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Effect of Binaural Auditory Beats Beta Wave on Heart Rate Variability and Visual Attention on Shift Workers Sleep Disorders

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ABSTRACT

Introduction: Shift work often leads to sleep disorders, affecting workers health and cognitive functions, including attention and heart rate variability (HRV). This study investigates the effect of binaural auditory beats with beta waves on HRV and attention among shift workers with sleep disorders. **Objective**: To determine the impact of binaural beats on HRV parameters and attention in shift workers suffering from sleep disturbances. **Method**: The study employed a pre-test and post-test experimental design with 30 participants divided equally into control (white noise) and stimulation (binaural beats) groups. HRV was measured using Polar H10 heart rate sensors and analyzed using the Kubios HRV software. Attention was assessed using the Visual Attention Test Version 1.0.6. **Results**: The results indicated a significant increase in SNS index ($p<0.05$) and a decrease in mean RR ($p<0.05$) in the stimulation group compared to the control group. Additionally, the stimulation group showed a significant reduction in omissions error ($p<0.05$), indicating improved attention, while the control group showed no significant changes. **Conclusion**: Binaural beats with beta waves positively influence sympathetic nervous activity and enhance attention in shift workers with sleep disorders. **Recommendation**: Further research is needed to explore the duration of binaural beats' effects on HRV and attention across different populations.

Keywords: Binaural beats, heart rate variability, attention, shift work, sleep disorders.

INTRODUCTION

Shift work involves a schedule that allows workers to replace one another at the same position after a certain agreed period, usually lasting 8 or 12 hours, to maintain continuous production or service for 24 hours (Saraswati et al., 2018). This work system is prevalent in sectors such as healthcare, transportation, telecommunications, electricity, and more, where work stoppages can disrupt services or reduce quality (Widyanti, 2022). Globally, about 20-29% of workers are shift workers, with numbers expected to rise due to increasing demands in the workforce (IARC Monograph Working Group, 2019). The impacts of shift work on health, especially due to sleep disturbances, are gaining attention from researchers across multiple disciplines (Kecklund et al., 2016).

Shift Work Disorder (SWD) is a health condition caused by working non-traditional hours and has been linked to physical and mental health issues such as anxiety, depression, digestive disorders, and cardiovascular problems (Rehman et al., 2023; Torquati et al., 2018). The prevalence of SWD is estimated to be around 26.5% among shift workers, posing a significant challenge due to the negative effects on health, absenteeism, and reduced productivity (Pallesen et al., 2021; Vallières et al., 2021). Lifestyle factors like alcohol consumption, smoking, and unbalanced diets further exacerbate SWD among shift workers (Wickwire et al., 2017).

Shift Work Sleep Disorder (SWSD) is a circadian rhythm sleep disorder characterized by insomnia and excessive daytime sleepiness, often reducing total sleep time by 1 to 4 hours (Suliani et al., 2016). SWSD disrupts the neuroendocrine system and affects brain areas responsible for cognitive functions, such as the frontal cortex and hippocampus, leading to attention deficits (Azam et al., 2021). Such attention impairments can pose serious safety risks for shift workers and those around them (Shu et al., 2015). Studies have shown that interventions like mid-day napping can improve attention functions in shift workers before starting their shifts (Febrian, 2022).

Binaural auditory beats are sound stimuli created when two different frequencies are presented separately to each ear, resulting in a perceived third sound that influences brainwave activity (Oster, 1973). Binaural beats have shown potential in enhancing various cognitive functions, such as attention, anxiety reduction, pain management, and memory improvement (Basu et al., 2020; Garcia-Argibay et al., 2019). The most detectable frequencies occur around 440 Hz, and studies have found that binaural beats at beta wave frequencies (16-25 Hz) can enhance alertness and concentration (Crespo et al., 2013).

Beta waves are associated with alertness and cognitive performance, making them an ideal target for enhancing attention among individuals with SWSD (Santoso et al., 2020). Beta wave binaural beats increase neuronal oscillation frequencies, thereby modulating cognitive functions and autonomic nervous system responses (Garcia-Argibay et al., 2019; Sharma et al., 2017). As brainwave entrainment mechanisms increase sensory stimuli, more information is processed at the neuronal level, enhancing neural excitability, memory encoding, and reaction times (Hickey, 2021).

