Effect of Binaural Beats Combined with Continuous Rhythmic Noise on Sleep Quality

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To my beloved parents whose endless love and countless sacrifices have shaped my journey. Every success I achieve is a testament to their unwavering support.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

BBs	Binaural Beats
dB	Decibels
SMH	St. Mary Hospital Sleep Questionnaire
PSQI	Pittsburgh Sleep Quality Index
rMEQ	reduced Morningness-Eveningness Questionnaire
SWS	Slow wave sleep
NREM	Non-rapid Eye Movement
REM	Rapid Eye Movement
AASP	Adolescent/Adult Sensory Profile
std	Standard deviation

ABSTRACT

Getting enough sleep is linked to several important aspects of human existence, such as preserving health and achieving better results at work. Sleep disturbance can result in several physiological and psychological problems. There are many factors affecting sleep quality including sleep habits, exercise, stress and anxiety, sleep disorders, light intensity, temperature and environmental noise. The primary goal of the study was to determine if continuous rhythmic white noise in combination with 3Hz binaural beats might be used as a non-pharmacological therapy for improved sleep quality, sleep fragmentation, latency, and relevant sleep parameters. The impact of continuous rhythmic white noise on sleep parameters was assessed using both hardware and questionnaire methods. Data from thirty subjects (16 females, mean age, 24.9±1.08 years), was collected using a variety of questionnaires, including the Pittsburgh Sleep Quality Index, reduced Morningness-Eveningness Questionnaire, Adolescent/Adult Sensory Profile, St. Mary Hospital Sleep Questionnaire, and a wearable sleep tracking device, Fitbit Charge 4. The questionnaire-based data was evaluated using chi mean square and the hardware-based data was analyzed using ANOVA and post hoc analysis where applicable. The results show that continuous rhythmic white noise combined with binaural beats has a significant impact on sleep quality, sleep score, total sleep duration, deep sleep duration and REM duration (p-value<0.05). The continuous rhythmic white noise in combination with binaural beats can be used to enhance specific aspects of sleep, particularly REM sleep, which is critical for cognitive and emotional well-being. In conclusion, this study demonstrated the potential of continuous rhythmic white noise in combination with 3 Hz binaural beats for improving the sleep quality of the individuals in noisy settings.

Keywords: Sleep, Continuous rhythmic white noise, Binaural beats, Sleep duration.

CHAPTER 1 : INTRODUCTION

1.1 Sleep:

Sleep is a phenomenon of the brain. Reduced engagement with the environment, decreased physical activity, and altered awareness are the features of sleep, a natural and reversible condition of rest. It is vital for many physiological functions and is necessary for both mental and physical well-being. The brain sleeps while the body relaxes. Several vital bodily functions only take place when the brain is sleeping. However, the brain is the organ responsible for sleep [1]. Another fundamental idea is that sleep is not an isolated event. Sleep comes in a variety of forms, each with unique traits, purposes, and regulation mechanisms. Sleep is not only a passive condition; rather, it involves active activities that are essential for maintaining psychological balance, cognitive function, and overall health [2]. Sleep's precise function is still mostly unknown. Numerous well-known theories have focused on the brain in an effort to explain why humans sleep. These theories include the inactivity theory, recovery theory, energy conservation theory, and brain plasticity hypothesis. These theories contribute to clarifying the concept that sleep is still not entirely understood; they are neither exhaustive nor all-inclusive of widely held beliefs. It is becoming more widely acknowledged that no single theory can adequately account for everything and that a mix of different theories is responsible for the enigma of sleep [3].

1.2 Functions of Sleep:

Sleep is an active condition that is crucial to the survival of almost all living things on Earth, with normal neural activity throughout certain sleep phases. A brief suspension of awake consciousness occurs during sleep, and behavioral, physiological, and brain activity changes also occur. It is a cyclical process with multiple stages that includes changes in eye movement patterns, brain wave patterns, and other physiological indicators. Although the physiology of sleep has been extensively studied, it appears that the precise role of sleep remains unknown. Sleep is necessary for several processes, such as memory consolidation, emotional control, physical and mental recovery, and general cognitive health. Sleep fulfils a variety of purposes that are critical to general health and the best possible functioning of humans. Facilitating physical recovery and repair is one of its main functions. The body goes through processes when you sleep that help with immune system support, muscular growth, and tissue repair, which keeps the body healthy for the demands of the day. Sleep has been shown to maximize the consolidation of freshly learnt information in memory, depending on the specifics of learning and sleep time [4].

Certain phases of sleep may influence neurodevelopment. This role in rapid eye movement (REM) sleep has been hypothesized. Neurogenesis may benefit from REM sleep. Research has demonstrated that rats who are deprived of REM sleep have reduced hippocampal neurogenesis, and that REM sleep promotes the growth of progenitor cells into neurons [5].

Sleep is essential for memory consolidation, the process of stabilizing memories and integrating learnt material into long-term storage, even if knowledge acquisition and recall only happen during wakefulness. Additionally, there seems to be a screening mechanism that prevents irrelevant memories from being consolidated. During stage 3 NREM sleep, neural replays of hippocampal representations cause representations to gradually change and integrate into neocortical networks (a process known as systemic consolidation) [6].

The cardiovascular system is significantly impacted by the quality of sleep. Normal sleep causes the autonomic balance to go from sympathetic to more parasympathetic, the heart rate to decrease, and the blood pressure to drop. It seems that the cardiovascular system needs to relax in order to function at its best. The cardiovascular system is under stress from increased autonomic activity, which raises the possibility of negative CV consequences. Furthermore, there is significant evidence that a lack of sleep raises the incidence of cardiac arrhythmias. The immune system and sleep are intimately related, and their interaction is reciprocal. In addition to strengthening the immune system, illness can affect sleep by either increasing the length or intensity of sleep or interfering with it.32 It has been demonstrated that sleep deprivation and disruption lower natural killer cell activity and antibody production, raising the risk of infections and maybe even cancer. Inflammatory cytokines produced by sleep deprivation also raise the risk of chronic metabolic and cardiovascular diseases [7].

Studies on behaviour and the body demonstrate that sleep deprivation results in affective dysregulation, which impacts how emotions are processed and can occasionally show up as negative bias, increased reactivity, reduced reaction, or the emotional interpretation of neutral information. Another important role of sleep is emotional regulation, especially during REM sleep, when the brain synthesizes and analyses emotions. This makes it possible for people to manage everyday challenges and preserve their emotional strength [8]. Through the system of lymphatics, which aids in the removal of waste materials and poisons, sleep also promotes brain detoxification, which promotes long-term brain health. Sleep and metabolic balance are closely related, impacting hormone balance, appetite management, and glucose regulation. Getting enough sleep is essential for keeping a healthy weight and lowering the risk of metabolic diseases. Sleep is a reliable ally of the immune system, promoting the generation of cytokines and immune cells that combat infections and diseases. Lack of sleep impairs immunity, making the body more susceptible to illnesses [9].

1.3 Sleep Stages:

Rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep are the two basic phases of the human sleep cycle, which are further divided into three separate stages. The five phases of sleep include alertness, N1, N2, N3, and REM. NREM sleep, which is defined by a gradual development into deeper sleep, is made up of the N1 to N3 phases. The NREM stages account for over 75% of total sleep duration, with the majority of the time spent in the N2 stage. Four to five sleep cycles, including a series of phases in the order of N1, N2, N3, N2, and REM, comprise a normal night's sleep. An average sleep cycle lasts between 90 and 110 minutes [10].

There is a short REM phase at the beginning of the night, followed by longer REM intervals and less time spent in deep sleep (NREM). There are variations in eye movements, brain wave patterns, and muscle tone during each stage and phase of sleep. Rapid eye movements are a hallmark of REM, whereas no eye movements are a hallmark of NREM. Every night, the body cycles through all of these stages four to six times, with a 90-minute break in between. But there are gender variances as well. Because they often wake up at night and spend more time in stage N1 sleep, men are inclined to complain of daytime tiredness. On the other hand, compared to males, women often complain more about having trouble falling asleep and staying in a deep sleep [11].

1.3.1 Awake:

Alpha waves are observed during tranquil or relaxed wakefulness, whereas beta waves have the highest frequency and lowest amplitude in an EEG recording. The wake stage, also known as stage W, is the initial stage and is further influenced by whether the eyes are open or closed. The predominant waves during eye-open wakefulness are beta waves. When people close their eyes and go sleepy, alpha waves take over as the dominating pattern [12].

1.3.2 N1 - Light Sleep:

EEG recording: low voltage theta waves

N1 makes up 5% of the sleep cycle. This is the lightest stage of sleep, which starts when low-amplitude mixed-frequency (LAMF) activity replaces more than 50% of the alpha waves. The skeletal muscle has tone, and breathing happens on a regular basis. This phase, which makes about 5% of total sleep duration, lasts between one and five minutes.

1.3.3 N2 - Deep Sleep:

EEG recording: sleep spindles and K complexes

N2 makes up 45% of the sleep cycle. This stage is associated with deeper sleep as body temperature and heart rate decrease. It is characterized by the presence of either K-complexes or sleep spindles, or both. Numerous studies indicate that sleep spindles are crucial for memory consolidation, particularly declarative and procedural memory. Sleep spindles are short, strong bursts of neuronal firing in the thalamus, anterior cingulate, insular cortices, and superior temporal gyri, inducing calcium influx into cortical pyramidal cells. This process is thought to be essential to synaptic plasticity [13].

The longest and most identifiable brain waves are K-complexes. The duration of these lengthy delta waves is around one second. K-complexes have been shown to promote sleep and memory consolidation. About 25 minutes is the duration of the first cycle of stage 2 sleep, which increases in length with each cycle until it accounts for about 45% of total sleep. Teeth grinding, also known as bruxism, occurs during this stage of sleep .

1.3.4 N3 – Deep Non-REM Sleep:

Delta waves are the lowest frequency and largest amplitude in EEG recordings. Another name for N3 is slow-wave sleep (SWS). This stage of sleep, which is thought to be the deepest, is distinguished by signals called delta waves that have larger amplitudes and lower frequencies. Loud noises (more than 100 dB) may not wake some people from this stage, which is the hardest to wake from. People spend more time in stage N2 sleep and less time in this sluggish, delta-wave sleep as they get older. Despite having the highest arousing threshold, if someone is awakened in this stage, they will experience sleep inertia, which is a brief period of mental haziness [14]. During this phase, the body produces muscle and bone, improves the immune system, and repairs and regenerates tissues. Additionally, bedwetting, nocturnal terrors, and sleepwalking start at this point.

1.3.5 N4 – REM:

Beta waves, which resemble brain waves while waking, are recorded by EEG. REM has been linked to dreaming and has not been seen as a restful sleep stage. Even if the EEG is similar to that of an awake individual, the skeletal muscles are atonic and immobile, with the exception of the eyes and diaphragmatic breathing muscles, which are still active. However, the breathing rate becomes more erratic and irregular. This phase, which usually starts 90 minutes after you fall asleep, prolongs each REM cycle. The first phase typically lasts ten minutes, while the last one may go up to an hour. REM sleep is when dreams, dreadful vision and penile/clitoral tumescence occur [15].

1.4 Impact of poor sleep quality:

The importance of sleep for both physical and mental wellness cannot be overstated. Human growth, development, and lifespan are strongly correlated with the quality of one's sleep. Living things require sleep as a physiological condition in order to recuperate properly. By supporting a number of activities, including learning, memory consolidation, neuronal maturation, metabolic waste product removal, restorative processes, and brain and body development and repair, regular sleep improves health [16]. But since people's lives are moving more quickly and they are under more strain at work, their mental load is growing as well, which lowers the quality of their sleep and increases the prevalence of related mental illnesses. period of sleep, which causes disruption and disarray in people's lives[17].

