sleep quality", "Soundwave" were used in different combinations to locate the precise and relevant articles. The timeframe of the literature reviewed in this paper were limited to the past ten years (2015-2025), but mostly focusing on the range within the past 5 years (2020-2025), ensuring relevance and recency. To examine the relationship between sleep, sound, and music, this review includes a variety of peer-reviewed research articles, literature reviews, and meta-analyses to ensure accuracy and precision. Studies that contain measurable outcomes of sleep quality, such as sleep efficiency and reported sleep satisfaction, were prioritized, and sources and articles were excluded if they lacked clear methodological structures, did not include human participants, focused solely on general health impacts without measuring or evaluating sleep-related outcomes, focused only on environmental noise pollution, and if the auditory component was not well defined.

PURPOSE

The major research question guiding this review is to understand what sound frequencies can enhance or improve sleep quality (Richards and Hammond). The aim is to synthesize evidence regarding the impact of different types of sound, such as white and pink noise, music, and brainwave entrainment frequencies, on sleep quality (Menzies et al.). Sleep is essential for both physiological and cognitive functioning and could be measured by sleep–wake cycle duration and continuity, as well as nighttime waking (Young et al.). Sound also plays a multi-dimensional role in controlling sleep (Feld and Born). While sudden or startling sounds will awaken, persistent patterns of sound, such as white or pink noise, will mask sounds disturbing the environment and normalize sleep (Richards and Hammond). Experiments also discover that the brain will synchronize its activity with external auditory frequencies so that persistent patterns of sound will aid the brainwave states that help relaxation and deep sleep (Gupta and Johns). Sound Masking: White and Pink Noise. Sound masking involves introducing a constant background sound to reduce the disruption of unwanted sound (Feld and Born). Its effectiveness in different environments has been explored in many studies (Richards and Hammond). A study among office workers found that pink noise reduced perceived disruptions and improved concentration in open-plan offices (Feld and Born). Another study in a hospital setting found that white noise reduced patient-reported sleep disturbances (Richards and Hammond). However, one experiment with college students found no significant differences between pink noise and silence conditions (Menzies et al.). Differences among these studies may be attributable to methodological and contextual factors (Richards and Hammond). As the first two studies found that sound masking improved concentration and sleep quality, the third found none of these effects (Richards and Hammond). These differences may be attributable to differences in noise baselines, participant sensitivity, and laboratory environments (Menzies et al.).

The theory of auditory masking is that which describes how a single sound can make another sound less detectable by covering its frequency spectrum (Feld and Born). Pink noise, with its equilibrium of low pitches like that of rain, and brown noise, with lower low-frequency notes like that of waterfalls, both follow this theory (Richards and Hammond). White noise, however, has all frequencies equally and possibly is less good at causing sleep-inducing brainwave patterns (Feld and Born; Richards and Hammond). Sound masking includes the hypothesis that confined sensory spaces can reverse the negative effects of noise pollution on concentration, sleep, and health (Menzies et al.).

BRAINWAVE ENTRAINMENT AND FREQUENCY SYNCHRONIZATION

Brainwave entrainment is the use of rhythmic sound stimulation, such as binaural beats or isochronic tones, to synchronize brain frequency with outside frequencies (Feld and Born). It is increasingly being studied for inducing relaxation, enhancing mental function, and regulating sleep (Gupta and Johns). It is established from research that delta frequencies ranging from 1 to 4 hertz are linked to deep sleep and theta frequencies ranging from 4 to 8 hertz are linked to light sleep and meditation (Feld and Born; Richards and Hammond). Higher frequencies, such as beta and gamma, are linked to wakefulness and cognitive processes but are less reliable for relaxation (Feld and Born). Several theoretical models explain brainwave entrainment (Feld and Born). Brainwave Entrainment Theory supposes that rhythmic sound entrains brainwaves to external stimulation, while Neural Resonance Theory supposes that the brain will resonate to rhythmic auditory stimulation (Richards and Hammond). Psychoacoustic Theory explains rhythm and sound perception on neural activity (Feld and Born; Menzies et al.). In general, brainwave entrainment offers a painless, drug-free way of controlling mental state and supporting sleep and stress management in clinical and normal situations (Menzies et al.).

MUSIC AS A MEANS OF RELAXATION

Music has long been a popular means of relaxation and mood management (Killgore et al.). Slow-speed, low-frequency music is found to stimulate the parasympathetic nervous system to reduce heart rate, breathing, and muscle tension (Barbo and Alam; Killgore et al.). Instrumental or ambient songs with no vocal content are particularly effective because they alleviate cognitive load (Killgore et al.). Individual preference controls the music relaxation impacts (Feld and Born). Music that is familiar or emotionally meaningful enhances comfort and emotional release (Feld and Born). Lyrics, though distracting at times, can allow for emotional catharsis depending on the listener's intention (Killgore et al.). Several theoretical models explain these effects. The music therapy theory views music as a vehicle of emotional access and self-regulation (Killgore et al.). The arousal regulation theory proposes that music returns to baseline levels of calm arousal (Feld and Born). Entrainment theory explains how body rhythms synchronize with musical rhythms, and cognitive-affective theory explains how music shapes both thinking and feeling (Feld and Born). Music-based interventions are a low-cost, accessible, and non-pharmacological way to produce relaxation and improve sleep quality (Barbo and Alam).

INDIVIDUAL SOUND RESPONSE VARIABILITY

Individual differences in terms of genetics, cultural identity, and psychological status greatly affect the response of individuals to sound (Richards and Hammond; Menzies et al.). For others, white noise is soothing, while for others it is overbearing (Feld and Born). These differences explain contradictory findings in research on sound masking, brainwave entrainment, and music intervention (Richards and Hammond; Gupta and Johns). Conceptually, environmental psychology and psychoacoustic theory emphasize the importance of perception and context on a personal level in terms of auditory experience (Menzies et al.). These variations need to be recognized in order to develop adaptive, individualized sound interventions that maximize sleep and well-being (Feld and Born; Richards and Hammond).

DISCUSSION

Evidence considered proves that continuous, low-intensity sounds such as pink noise, delta-range entrainment tones, or slow music facilitate sleep by maintaining constant brainwave activity and reducing outside distractions (Menzies et al.; Killgore et al.). Continuity of auditory stimulation tends to entrain neural rhythms into relaxation states (Feld and Born). Data from applied research shows how particular compositions, such as Weightless by Marconi Union, use a 60-beat-per-minute rhythm to imitate theta wave activity associated with drowsiness, while Svefn-g-englar by Sigur Rós uses slow rhythm-like breathing and minimal lyrics to reduce mental work (Feld and Born). Compared to the pharmacological intervention, sound interventions are sustainable, inexpensive, and harmless, offering good options for individuals with sleeping disorders (Menzies et al.). However, the available evidence is constantly marred by small samples, short intervention durations, and meager physiology data (Richards and Hammond). Subsequent research should use larger, more representative sample sizes, include objective assessment of sleep such as polysomnography, and explore individually tailored auditory interventions (Menzies et al.). This work has the potential to advance theoretical frameworks and practical application of sound as a mechanism for enhancing sleep and mental well-being (Killgore et al.).

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