Heart Rate Variability (HRV) reflects the physiological phenomenon where the time intervals between consecutive heartbeats vary, indicating the organism's adaptability to internal and external influences (Forte et al., 2023). HRV is commonly used as a biomarker to assess autonomic nervous system regulation and has been linked to cardiovascular and cognitive health (Moon et al., 2018). Research suggests that increased sympathetic nervous system activity, as indicated by HRV parameters, may correlate with impaired attention and cognitive functions, particularly in shift workers with sleep disturbances (Tarvainen et al., 2014). This study seeks to explore the impact of binaural beta wave beats on HRV and attention in shift workers with sleep disorders, as such investigations remain limited.

MATERIALS AND METHODS

This study employed an experimental research design with a pre-test and post-test approach to evaluate the effects of binaural auditory beats on heart rate variability (HRV) and attention among shift workers experiencing sleep disorders. The research was conducted at the Brain Center of RSUP Wahidin Sudirohusodo Makassar from June to July 2024. The experimental design was chosen to observe the direct effects of binaural beats by comparing HRV and attention scores before and after the intervention. This design allows for a controlled environment to assess the immediate impact of the binaural beats on cognitive and physiological parameters.

Participants included 30 shift workers aged 20 to 40 years with a confirmed diagnosis of Shift Work Sleep Disorder (SWSD), who were recruited using purposive sampling. Inclusion criteria were male and female shift workers who had experienced SWSD for more than three months and were willing to participate by signing informed consent forms. Exclusion criteria included those with a history of seizures, hearing impairments, brain diseases such as stroke or brain tumors, and recent use of psychoactive substances within the last 16 hours before the study. Participants were randomly divided into two equal groups: a stimulation group receiving binaural beats at 18 Hz and a control group exposed to white noise.

Data collection involved measuring HRV using Polar H10 heart rate sensors connected to the Elite HRV app on smartphones, which provided real-time HRV readings. Data were further extracted using the Kubios HRV scientific software, a widely validated tool used globally for HRV analysis. HRV parameters assessed included Mean RR, SNS Index, and PNS Index, which reflect sympathetic and parasympathetic nervous system activities. These measurements were taken before and after the intervention to capture any changes attributable to binaural beats.

Attention was assessed using the Visual Attention Test Version 1.0.6, a validated tool for measuring sustained attention by evaluating omission errors (inattention) and commission errors (impulsivity) (Towey et al., 2019). Participants were tested in a quiet room to minimize distractions, ensuring the accuracy of the attention assessments. The attention test was administered both before and after the intervention for both the stimulation and control groups. The reduction in omission errors was used as a key indicator of improved sustained attention in the stimulation group (Febrian, 2022).

The statistical analysis was conducted using IBM SPSS Statistics 27. Data normality was assessed with the Shapiro-Wilk test. Paired T-tests were used for normally distributed data to compare pre- and post-test results within each group, while Wilcoxon tests were applied to non-normally distributed data. For between-group comparisons, Independent T-tests and Mann-Whitney tests were employed, with a significance level set at $p < 0.05$. This approach ensured robust statistical analysis to confirm the effects of binaural beats on HRV and attention.

Ethical approval was obtained from the Ethics Committee of the Faculty of Medicine, Universitas Hasanuddin, with ethical clearance number 281/UN4.6.4.5.31/PP36/2024. All participants were briefed on the research procedures, potential risks, and benefits, and were asked to provide informed consent before participation. Data collection was conducted according to ethical standards, maintaining participant confidentiality and adhering to research protocols approved by the hospital and university.

RESULTS AND DISCUSSIONS

The study involved 30 shift workers divided equally into two groups, a stimulation group exposed to binaural beats at 18 Hz and a control group exposed to white noise. The groups were similar in demographics, including age, gender, and occupation, ensuring comparable baseline characteristics (Table 1). HRV parameters and attention scores were assessed pre- and post-intervention. The results demonstrated significant changes in HRV parameters and attention scores in the stimulation group compared to the control group,

supporting the efficacy of binaural beats in improving these cognitive and physiological metrics.

In the stimulation group, the Mean RR significantly decreased post-intervention (758.33 ± 109.79 pre-test vs. 728.47 ± 103.78 post-test, $p = 0.011$), indicating an increase in sympathetic nervous system activity. Conversely, the control group showed a slight increase in Mean RR post-intervention (714.87 ± 58.86 pre-test vs. 734.07 ± 69.88 post-test, $p = 0.026$), suggesting reduced sympathetic activity (Table 2). The SNS Index also significantly increased in the stimulation group (0.61 ± 1.21 pre-test vs. 0.73 ± 1.18 post-test, $p < 0.001$), whereas changes in the control group were not significant.