Increased stress responsiveness, physical discomfort, a worse quality of life, psychological issues and mood disorders, and deficiencies in cognition, memory, and performance are some of the short-term effects of sleep disturbance in healthy individuals [18]. The physiological side effects of sleep disorders include tachycardia, cardiac arrhythmias, and hemodynamic instability as a result of increased sympathetic activity and reduced cardiac parasympathetic activity. Around the world, 35% of people suffer from insomnia.

1.5 Methods to improve Sleep Quality:

1.5.1 Pharmacological Treatments:

The risk-benefit profile of each patient must be carefully evaluated, even though many pharmacological therapies for insomnia and other sleep problems have previously been developed. Although psychological-behavioral therapies are often preferred over pharmaceutical therapy, the number of people who primarily use sleep-inducing medications to increase or improve their sleep is steadily increasing, despite the drawbacks of these treatments, such as addiction and rebound reactions [19]. Central inhibition, digestive issues, and drug dependence are the primary adverse effects of sleeping tablets, which are the conventional method of addressing sleep problems [20].

1.5.2 Therapies:

Numerous effective treatments are available to address insomnia-related issues and enhance the quality of sleep. Cognitive behavioural therapy (CBT-I), which tries to alter thinking and behaviour patterns that disrupt sleep, is a particularly successful treatment for insomnia. Stress and anxiety that disrupt sleep can be lessened by employing mindfulness-based methods like Mindfulness-Based Cognitive Therapy (MBCT) and Mindfulness-Based Stress Reduction (MBSR). To lower stress and learn more about healthy sleeping habits, people can employ biofeedback, relaxation training techniques, and sleep education [21]. Two behavioural strategies that assist people in creating more efficient sleep patterns and better sleep habits are Stimulus Control Therapy and Sleep Restriction Therapy. For those who suffer from issues related to their circadian rhythm, light therapy offers a non-invasive solution. Collective therapy, yoga, tai chi, and physiotherapy all promote a holistic approach to relaxation that promotes deeper, more restful sleep. These kinds of treatments can be used to meet the specific needs of each patient under the supervision of medical specialists, which may lead to improved sleep and overall health [22].

1.5.3 Devices:

There are several solutions available to address different sleep-related problems and enhance the quality of sleep. White noise machines create relaxing background sounds that mask distractions and encourage sound sleep. To promote relaxation, sound therapy devices offer a range of calming audio options. You may keep an eye on your sleeping patterns, identify patterns, and make the required adjustments for improved sleep quality by wearing a smart sleep monitor while you sleep. Sensors are used by smart mattresses and sleep trackers to track heart rate, breathing, and movement, giving precise data on the quality of sleep. Alarm clocks that include wake-up lights simulate a genuine dawn in order to gently wake users and synchronize their circadian cycle. Blue light from gadgets can be avoided by using blue light-blocking eyewear [23].

Mattress toppers and other temperature-controlled furniture, like heated blankets, can be used to provide a cozy sleeping environment. The ideal setting for relaxing is created by using smart home technology to automate the lighting, temperature, and sound. Mouthpieces and pillows are among the devices used to treat sleep apnea and snoring. Sleep apnea is treated with continuous positive airway pressure (CPAP) equipment, which maintain open airways by continually providing air pressure [24]. Weighted blankets encourage comfort and relaxation by gently pressing against the body. Aromatherapy essential oil diffusers may help you unwind before bed. Smart home sleep environment monitors evaluate moisture, temperature, and level of noise to encourage rest. In order to encourage a peaceful morning, dawn simulators mimic the sun's rays.

1.5.4 Noise:

Evidence is mounting that broadband sound administration can be used as a non-pharmaceutical substitute and, more importantly, as a way to hide ambient noise disruptions due to technological improvements [25]. Issues with initiating and maintaining sleep are frequently caused by noise disturbances both inside and outside the house. A 2012 National Sleep Foundation survey found that 5% of Americans already use sound conditioners, such as fans, air purifiers, hoover cleaners, and broadband (e.g., "white") noise gadgets in their rooms as makeshift sleep aids, despite the dearth of well-designed, randomized controlled trials [26]. The "auditory masking phenomenon," which states that a masker (such as continuous low-level noise) reduces the audibility of a distressing signal (such as indoor/outdoor noise), is the foundation of broadband sound administration. Masking happens as a result of a decrease in the bilateral auditory stimulated reaction to the signal and a rise in the subjective alertness threshold caused by the drop in the volume of the background sound level compared to the distressing signal

[27]. Furthermore, the auditory stimulus's effect on electrical activity in the brain may have a direct impact on sleep through sound administration [28].

White noise, which may mask all the sounds from the surroundings that are very upsetting, is made up of a mix of continuous sound frequency fluctuations and ambient sounds. White noise used for medicinal purposes typically has a decibel level of no more than 10,000 hertz. It's yet unknown how white noise might enhance the quality of sleep. By raising the auditory threshold to its maximum, white noise can continually enhance the quality of sleep by reducing the ability of ambient noise to activate the brain as you sleep, according to some studies conducted overseas [29].

Combining autonomous sensory meridian response (ASMR), a stimulation that is believed to encourage serenity and relaxation, with binaural beats is also used as sleep aid. There is potential for improving NREM 3 sleep and encouraging delta band activity when the auditory stimuli of ASMR and a 3 Hz binaural beat are coupled [30].

The interesting auditory phenomenon known as binaural beats has attracted attention due to its possible medical uses. Essentially, a binaural beat is an acoustic impression produced by employing stereo headphones to transmit two tones with slightly different frequencies to each ear independently. The binaural beat is a tone that the brain senses after processing the difference between the two frequencies. The brain interprets a beat of 10 Hz, for example, if a 200 Hz tone is played in left ear and 210 Hz tone in the right. A fundamental idea in comprehending the operation of binaural beats is the frequency-following effect. The brain's innate propensity to align its electrical activity with the amplitude of an external hearing stimulus is known as this effect. The electrical activity of the brain starts to synchronize with the perceived beat frequency when subjected to binaural beats [31]. For instance, the brain may be stimulated to generate brain waves at the same frequency by hearing to a binaural beat of 10 Hz. Brainwave entrainment is the term for this synchronization, which can alter mental faculties and cognitive processes.

The slowest brainwaves, known as delta waves, are usually seen during deep, rejuvenating sleep. This stage of sleep is essential for mental and bodily recovery and renewal. Deep sleep is crucial for general health and wellbeing, and it may be encouraged using BB in the delta range. They may help produce a state of profound tranquilly and comfortable sleep, which may be especially helpful for those with insomnia or other sleep problems[32].

1.6 Problem Statement:

Sleep disruption is closely related to life-altering events. Sleep pattern disruption can result in both physical and mental health problems. Most of the time, it can lead to a higher risk of morbidity and the development of several mental and physical illnesses. It is hypothesized that broadband sounds can enhance sleep quality by masking disturbing noises.

Patients of all ages can benefit from broadband noise as a non-pharmacological therapy that improves their daily functioning due to higher-quality sleep. White noise is typically utilized to enhance the quality of sleep through these broadband frequencies. White noise generators or smartphone apps might be used for this. In either case, white noise might be an affordable approach to enhance the quality of your sleep.

Numerous populations and environments have demonstrated the effectiveness of using auditory stimuli, such as music, pink noise, and white noise, to enhance the quality of sleep. 19 studies out of 34 reported positive effects on improving sleep quality, according to a 2022 systematic review [25]. Six of these studies used white noise (33%), nine used pink noise (81.9%), and four used multi-audio (66.7%). Multi-audio had the lowest risk of bias (mean/standard deviation: 1.67/0.82) when compared to white noise (2.38/0.69) and pink noise (2.36/0.81) [25].

The usage of 432 Hz music, which is popular in the New Age genre, is another intriguing aural stimulation that has changed in recent years. This is accomplished by utilizing music editing software to slow down (by 32 hundredths of a tone) the performance of a song that was originally tuned at 440 Hz [33]. It is hypothesized that music heard at 440 Hz, the frequency currently employed to tune musical instruments, has a distinct effect on the body and mind than music played at 432 Hz[34]. In a 2020 research, 12 individuals with spinal injuries listened to their preferred music set to 440 Hz or 432 Hz for 30 minutes every day for two periods. When compared with those listening to 440 Hz music (-1.50, $p = 0.34$), those who listened to music at 432 Hz had a substantial improvement in sleep ratings ($+3.6$, $p = 0.02$) [34]. Alpha, theta, and delta mixed binaural beats are found to enhance the ISI, overall sleep quality, and quality of sleep of students with insomnia. Furthermore, this kind of therapy may be applied as a contemporary non-invasive remedy [35].

To examine how ventilation and associated ventilation noise affect the quality of sleep, three conditions were set up: Low noise and no mechanical ventilation (A); low noise and mechanical ventilation (B); and high noise and mechanical ventilation (C). A mechanical ventilator was either left idle or run in two distinct modes to accomplish the interventions [36]. The findings support the notion that sleep quality is negatively impacted by inadequate ventilation rates and that noise levels of 50dB(A) or higher may cause sleep disturbances [36]. None of the research found any negative effects from short-term auditory stimulation during sleep, despite the lack of compelling evidence to promote its usage. Future studies must take into account confounding variables that may influence results, such as personality, noise sensitivity, and other illnesses or drugs that may interfere with sleep [25]. In order to estimate the effect of continuous white noise combined with Binaural Beats on sleep quality, further research is needed.

1.7 Aims and Objectives:

According to some research, the non-pharmacological remedy for improved sleep is a variety of broadband sounds. The degree of improvement must be tested under controlled circumstances utilizing dependable, extensive data gathering and analysis technologies. The following are the primary goals of this study:

1. To measure sleep quality, fragmentation, latency, and other pertinent sleep parameters by using continuous white noises as stimuli.

2. To evaluate the potential of Continuous white noises as a non-pharmacological remedy for improved sleep quality.

3. To use the PSQI questionnaire to determine whether white noise affects both good and poor sleepers.

4. Using the rMEQ questionnaire, determining whether a person's personality type-whether they are an evening or morning person-affects the quality of their sleep.

In this study, two types of protocols are designed to check the effect of continuous rhythmic white noises on the sleep quality including hardware device and questionnaires for evaluation of the sleep quality.

CHAPTER 2 : LITERATURE REVIEW

A basic physiological function that is necessary for both physical and mental health is sleep. Despite its significance, millions of people worldwide suffer from sleep problems and poor sleep quality. Sleep quality-enhancing non-pharmacological methods, such aural stimulation, have drawn a lot of interest. Two such auditory therapies that have been studied separately and, more recently, in combination for their effects on sleep quality are binaural beats and continuous rhythmic white noise.

A steady sound with all the hearing range's frequencies played at the same volume is referred to as "white noise." White noise has been proposed as a way to reduce ambient noise and create a steady, sleep-friendly aural environment. White noise dramatically decreased sleep start latency and increased total sleep efficiency in those with insomnia, according to a comprehensive analysis [26]. In a similar vein, research like that conducted by Ebben and associates [27], shown the value of white noise in establishing a steady acoustic environment that promotes restful sleep, especially in loud environments. White noise creates a "sound blanket" that muffles unexpected external noises that might interfere with sleep, according to McGuire et al. [37]. This masking effect can be affected by the type of white noise that is utilized; pink noise, with its balanced frequency distribution, may offer deeper relaxation. According to research, these systems could aid in controlling the architecture of sleep, promoting smooth transitions between sleep phases and preserving general stability when at rest [38].

Deep sleep, or slow-wave sleep (SWS), is crucial for physical restoration and memory consolidation. The effects of different types of white noise on deep sleep have been a focal point in recent studies. A study found that pink noise enhanced the proportion of deep sleep in participants, likely due to its calming effect on the central nervous system. Brown noise has also been linked to prolonged SWS durations, particularly in environments with high ambient noise levels [28].

These findings suggest that the type of white noise used can influence not only the quantity but also the quality of sleep by promoting deeper restorative stages. However, more research is needed to understand the underlying neural mechanisms and the optimal parameters for different populations. Different types of noise are categorized based on their frequency spectrum and sound characteristics:

White Noise:

Contains equal intensity across all audible frequencies, producing a consistent "hissing" sound. It is often used to mask sudden noises and create a uniform auditory environment.

Pink Noise:

Emphasizes lower frequencies while reducing higher frequencies. Its balanced sound is perceived as more natural and soothing, making it a popular choice for sleep enhancement.

Brown Noise:

Also known as red noise, it focuses on even lower frequencies than pink noise, resulting in a deeper, richer sound often compared to the roar of a waterfall.

Blue Noise:

Opposite to pink and brown noise, blue noise has higher energy at higher frequencies, producing a sharper and brighter sound that is less commonly used for sleep.

Gray Noise:

Adjusted across frequencies to match the human ear's sensitivity, gray noise provides a more uniform perceived sound intensity.

These variations in sound profiles influence how individuals respond to each type of noise, particularly in the context of sleep.

The practical application of different white noise types spans various contexts. In clinical settings, pink noise has been integrated into sleep therapy programs to enhance deep sleep, while brown noise is often recommended for individuals in noisy environments. Devices and mobile applications now offer customizable white noise options, allowing users to select the type and intensity that best suits their needs. For shift workers and individuals with irregular schedules, tailored interventions involving specific white noise types may provide significant benefits. For example, pink noise might be used to facilitate sleep onset, while brown noise could help maintain deep sleep in challenging conditions.

Numerous research has evaluated the effects of different kinds of white noise on the length and quality of sleep. In comparison to ordinary white noise, exposure to pink noise greatly improved sleep efficiency and decreased sleep onset latency, according to a randomized controlled experiment [25]. Similarly, another investigation found that brown noise, which has a richer and deeper sound profile, was linked to longer deep sleep. Additional information is provided by research on sleep disorders. A study found that when exposed to pink noise instead of regular white noise, those with insomnia slept longer overall and had fewer nightly awakenings [39].

Binaural beats are auditory illusions perceived when two tones of slightly different frequencies are presented to each ear, resulting in a perceived third tone. This phenomenon has been linked to brainwave entrainment, where the frequency of the binaural beat influences brain activity. Delta (0.5–4 Hz) and theta (4–8 Hz) binaural beats have been associated with relaxation and sleep induction [35]. Research demonstrated that delta binaural beats improved sleep quality, as measured by subjective and objective metrics, such as polysomnography and self-reported sleep scales. Additionally, it was reported that binaural beats could reduce pre-sleep anxiety, a common factor contributing to insomnia [40].

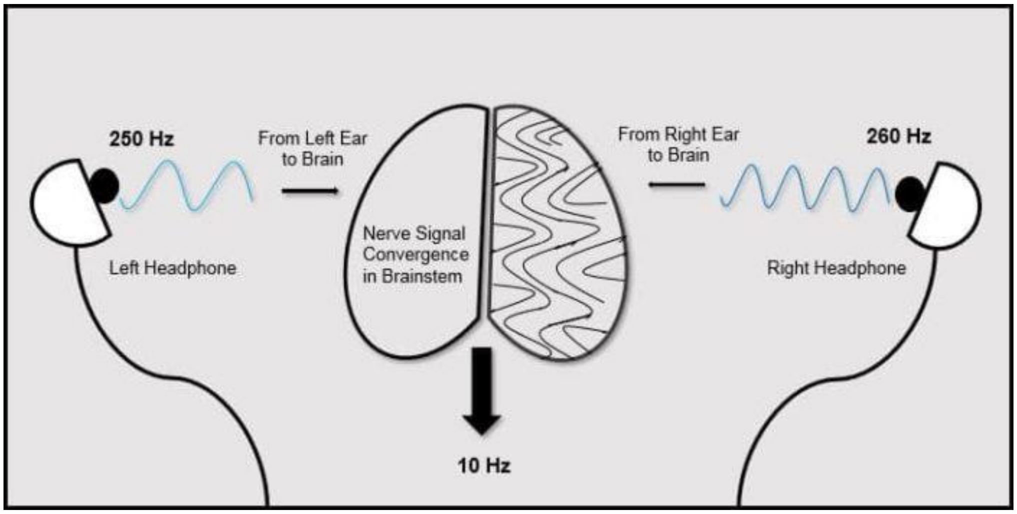

Figure 2.1: Phenomenon of Binaural Beats [41]

Recent studies have explored the synergistic effects of combining white noise and binaural beats to enhance sleep quality. For instance, a randomized controlled trial found that the combination significantly improved total sleep time and reduced awakenings compared to either intervention alone [42]. The study hypothesized that white noise provides a masking effect, reducing external disruptions, while binaural beats facilitate brainwave entrainment, leading to deeper and more restorative sleep stages. These findings are supported by neural imaging studies showing increased delta wave activity during combined auditory interventions [43].

The mechanisms by which white noise and binaural beats influence sleep are not entirely understood but are thought to involve both auditory and neural processes. White noise may operate by masking sudden auditory changes, maintaining a consistent auditory environment conducive to sleep. In contrast, binaural beats are believed to directly affect brainwave patterns through frequency-following response (FFR), promoting relaxation and transitions into sleep stages.

Broadband noise, which includes white noise and other types of broadband auditory stimuli, has been used by several studies to evaluate its effects on sleep quality in a variety of settings. This has been achieved by employing a variety of data gathering techniques and instruments. To examine the impact of white noise on people's sleep quality, several researchers have employed a variety of questionnaires. Subjects were asked to complete questionnaires after sleeping in a particular setting, such as their home, place of education, or college. The quality of sleep following white noise therapies has been assessed using a variety of questionnaires. Depending on the kind of study, the majority of researchers utilized the Stanford Sleepiness Scale (SSS), Pittsburgh Sleep Quality Index (PSQI), Consensus Sleep Diary, Col-icky Baby's Diary, State-Trait Anxiety Inventory, St. Mary, and other questionnaires. On the other hand, several other researchers have done this using sleep monitoring equipment. These gadgets include motion logger Actigraph, an actigraph unit wristwatch set, and additional smartwatches for tracking sleep. However, some sleep researchers simply use information from the patient or their recordings. Studies from several researchers have been categorized into two groups based on data collecting.

2.1 Hardware-based

Instead of using the conventional questionnaire approach, fewer research examined the impact of white noise on sleep quality using smart sleep monitoring equipment. Based on Motion-logger Actigraph and Consensus Sleep Diary data, researchers in [24] found that using white noise to drown out loud external noise in New York City enhanced sleep quality. There was no discernible beneficial impact of AC sound on sleep duration, latency, or efficiency, according to the researchers in [44], who employed white noise generated by AC sound and gathered data using an actigraph unit wristwatch set. This study has several limitations, including age groups, the inability to objectively monitor background noise, the insensitivity of actigraphy to measure awakenings and arousals, and the study's short length.

2.2 Questionnaire-based

Improved sleep quality has been linked to improved cognitive and physical functioning. Researchers have discovered in recent years that broadband sounds may improve the amount and quality of sleep for those who are healthy or afflicted with any illness. The wideband noise intervention was investigated on healthy subjects by certain researchers. The visual analogue scale (VAS) and Stanford sleepiness scale (SSS) were used to examine 18 healthy people using various noise generator types, broadband noise, and ambient noise.

According to the findings, wideband noise could work well as a subgroup. On improved sleep, nevertheless, they were in agreement. For 30 days, Putri Rajawali Makassar high school pupils have had access to white noise, which consists of a 60-minute rainstorm played with carefully regulated outside influences. Based on PSQI surveys, the results supported improved sleep quality [45]. However, students reported not getting enough sleep.

Compared to similarly researched ICU groups, elective general surgery patients had a more severe inpatient sleep disruption. Nighttime awakenings are the main cause of this disruption. Prior studies have examined the potential effects of broadband and white noise on patients' sleep quality, finding that they either had no discernible impact or improved their quality of sleep. For three nights, 60 patients receiving coronary care were exposed to 50–60 dB white noise in a hospital setting. The PSQI questionnaire findings indicated that white noise enhanced the quality of their sleep [46].

In a publication [47], patients in intensive care units were given white noise for three days, and it was found that their sleep quality improved. A 4-point Likert scale questionnaire was used to gather data. Researchers also found no effect of white noise-based State-Trait Anxiety Inventory after exposing operating room staff to function-based white noise for three days with a 10-day wash-off time [27]. Patients with insomnia have been treated with the broadband noise intervention by [21]. Researchers examined how administering surrounding broadband sound affected healthy volunteers' subjective sleep quality, sleep architecture, and sleep onset latency in a randomized controlled study. They were randomly assigned to either broadband sound administration evenly dispersed over the room by two speakers (46.0 dB) or typical ambient noise (40.1 dB). The Pittsburgh Sleep Quality Index (PSQI) was then used to gather data. In comparison to ambient noise, this study found that administering broadband sound dramatically decreased sleep onset delay by 38%. Research has been conducted to determine whether playing white noise can assist parents and medical professionals lessen their infants' gas discomfort [48]. A "Colicky Baby's Diary" has been used to assess this and determine how long the babies have been crying and sleeping overall. Researchers found that playing white noise for colicky newborns boosted their sleeping durations and considerably reduced their daily crying durations ($p < .05$).

Additionally, prior research has examined the impact of white noise on children with attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder (ASD) in order to assess improved sleep quality. Three children with ASD were given white noise with a particular rhythm, a suitable bedtime routine, and progressive extinction for a month (one week of follow-up). According to the parents' reports, there was a decrease in sleep latency and a decrease in the frequency of night awakenings [49]. Researchers found that parents reported fewer spontaneous night awakenings and a reduction in sleep latency when adolescents with ADHD were exposed to a constant 75dB white noise level at home and at school. Due to significant bias risks, a lack of trustworthy data for sleep data in the homes, findings dependent on parents' report selection, unmeasured sound levels, and time limits, these results are unclear [14].

Due to limited sample size, uncontrolled outside noise, faulty and invalid data collecting or processing methods, and results derived only from questionnaires, these studies have produced a variety of outcomes.

White noises, however, are thought to enhance sleep quality by masking distracting sounds. It's unclear, though, if noise can actually enhance sleep measurements. The research is inconclusive because of the small sample size, lack of statistical analysis, use of imperfect noise measurement equipment, and uncontrolled disruptive elements. The aforementioned studies were conducted to assess the effects of wideband noise, or white noise, on sleep.

Thus, more investigation is needed to determine how wideband noise affects sleep.

This study collects data using a combination of sleep monitoring devices and questionnaires. Additionally, the data was gathered in a somewhat controlled setting from a large number of samples.

To distinguish between real white noise and other distracting noises, the decibel meter has also been used to measure the outside noise. Time awake, time sleeping, number of awakenings, and both REM and non-REM periods were all included in the comprehensive sleep data that the sleep monitoring equipment gave. For additional data analysis, a number of questionnaires have been employed, including the PSQI, Adult/Adolescent sensory profile, decreased Morningness-Eveningness questionnaire, and St. MARY questionnaire. Compared to earlier research, our study design offers a number of aspects to validate the findings of white noise's impact on sleep quality.

CHAPTER 3 : MATERIAL AND METHODS

3.1 Participants:

The study comprised of 36 subjects including both healthy individuals and those with sleep problems. Each of them signed an informed consent to participate in the study. The screening of participants was done based on taking any type of prescribed or unprescribed medication for sleep and neurological or psychiatric problems. The participant not using any medication or therapies for sleep are included in the inclusive criteria. The study comprised of two types of experiments: hardware-based & questionnaire-based. Each participant was conditioned to take part in only one of the two types of studies based on their willingness. The participants who took part in the questionnaire-based study were aged 24.8 +/- 0.87 and those who took part in hardware-based study were aged 24.9 +/- 1.08 years. The details of the participants are given in the table below.

Table 3.1: Details of the Participants

Details	Hardware	Questionnaire
No. of Subjects	15	15
Mean Age	24.9 +/- 1.08	24.8 +/- 0.87
Gender	7M,8F	7M,8F

3.2 Stimuli:

The continuous rhythmic white noise used in this study is aimed to mask the environmental noise. The continuous rhythmic white noise that was provided to the participants as a stimulus was comprised of continuous fan noise embedded with the binaural beats of 210 Hz of carrier frequency. The stimulus for the intervention was created specifically for this study by using Audacity Software. The spectral characteristics of the stimulus include the 210 Hz binaural tone to the left channel and a tone of 213 Hz to the right channel, with continuous fan noise superimposed on both channels. The sound level of the stimuli was adjusted individually by the participants according to their comfortability and power of signal was constant for 8 hours. The participants were provided with two types of noise; continuous rhythmic white noise embedded with BBF and Fan noise.

3.2.1 Fan noise+BBs:

The rhythmic white noise used for the intervention is continuous and embedded with Binaural Beats with 210 Hz carrier frequency. This stimulus was given to the participants for two consecutive nights.

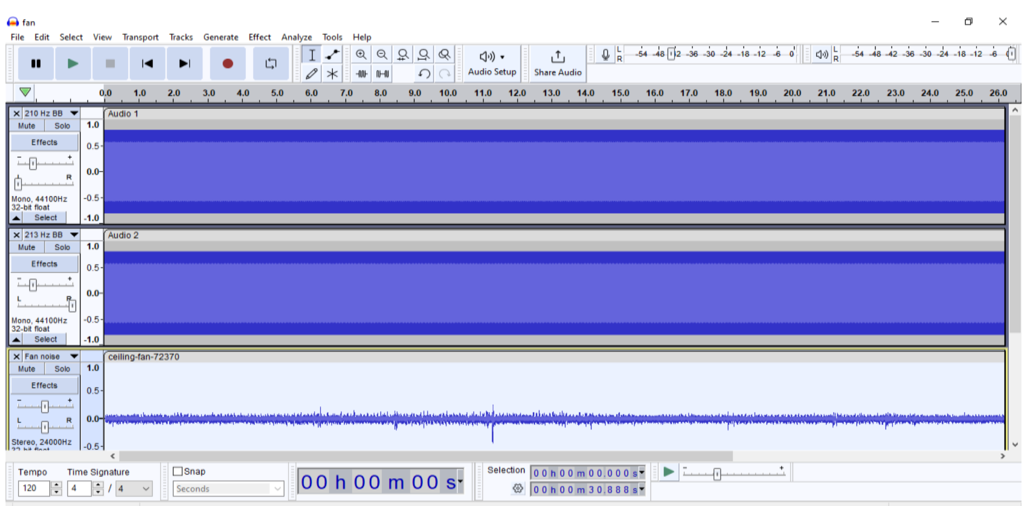

Figure 3.1: Generating Continuous White Noise embedded with Binaural Beats in Audacity

3.2.2 Fan Noise:

The second audio stimulus that was provided to the participants was continuous white noise only without any binaural beats embedded. This noise aimed to check the effect of fan noise present in the environment on the sleep of the individuals. To test the impact on the participants, the audio file was given to each individual for two nights in a row.

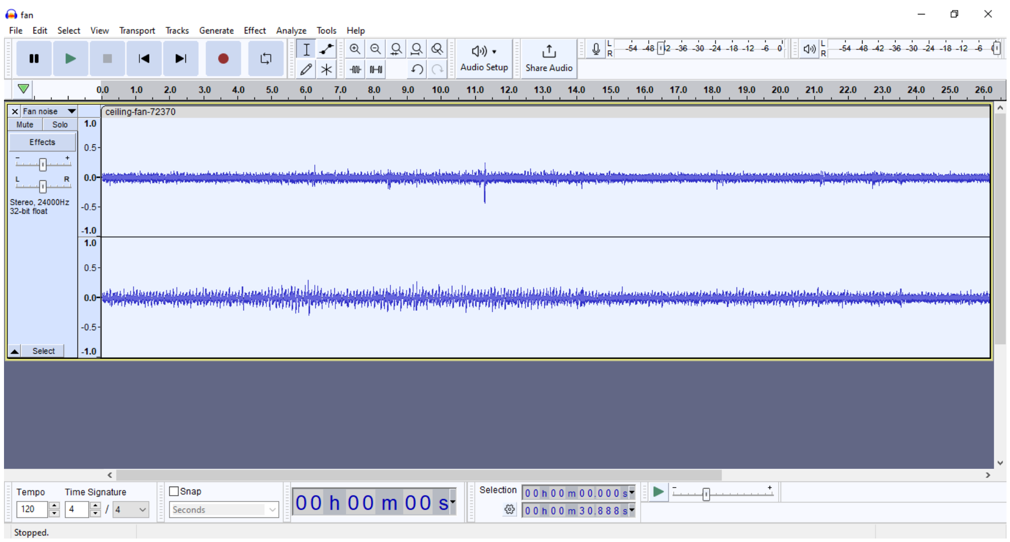

Figure 3.2: Generating Continuous rhythmic white noise in Audacity Software

3.3 Sleep Headphones:

Since the audio stimuli used in this study contains binaural beats that can only be perceived through stereo headphones. For this purpose, specially designed soft headphones known as SleepPhones, are utilized with movable left and right speakers that fit around the head. To avoid interfering with sleep, a single cable connects the speakers to the battery power supply. These SleepPhones contain Bluetooth 5.2 technology that easily pairs with any Android or iOS device. It is equipped with long lasting battery that provides up to 10 hours of playback with just 2 hours of USB charging. It is made with durable and soft fabric that is sweat-proof and lightweight (0.08 Kg) for comfortable sleep experience. The participants were advised to connect sleep headphones with their mobile phones to play the audio stimuli on the experimental night before going to bed.

Figure 3.3: Sleep Headphones with stereo speakers

3.4 Sleep Monitoring device:

Fitbit Charge 4 (Fitbit Inc.) smart watches have been used for sleep monitoring. The reason for using this device is that, in comparison to other smartwatches, it delivers sleep data that is more precise. Due to its biological periodicity, human sleep follows sleep architecture. Rapid eye movement (REM) and non-rapid eye movement (NREM) sleep are the two categories into which the International Society of Sleep Medicine divides sleep. NREM sleep is further subdivided into three stages, N1–N3. There are differences in muscle tone, brain wave patterns, and eye movements during each stage and phase of sleep. The body goes through each of these phases four to six times per night, with an average duration of ninety minutes.

The Fitbit device estimates different sleep stages such as light sleep, deep sleep and REM stages and also determines the sleep patterns by utilizing the combination of metrics of movement and heart rate measures. Fitbit's integrated accelerometers have been used to track movement metrics, that determines when the subject wearing the device gets out of bed or toss and turns during the night. When a person transitions from one stage of sleep to another, their heart rate has been used as an indicator. Fitbit Charge 4 (Fitbit Inc.) was used to gather activity and heart rate data.

The participants were instructed to wear the Fitbit device on their non-dominant hand before going to bed for five days consecutively. The information gathered included the participant's sleep duration, the amount of movement that took place while they were asleep, the number of times they woke up throughout the night, and the approximate amount of time they spent in each stage of sleep. The data gathered has been exported in an Excel file for additional processing. Fitbit data using the Fitbit mobile application is displayed in Figure below. It presents sleep-related characteristics such as total awake time, total sleep time, time asleep, and length of light sleep, deep sleep, and REM sleep in minutes. The sleep monitoring device measures restlessness and sleep heart rate, and the restoration percentage.

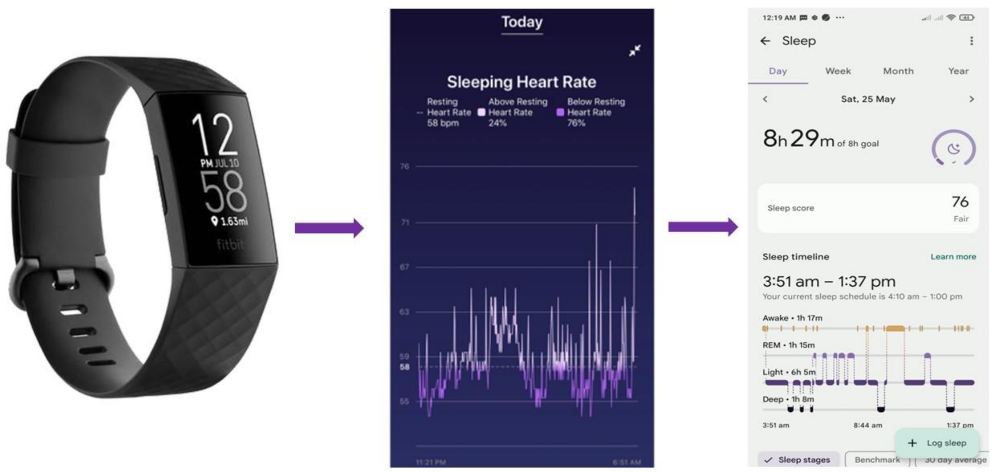

Figure 3.4: Sleep Data in the Fitbit Mobile App using Fitbit watch

3.5 Psychomotor Vigilance Task:

A sustained attention, reaction-timed test called a psychomotor vigilance task (PVT task) evaluates how consistently and promptly a person reacts to a changing visual input.

Two popular variants of the Psychomotor Vigilance Test (PVT), a behavioral attention assessment, are the 10-minute (PVT-10) and 3-minute (PVT-3) versions. The next day, we measured the participants' attention spans using PVT-3, or the 3-minute test, with or without a white noise intervention. Prior to completing the pre- and post-study questionnaires, the task was completed. The PVT task, which is depicted in figure 4.3, was created such that when the numbers, or delayed time, appear on the screen, you must click on them to gauge your level of alertness related to sleep aspects.

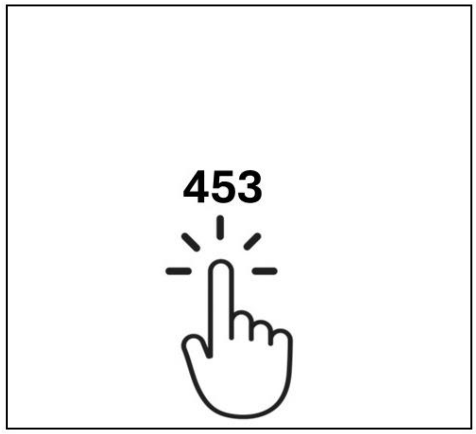

Figure 3.5: PVT Screen during Task

3.6 Questionnaires:

This study uses a number of questionnaires, including pre- and post-study surveys. After signing the consent form, the participants had to answer questions on the pre-study questionnaire. The Adolescent/Adult Sensory Profile, the Pittsburgh Sleep Quality Index (PQSI) questionnaire, and the Reduced Morningness-Eveningness Questionnaire are the pre-study questionnaires included in the study [50]. Data from intervention nights and the subjects' usual data are also assessed using post-study questionnaires which include St. Mary's Sleep Questionnaire, often known as SMH.

3.6.1 Pittsburgh Sleep Quality Index (PSQI)

The majority of sleep research have utilized this questionnaire to examine how white noise affects the quality of sleep. It is employed to evaluate the quality of sleep throughout the preceding month. The PSQI was created to assess these clinical populations' general sleep quality. Subjective sleep quality, sleep latency, length, habitual sleep efficiency, sleep disruptions, usage of sleeping medicine, and daytime dysfunction are the seven subcategories into which each of the questionnaire's 19 self-reported questions falls. For therapeutic purposes, five more questions that are not scored but are evaluated by the respondent's bed partner or flat mate are added. The scale's psychometric qualities have been evaluated in a number of studies, but the designers' first assessment revealed an internal reliability of a =.83, a test-retest reliability of.85 for the global scale, a sensitivity of 89.6%, and a specificity of 86.5%. This PSQI [45] questionnaire is primarily used to grade the participants' overall sleep quality and assess the frequency with which they have encountered certain sleep issues during the previous month. Each question has a value between 0 and 3, where higher scores correspond to more severe sleep disruptions.

3.6.2 Adolescent/Adult Sensory Profile (ASP)

The purpose of the Adolescent/Adult Sensory Profile is to encourage self-assessment of behavioral reactions to common sensory stimuli. Measurement of sensory processing patterns and their impact on functional performance is made easier using the Adolescent/Adult Sensory Profile. Instead, answering questions on how they react at any moment, a person answers questions about how they typically react to experiences. Investigating the connections between adult sleep quality and sensory processing issues was the primary goal of the Adolescent/Adult Sensory Profile. Additionally, how the participants react to sounds prior to being exposed to white noise while they sleep.

3.6.3 reduced Morningness- Eveningness questionnaire (rMEQ)

A person's circadian rhythm, or biological clock, has been utilized to determine whether their peak alertness occurs in the morning, the evening, or somewhere in between using the reduced Morningness-Eveningness questionnaire (rMEQ) [46]. The aim of this questionnaire was to examine individual variations in morningness and eveningness, the extent to which respondents are busy and aware at particular times of the day. Items on the scale ask about subjective "peak" periods when individuals feel their best as well as preferences for waking and sleeping hours [51]. A number between 1 and 5 is assigned to each segment of the scale. Each component is totaled, and the total is then transformed to a 5-point scale: certainly evening type (16–30), neither type (42–58), moderately evening type (31–41), definitely morning type (70–86), and somewhat morning type (59–69).

3.6.4 St. Mary's Hospital Sleep Questionnaire:

In order to verify the subjects' data from intervention nights and normal sleep nights, post-study questionnaires are used. The Sleep Questionnaire from St. Mary's Hospital has been used for this. The St. Mary's (or SMH) Sleep Questionnaire is a tool that consists of items with proven dependability and conducts a methodical investigation of the subject's sleep experience. The scale's test-retest reliability ranged from.70 to.96 in a psychometric review by Ellis and colleagues [52]. The scale's validity as a significant indicator of sleep change is supported by additional studies conducted by the researchers. The scale's scoring procedure has not been standardized and will rely on the particular goals of the study or therapist because it asks for both Likert-type and fill-in-the-blank responses. While some research uses data from the full scale, others decide to concentrate on just one or two components (such as sleep delay). A respondent's findings, as a metric intended to identify change, are most significant when compared to those acquired by other people or at various dates.

One of the best tools for recurrent usage during a research or treatment period is the St. Mary's (or SMH) Sleep Questionnaire, which assesses the length and subjective quality of a person's sleep from the night before. The 14 items on the scale ask about a range of sleep-related problems, such as morning alertness, sleep latency, restlessness, and overnight awakening. This questionnaire has to be completed by participants, either with or without white noise treatments.

3.7 Intervention Protocol:

The experimental technique has been separated into two categories: questionnaire-based and hardware-based. For every protocol design, the data has been gathered for a certain number of days. For a certain number of days, the subjects had to sleep both with and without white noise. Additionally, the individuals were given many questionnaires to complete both before and after bed. Additionally, participants were given the Psychomotor Vigilance Task (PVT), which they had to do each time before completing the questionnaire. A smart watch-based sleep monitor, Fitbit Charge 4 was used to get hardware-based data.

3.7.1 Questionnaire Based Experiment

The questionnaires were given to participants at the beginning of the research. Pre-study questionnaires were used to assess individuals' stress levels, exercise responses, and sleep habits. The Pittsburgh Sleep Quality Index (PSQI) questionnaire, which determines a person's sleep habits from the preceding month, was the first. The second was the Adolescent/Adult Sensory Profile, which measured how an individual reacted to everyday sensory experiences. To determine if a person is an evening or morning person, the third questionnaire was the Reduced Morningness-Eveningness Questionnaire. To determine your daily stress level, the final one was a three-minute daily stress assessment activity. Before the research began, the entire process took around thirty to forty minutes.

Additionally, a post-study questionnaire, the St. Mary's Hospital Sleep Questionnaire, was used to assess participants' experiences with data collecting nights. Participants were invited to participate in sleep sessions with planned sleep patterns, such as three consecutive nights per week and around eight hours of sleep each night, on the designated days after completing the questionnaire. Participants have been told to sleep well for eight hours throughout the first week. In the second week, individuals listened to white noise both before and while they slept. Additionally, participants listened to a placebo white noise as they slept in week three. Each participant's data collection days were chosen at random using a randomizer. The post-study questionnaire was completed by participants at the conclusion of three nights per week.

The data collecting process, which includes three weeks of sleep data and three consecutive days of each, is depicted in Figure 3.6. The remaining four days were designated as the washout phase.

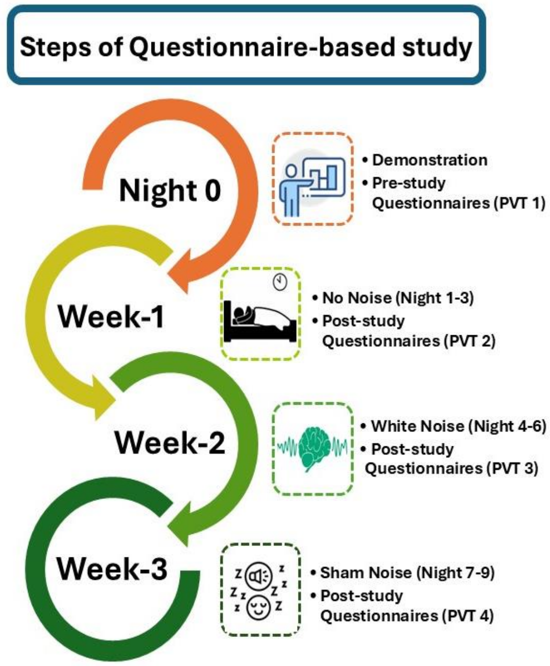

Figure 3.6: Protocol of Questionnaire-based experiment

3.7.2 Hardware-based Experiment:

Participants in hardware-based data collection were requested to use sleep monitoring devices and complete questionnaires. All of the pre-study questionnaires listed above, including the Reduced Morningness-Eveningness Questionnaire, the Adolescent/Adult Sensory Profile, and the PSQI questionnaire [42, 44]. Additionally, as a post-study questionnaire, the St. Mary's Hospital Sleep Questionnaire [52] was added. Every time, a psychomotor vigilance exercise is completed prior to completing the questionnaire. Participants were expected to participate in sleep sessions with planned sleep patterns, meaning they had to sleep for about eight hours per night for a total of one week, on the designated days after finishing the questionnaire.

Participants were given the hardware setup, which includes a wearable sleep monitoring device and sleep headphones. The sleep headphones were used to deliver the audio stimuli to the participants while sleeping. On the other hand, each participant's sleep data, such as length and phases, were measured using a sleep monitoring device. The sleep monitoring equipment had to be worn by the participants while they slept.

Participants in this study were provided with two audio files. Participants were required to have about eight hours of noise-free sleep on the first night. They must listen to white noise as they sleep for the remainder of the day. The post-study questionnaire has to be completed by participants at the conclusion of each evening. Figure 3.7 illustrates the data collecting process, which includes a week's worth of sleep data where participants must sleep with white noise for two nights in a row and without noise for one night. In order to examine the impact of noise on the length of sleep latency and determine whether or not the influence of sham noise lasts the entire night, participants must also sleep with it for two nights in a row.

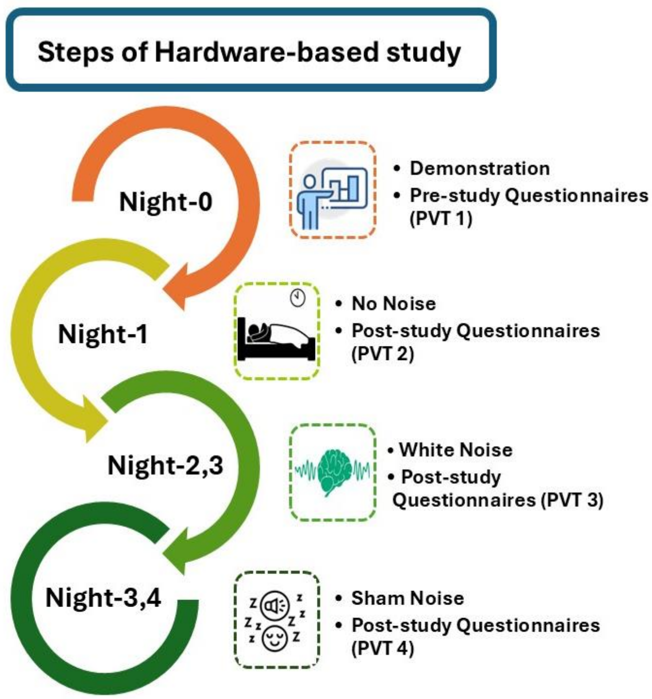

Figure 3.7: Protocol of Hardware-based experiment

The hardware package included a sleep aid, a Fitbit watch that was linked to a smartphone app, surveys, and a psychomotor awareness exercise. Using their own smartphones, participants were directed to access the Fitbit app, and settings were modified based on their Body Mass Index (BMI). White noise was also provided; it was played on the participants' computers or cell phones according to their charging condition and availability, guaranteeing uninterrupted replay the whole night.

CHAPTER 4 : RESULTS

4.1 Questionnaire-Based

The individuals have completed many surveys. The subject responds to the surveys in a variety of ways. To examine the differences between participants sleeping with fan noise only, fan noise+BBs and subjects sleeping with no noise, statistical analytic approaches have been applied to that data.

4.1.1 PSQI Vs ASP

In order to examine the relationship between sensory processing patterns and sleep quality metrics, PSQI and the AASP were compared in this study. While the PSQI questionnaire was used to determine whether a person slept well or poorly, the Adult Sensory Profile was used to gather data on sensory patterns. This information forces us to compare how well and poorly sleepers receive sensory information. Data was gathered from two categories of participants: 30 participants who had recently utilized gear for sleep quality monitoring, of whom 13 were good sleepers and 17 were bad sleepers.

To examine the relationship between sensory metrics and sleep quality, chi-square tests have been used. All four quadrants—low registration ($p = 0.804$), sensation seeking ($p = 0.285$), sensory sensitivity ($p = 1.000$), and sensation avoidance ($p = 0.233$)—show non-significant variations, according to the data. The correlation between the AASP and PSQI questionnaires is seen in Figure 4.1.

	Good Sleepers (n=11)			Poor Sleepers (n=15)				
Sensory Behaviors	> Less than most people	= Similar to most people	< More than most people	> Less than most people	= Similar to most people	< More than most people	Chi Square	P-Value
Low Registration	0	8.0	36.0	4.0	16.0	36.0	1.131	0.804
Sensation Seeking	28.0	8.0	8.0	24.0	28.0	4.0	2.869	0.285
Sensory Sensation	0	28.0	16.0	0	24.0	32.0	0.108	1.000
Sensation Avoiding	0	28.0	16.0	0	20.0	36.0	2.345	0.233

Figure 4.1: Percentages of Good Versus Poor Sleepers Below (<), At (=) or Above (>) the Typical Performance Category in Each Sensory processing Quadrant

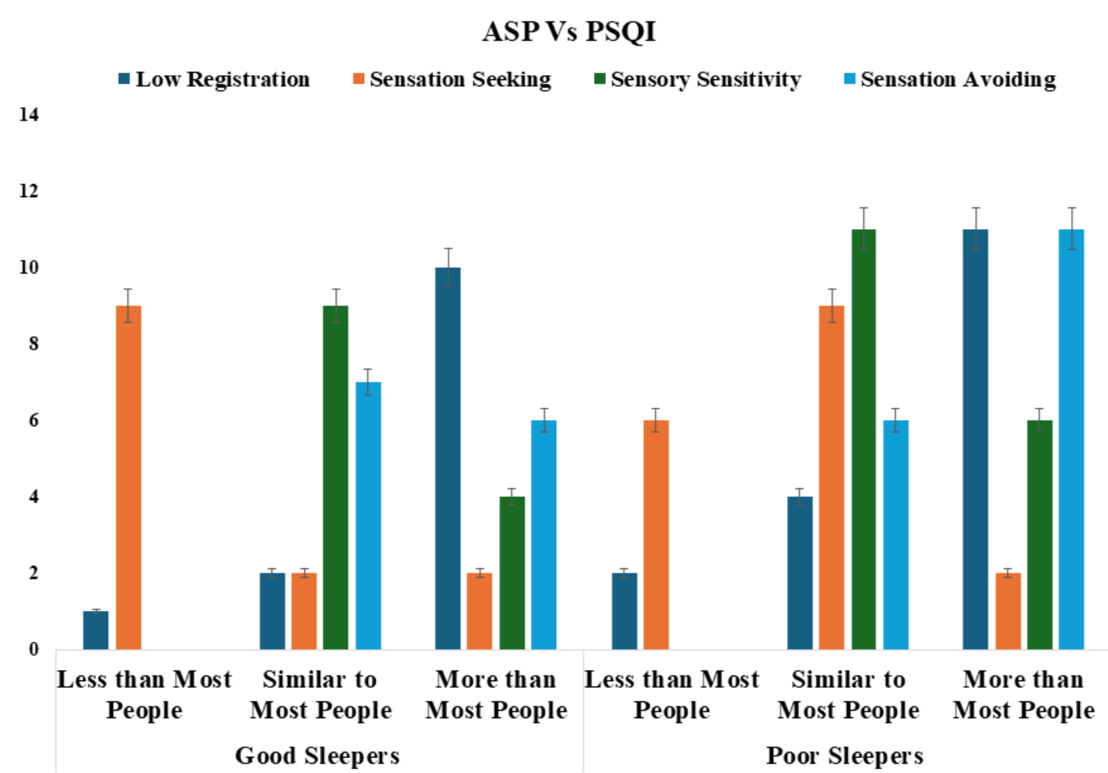

Figure 4.2: Graph of Good Versus Poor Sleepers Below (<), At (=) or Above (>) the Typical Performance Category in Each Sensory processing Quadrant

Across all categories (Low Registration, Sensation Seeking, Sensory Sensitivity, Sensation Avoiding), the p-values are greater than 0.05, indicating no statistically significant differences between good and poor sleepers in these sensory patterns. The sensory responses (e.g., low registration, seeking, sensitivity, avoiding) show different distributions, but none are significant enough to suggest a strong association between sensory behavior and sleep quality.

4.1.2 Reduced Morningness-Eveningness

Each scale item in the rMEQ has a value between 1 and 5. Each component is added together, and the total is then transformed into a 5-point rating system, ranging from clearly morning type to certainly evening type, to determine the overall score. This specific questionnaire's grading was completed by hand. The extracted text contains a comparison of "Good Sleepers" (n=11) and "Poor Sleepers" (n=15) regarding their chronotype (morning or evening preference). The p-value (0.025) is less than 0.05, indicating a **statistically significant difference** between the chronotype distributions of good and poor sleepers. The correlation between the rMEQ and PSQI questionnaires is seen in Figure.

Good Sleepers (n=11)			Poor Sleepers (n=15)				
Moderately Morning Type	Neither Type	Moderately Evening Type	Moderately Morning Type	Neither Type	Moderately Evening Type	Chi Square	P-Value
20.0	8.0	16.0	0.0	20.0	36.0	7.963	0.025

Figure 4.3: Percentage of Good Sleepers Vs Poor Sleepers Chronotype

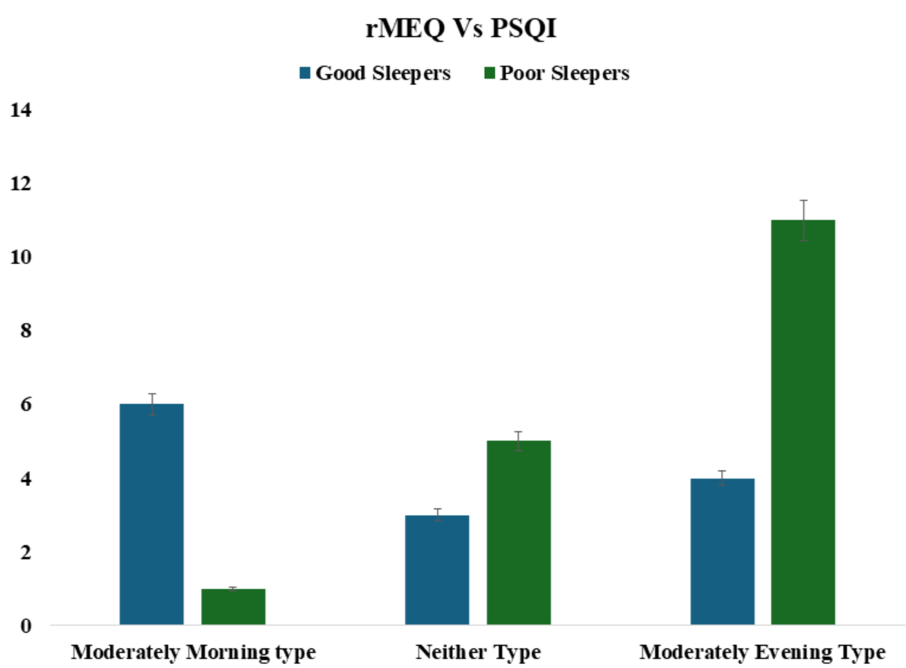

Figure 4.4: Graph of Good Sleepers Vs Poor Sleepers Chronotype

Poor sleepers are more likely to be "Moderately Evening Type" compared to good sleepers. Good sleepers show a higher tendency towards "Moderately Morning Type" than poor sleepers. This suggests that sleep quality might be associated with an individual's chronotype, with evening types being more prone to poorer sleep.

4.1.3 St. Mary Hospital Sleep Questionnaire:

The graph shows the effect of different noise conditions on sleep quality scores as measured by the St. Mary Hospital Sleep Questionnaire. The x-axis represents three conditions: **No Noise**, **Fan Noise**, and **Fan Noise + BBs**. The y-axis represents the Sleep

Quality Scale, with lowest score 1 representing very bad sleep quality, 2 representing bad sleep, 3 for fairly bad sleep, 4 indicating fairly well sleep, 5 indicating well and highest score 6 indicating very well sleep quality. Vertical bars denote standard deviations. The graph in Figure reports a highly significant effect of noise conditions on sleep quality (F(2, 50) = 20.428, p = 0.000). This indicates that the differences observed between conditions are not due to chance. **Fan Noise Alone**: Appears to disrupt sleep quality, likely due to the monotony or frequency of the sound, which might disturb participants' ability to fall or stay asleep. **Fan Noise + BBF**: Enhances sleep quality beyond the "No Noise" condition, potentially providing a soothing or masking effect against other disruptive environmental sounds. This suggests that specific types of noise combinations, such as white noise or broadband frequencies, might aid sleep.

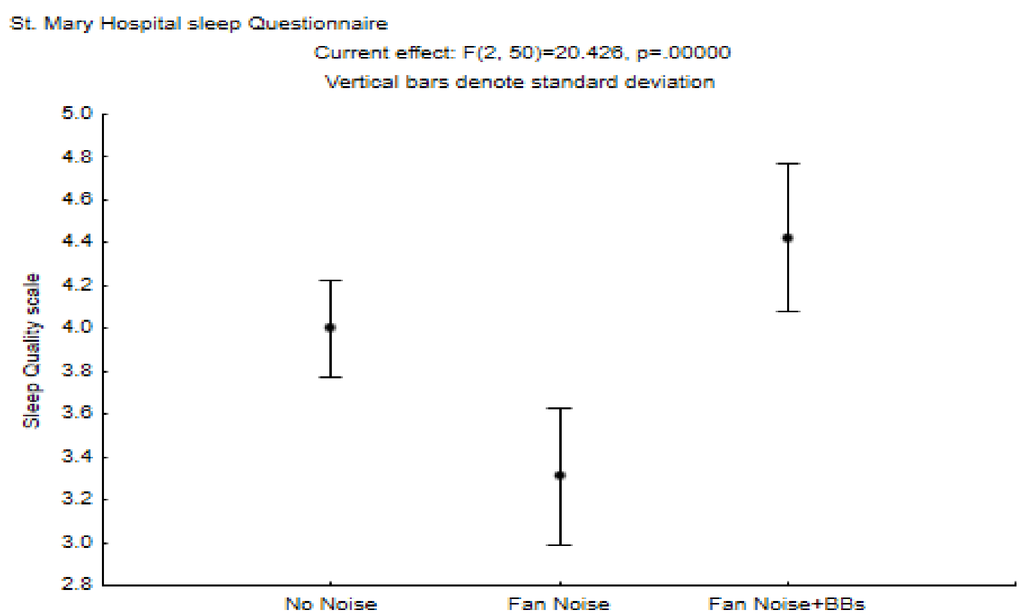

Figure 4.5: Effect of No Noise, Fan Noise and Fan Noise+BBs, Mean+/- std plot of Sleep Quality

4.2 Hardware-based:

The sleep monitoring device was used to measure a number of characteristics related to the quality of sleep. Light, deep, and REM sleep are among the phases of sleep that are included in the parameter, along with the overall sleep score and total sleep duration.

The current effect of continuous rhythmic white noise on sleep score is F (2, 34) = 2.9020 and having the p-value of 0.06861. There is no significant difference of continuous rhythmic white noise on sleep score. "No Noise" might be slightly better for sleep quality compared to the other two conditions. Adding "Fan Noise" appears to reduce sleep scores somewhat. Combining "Fan Noise" with "BBs" brings the score closer to the "No Noise" condition, which could suggest that the additional sound either counteracts or mitigates the negative impact of fan noise alone.

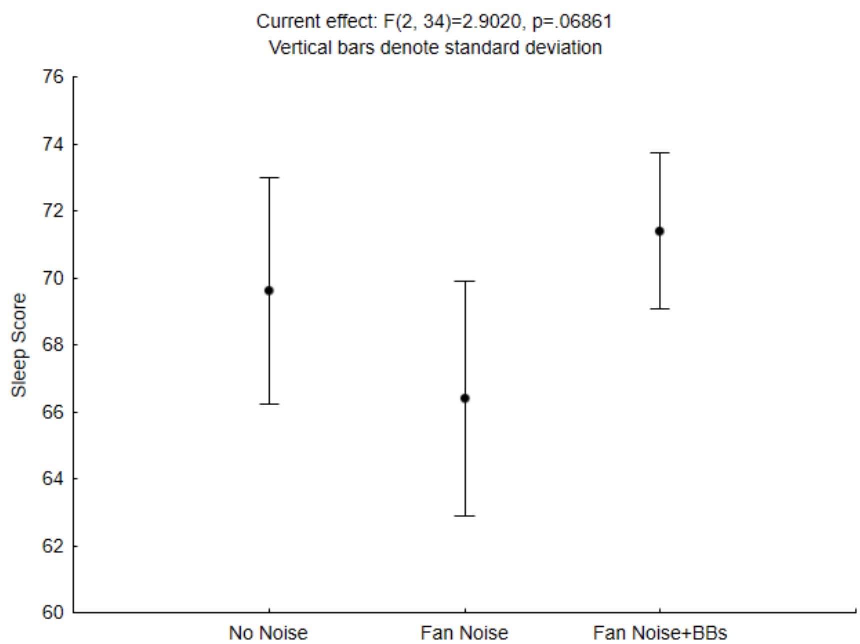

Figure 4.6: Mean +/-std plot of sleep score to check the effects of continuous rhythmic white noise on overall subject's sleep

The current effect of continuous rhythmic white noise on sleep score is F(2, 34)=13.193 and having the p-value of 0.0006. Sleep duration is significantly affected by noise conditions. "Fan Noise" alone has a strongly negative impact, reducing sleep duration compared to the other conditions. Adding "BBs" to the fan noise appears to mitigate some of the negative effects, resulting in longer sleep duration than "Fan Noise" alone. However, the "Fan Noise + BBs" condition still does not match the "No Noise" condition in total sleep duration.

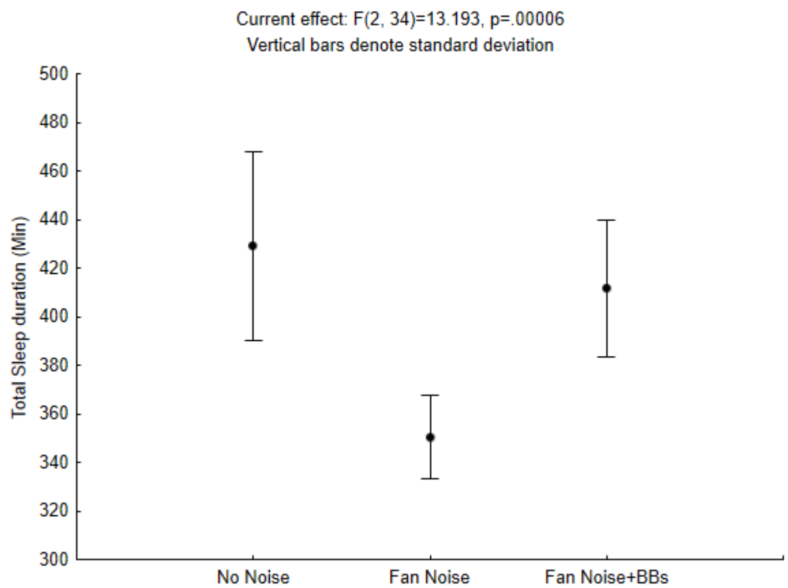

Figure 4.7: Mean +/-std plot of total sleep duration to check the effects of continuous rhythmic white noise on overall subject's sleep

The ANOVA results show $F(2,34)=6.5912$ and $p=0.00381$, which is statistically significant ($p<0.05$). This indicates that the differences in deep sleep duration across these experiment conditions are statistically significant.

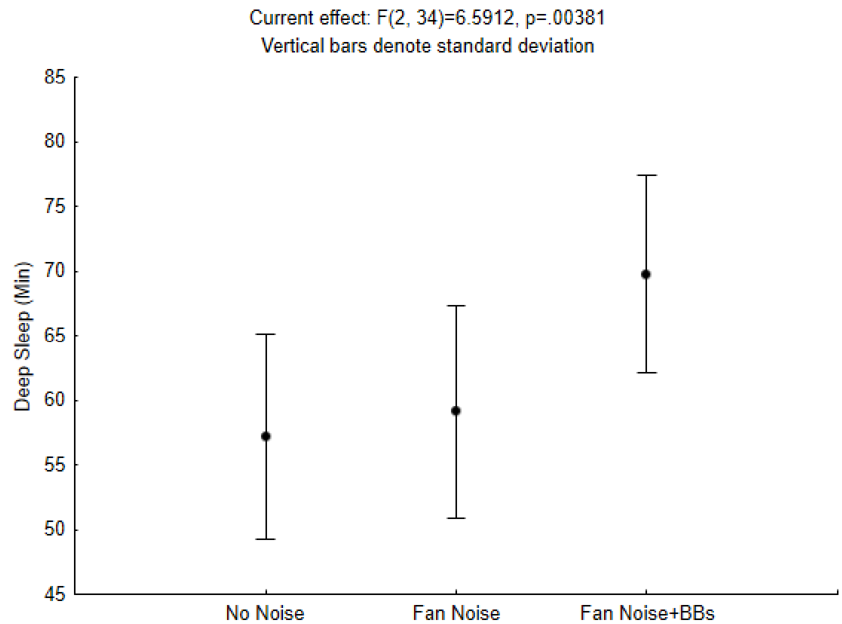

Figure 4.8: Mean +/-std plot of Deep sleep duration to check the effects of continuous rhythmic white noise on overall subject's sleep

The F-statistic F(2, 34) = 1.7679) and p-value (p = 0.18603) indicate that the differences in light sleep duration among the three groups are not statistically significant at the conventional 0.05 level. The No Noise condition shows the highest average light sleep duration. The fan noise and fan noise+BBs conditions have slightly lower means compared to No Noise, with Sham having the least light sleep duration.

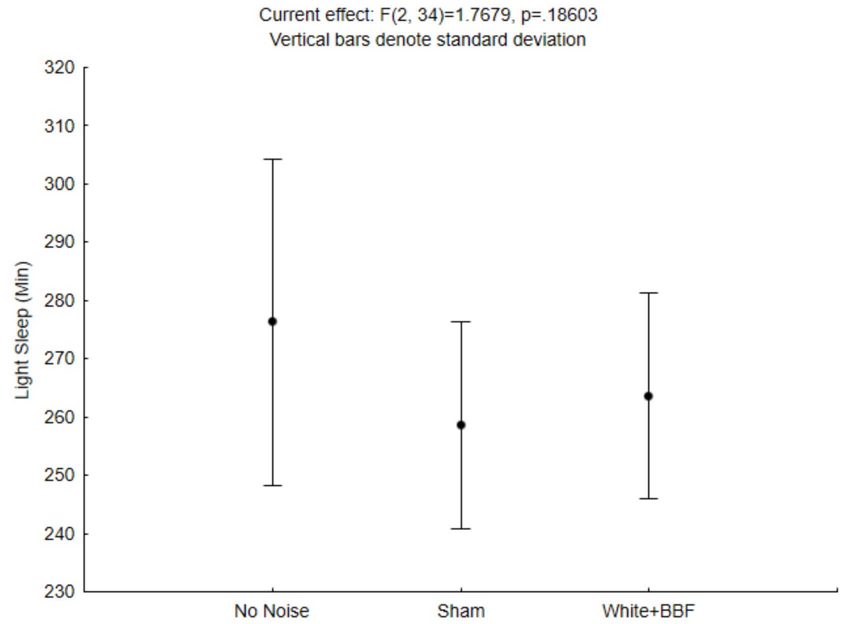

Figure 4.9: Mean +/-std plot of Light sleep duration to check the effects of continuous rhythmic white noise on overall subject's sleep

The F-statistic F(2, 34) = 12.127) and the p-value (p = 0.00011) indicate that the differences in REM sleep duration among the three groups are statistically significant (p < 0.05). The Fan Noise+BBs condition significantly increases REM sleep duration compared to No Noise and Fan Noise alone. Noise interventions, particularly those involving Broadband Frequency, may have a meaningful impact on enhancing REM sleep.

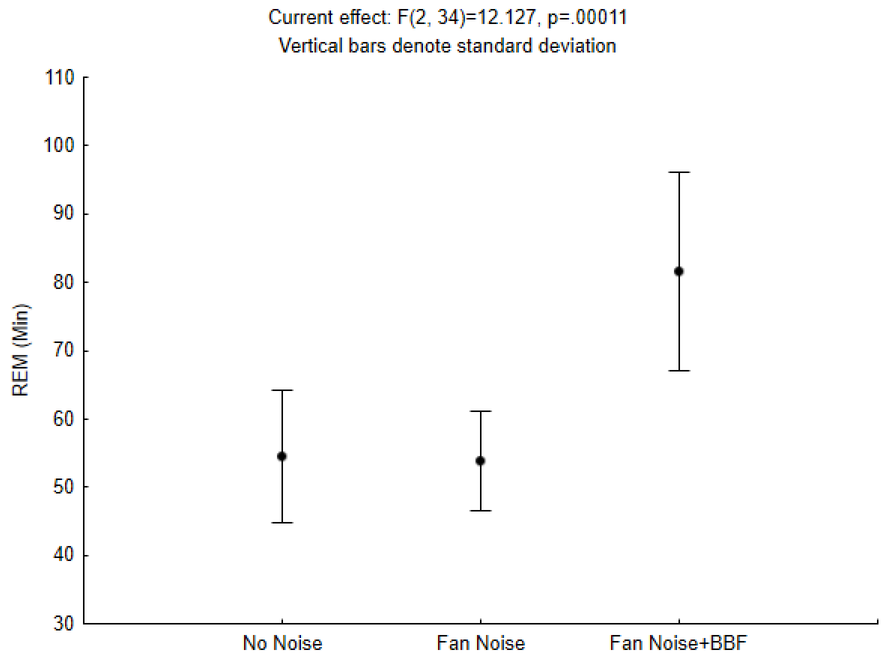

Figure 4.10: Mean +/-std plot of REM duration to check the effects of continuous rhythmic white noise on overall subject's sleep

CHAPTER 5 : DISCUSSION

The results of the current study highlight significant associations between chronotype, sleep quality, and sensory processing patterns as measured by the AASP and PSQI. In particular, differences in sensory processing patterns between Good Sleepers and Poor Sleepers provide additional insights into the mechanisms contributing to sleep quality variations.

5.1 rMEQ Vs PSQI

The Pittsburgh Sleep Quality Index (PSQI) revealed clear distinctions between Good Sleepers and Poor Sleepers, with chronotype playing a critical role. Good Sleepers were more likely to exhibit morning-type tendencies, while Poor Sleepers showed a pronounced evening-type preference. The p-value of 0.025 indicates a statistically significant difference in chronotype distribution, reinforcing the notion that evening types are predisposed to poorer sleep quality.

As discussed earlier, evening chronotypes may experience misalignment between their circadian rhythms and societal schedules, leading to increased difficulty initiating sleep, fragmented sleep patterns, and reduced overall sleep quality [50]. PSQI, as a reliable measure of subjective sleep quality, captures these disparities effectively. Poor Sleepers scored significantly worse on the PSQI, reflecting higher levels of sleep disturbance, latency, and daytime dysfunction.

5.2 ASP Vs PSQI

The AASP, which assesses sensory processing patterns across four domains (low registration, sensation seeking, sensory sensitivity, and sensation avoiding), adds a novel dimension to understanding the link between sensory behaviors and sleep quality. Sensory processing tendencies can influence an individual's ability to relax, fall asleep, and maintain sleep, thereby affecting PSQI scores. Poor Sleepers often exhibited heightened sensory sensitivity. This means they are more likely to be hyper-reactive to environmental stimuli such as noise, light, or temperature fluctuations, which can interfere with the ability to initiate or sustain restful sleep. Increased sensory sensitivity has been linked to heightened arousal states, making it difficult to achieve the calmness necessary for quality sleep. In contrast, Good Sleepers demonstrated better sensory modulation abilities, which likely contribute to their superior PSQI scores [45]. These individuals may be better equipped to filter out irrelevant stimuli or adapt to their environment, promoting more consistent and restorative sleep.

The integration of AASP and PSQI data provides a more comprehensive picture of how sensory processing tendencies influence sleep quality. While the PSQI measures subjective sleep quality, the AASP offers a framework to understand underlying sensory processing mechanisms that may drive these subjective experiences. Poor Sleepers may experience heightened sensory arousal due to increased sensory sensitivity (AASP), leading to higher PSQI scores (indicating poorer sleep quality). This aligns with the idea that hyperarousal, both physiological and sensory, is a key contributor to insomnia and poor sleep quality. Good Sleepers, with their better sensory adaptability (as suggested by lower AASP sensory sensitivity scores), are likely to have more stable sleep environments and routines, resulting in lower PSQI scores.

The combined use of AASP and PSQI highlights the importance of addressing sensory processing tendencies when developing interventions to improve sleep quality. For example, Evening chronotypes with high sensory sensitivity might benefit from tailored sleep hygiene strategies, such as reducing environmental stimuli (e.g., blackout curtains, white noise machines) or practicing mindfulness techniques to lower arousal levels. Sensory-based therapies, including occupational therapy interventions targeting sensory modulation, may help individuals with heightened sensitivity improve their sleep quality.

5.3 St. Mary Hospital Sleep Questionnaire

The current study investigated the influence of different noise conditions on sleep quality using the St. Mary Hospital Sleep Questionnaire. The three tested conditions included No Noise, Fan Noise, and Fan Noise+BBs**.** The results revealed significant differences in sleep quality scores across these conditions ($F(2, 50) = 20.428$, $p = 0.000$), highlighting the critical role of auditory environments in sleep regulation. The **No Noise** condition demonstrated moderately high sleep quality scores, indicating that a quiet environment supports restful sleep for most participants. The small standard deviation further suggests that this effect was consistent across individuals. These findings align with previous research emphasizing the benefits of silence in promoting uninterrupted and restorative sleep, free from external auditory distractions.

The introduction of Fan Noise resulted in a substantial decline in sleep quality, with the lowest mean score observed among the three conditions. The increased standard deviation indicates variability in participants' responses, suggesting that some individuals were more sensitive to fan noise than others. This aligns with existing literature on noise sensitivity, where exposure to continuous and monotonous sounds, such as fan noise, may interfere with the sleep cycle by disrupting relaxation and preventing deeper stages of sleep. Factors such as individual differences in sensory processing or habituation to background noise could explain the variability.

Interestingly, the Fan Noise+BBs condition significantly improved sleep quality, surpassing both the No Noise and Fan Noise conditions. This improvement suggests that the addition of binaural beats effectively masked the potentially disruptive nature of fan noise while introducing a soothing auditory environment conducive to sleep. The relatively low standard deviation highlights the consistency of this positive effect across participants. This may help minimize the impact of sudden or intermittent noises and facilitate a sense of calm, thereby enhancing sleep quality. These results align with studies showing the therapeutic potential of white noise in improving sleep latency and overall sleep satisfaction.

The findings hold practical significance for improving sleep quality in noisy environments. For individuals who struggle with sleep due to noise disturbances, introducing broadband frequency noise (e.g., through white noise machines or specialized applications) could provide an effective solution. This approach may be particularly beneficial in urban areas, hospitals, or other settings where ambient noise levels are challenging to control.

5.4 Sleep Parameters

The results of this study provide valuable insights into how different noise conditions-"No Noise," "Fan Noise," and "Fan Noise+BBs"-affect various aspects of sleep, including overall sleep quality, total sleep duration, and time spent in deep sleep. These findings have practical implications for optimizing sleep environments and understanding how external auditory stimuli can influence sleep architecture.

The first graph revealed that while sleep quality (measured by sleep score) appeared slightly higher in the No Noise condition compared to the Fan Noise and Fan Noise+BBs conditions, the differences were statistically significant (p=0.06861). This suggests that external noise, whether in the form of fan noise or fan noise combined with BBs, may not substantially impact perceived sleep quality in a way that is detectable with the sample size used in this study. However, the slight upward trend observed for Fan Noise+BBs warrants further investigation, as it hints at a potential positive effect of this noise combination on sleep perception.

Sleep duration was highest in the No Noise condition and decreased significantly in the Fan Noise condition, indicating that fan noise disrupts sleep continuity. Interestingly, the Fan Noise+BBs condition mitigated this reduction, resulting in a sleep duration closer to that of the No Noise condition. This suggests that the combination of fan noise with BBs might mask the disruptive effects of fan noise alone or create a more soothing auditory environment, thereby promoting longer sleep durations. While the No Noise and Fan Noise conditions resulted in similar deep sleep durations, the Fan Noise+BBs condition significantly increased deep sleep time. This finding suggests that the combination of fan noise and BBs may have a unique effect on promoting deeper restorative sleep, possibly due to the creation of a white noise-like effect that helps to stabilize sleep and mask disturbances.

These findings have important practical implications: A noise-free environment remains ideal for maximizing total sleep duration and maintaining stable sleep quality. The Fan Noise+BBs condition demonstrated potential benefits, particularly for increasing deep sleep duration and mitigating the negative effects of fan noise alone. This could have applications for individuals who live in noisy environments or who have difficulty falling or staying asleep. Fan noise alone appears to disrupt both total sleep duration and sleep quality, underscoring the need for careful consideration of the type and intensity of background noise in sleep environments. Unaffected by noise conditions, suggesting its regulation might be more dependent on internal circadian rhythms and sleep pressure rather than external auditory stimuli.

Highly sensitive to auditory interventions, with significant enhancements under Fan Noise+BBs. This suggests REM sleep may be more amenable to modulation by external factors. The significant improvement in REM sleep under Fan Noise+BBs highlights its potential for therapeutic use, especially for individuals with REM-related issues like insomnia, PTSD, or memory impairments. Developing devices or apps that deliver tailored noise profiles might optimize sleep quality.

Not all noise is equal; the type, frequency, and consistency of noise appear to matter. Broadband frequencies may be particularly effective at supporting REM sleep. Poorly designed noise interventions could disrupt sleep rather than enhance it, as suggested by the marginal effects on light sleep. The large standard deviations in both graphs suggest that responses to noise interventions vary widely across individuals. This reinforces the importance of personalized approaches to optimizing sleep environments. The findings suggest that while light sleep is not significantly affected by auditory conditions, REM sleep shows a marked improvement under Fan Noise+BBs. This highlights the potential for targeted noise interventions to enhance specific aspects of sleep, particularly REM sleep, which is critical for cognitive and emotional well-being [53].

5.5 Limitations and Future Research

Although this study provides valuable insights, certain limitations should be noted. The study's sample size limits the generalizability of these findings. It remains unclear whether sensory processing tendencies directly cause poor sleep quality or whether poor sleep exacerbates sensory sensitivity. Longitudinal studies are needed to explore causality. Future research should consider individual variability in noise sensitivity, as some participants may respond more strongly to auditory stimuli than others. There is also a need to explore the mechanisms underlying these effects and their broader applications in sleep health.

CHAPTER 6: CONCLUSION

A basic physiological function that is necessary for preserving both mental and physical health is sleep. Getting enough sleep is linked to several important aspects of human existence, such as preserving health and achieving better results at work. Sleep disturbance can raise the morbidity rate and lead to a number of mental and physical illnesses. It is hypothesized that continuous rhythmic white noises can enhance sleep quality by masking distracting sounds. It is uncertain, nonetheless, if noise can enhance sleep measurements.

The primary goal of the study was to determine if broadband noise might be used as a non-pharmacological therapy for improved sleep quality and to evaluate sleep quality, fragmentation, latency, and other sleep variables using broadband sounds. Fitbit Charge 4 has been utilized as sleep tracking devices for this purpose, and other questionnaires, such as the PSQI, rMEQ, AASP, and St Mary questionnaire, have been employed. White noise's impact on all aspects of sleep, including length, phases, and total score, was assessed using both hardware and questionnaire data. For data collection, primarily healthy subjects with ages of 25.07+/-4.66 for questionnaire-based study and 24.25+/- 2.57 for hardware-based data were chosen. The gathered data has undergone a number of statistical analyses. Fitbit data has been subjected to post-hoc analysis and ANOVA testing.

This study highlights the complex relationship between noise conditions and sleep. While a noise-free environment remains ideal for maximizing sleep duration, the combination of fan noise with BBs shows promise for enhancing deep sleep. These findings suggest that carefully designed auditory environments could play a role in optimizing sleep quality and duration, particularly for individuals in noisy settings. The findings suggest that while light sleep is not significantly affected by auditory conditions, REM sleep shows a marked improvement under Fan Noise+BBs. This highlights the potential for targeted noise interventions to enhance specific aspects of sleep, particularly REM sleep, which is critical for cognitive and emotional well-being.

Further research is needed to explore the mechanisms underlying these effects and their broader applications in sleep health. The findings underscore a critical interplay between sensory processing patterns (AASP), sleep quality (PSQI), and chronotype. Poor Sleepers are more likely to experience heightened sensory sensitivity, which may amplify the impact of their evening chronotype on poor sleep quality. These results emphasize the need for a multidisciplinary approach that integrates sensory and sleep interventions to improve health and well-being.

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NUST-IRB Certificate

1. Research Project Title: **Effect of Broadband Noise on Sleep Quality**

2	Name of PI:	Dr. Nabeel Anwar
3	Duration:	18 months
4	Name of Institution / Department	SMME
5	IRB No.	2024-IRB-A-26/26

6. The project proposal entitled above has been reviewed by the NUST Institutional Review Board Meeting held on 6-May-2024.

7. The Board approves project proposal on scale and criteria given below to be implemented before/during project execution.

- Safety Measures
- Workspace Requirements
- Protection from potential hazards & Risks
- The certificate is exclusively valid to work at NUST.
- Confidentiality Requirements (If Any)

Note: The Ethical Review Committee reserves the rights to re-review the project during the project execution to address the suggested guidelines.

Dr. Sobia Manzoor, PhD
Professor (Tenured)
Dept. of Healthcare Biotechnology, ASAB
National University of Sciences and Technology (NUST), Islamabad

Signature of the Head / Deputy Head of Thematic Research

Signature & Seal of the Chairman NUST-IRB

Pro-Rector (RIC)
National University of Sciences and Technology
(Dr. Rizwan Riaz)

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Approved:	■
Not Approved: (Comments)	☐
Comments: (if Any)	