Table 1. Sample Characteristics

Characteristics		Group	
		Control	Stimulation
Age (Years)			
Mean		27.40	27.60
Median & Range		27 (19-33)	28 (20-35)
Gender			
Man	n (%)	8 (53%)	8 (53%)
Woman	n (%)	7 (47%)	7 (47%)
Last education			
Senior High School	n (%)	8 (53%)	8 (53%)
Bachelor	n (%)	7 (47%)	7 (47%)
Field of work			
Security	n (%)	8 (53%)	8 (53%)
Health	n (%)	7 (47%)	7 (47%)
Length of service (Years)			
Mean		4.73	5.40
Median & Range		6 (1-8)	6 (1-10)
PSQI Score			
Mean		9.60	9.40
Median & Range		11 (6-13)	10 (6-12)

Source: Primary Data

The increase in SNS Index and the decrease in Mean RR in the stimulation group suggest that binaural beats effectively activate the sympathetic nervous system. This finding aligns with previous studies, which indicate that beta wave frequencies are linked to increased alertness and autonomic nervous activity (Santoso et al., 2020). The control group's increased Mean RR and insignificant SNS Index changes reflect that white noise does not significantly impact sympathetic activation, underscoring the specific influence of binaural beats on HRV (Crespo et al., 2013).

The PNS Index showed no significant changes in both groups, suggesting that binaural beats primarily influence sympathetic rather than parasympathetic activity. This finding aligns with the theory that beta waves are associated with heightened alertness rather than relaxation, which is typically modulated by parasympathetic activity (Forte et al., 2023). The lack of significant parasympathetic changes indicates that the effects of binaural beats are specific to certain autonomic functions, particularly those related to arousal and stress responses (Schwerdtfeger et al., 2019).

Table 2. Comparison of Pre and Post HRV Parameters

Parameter HRV	Time	n	Mean ± SD	P Value
Control				
Mean RR	Pre	15	714.87 ± 58.86	0.026*[a]
	Post	15	734.07 ± 69.88	
SNS	Pre	15	0.80 ± 0.60	0.076[a]
	Post	15	0.90 ± 0.97	
PNS	Pre	15	0.05 ±1.72	0.173[b]
	Post	15	0.21 ± 7.47	
Stimulation				
Mean RR	Pre	15	758.33 ± 109.79	0.011*[b]
	Post	15	728.47 ± 103.78	
SNS	Pre	15	0.61 ± 1.21	<0.001*[a]
	Post	15	0.73 ± 1.18	
PNS	Pre	15	0.286 ± 5.36	0.427[b]
	Post	15	0.292 ± 2.05	

[a]Paired T Test, [b]Wilcokson, *Significant at p<0.05
Source: Primary data

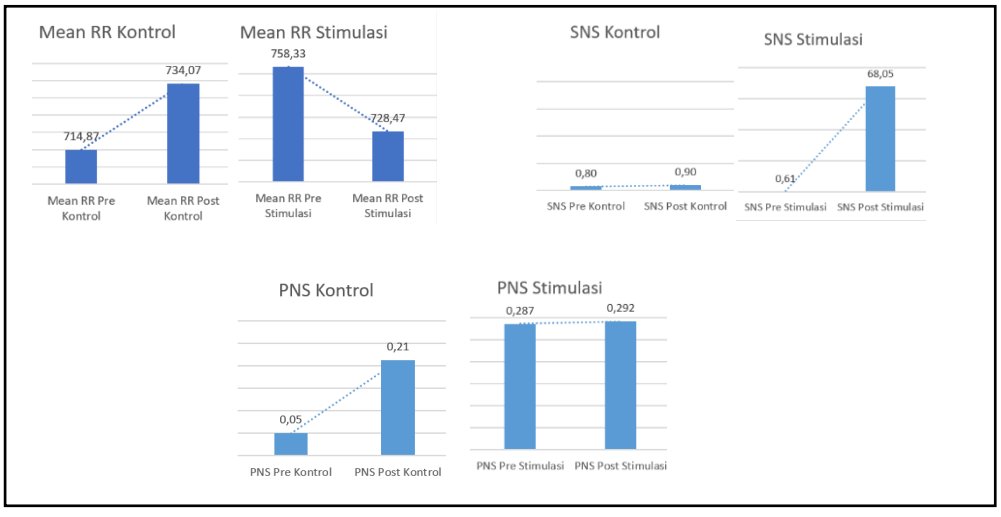

Figure 1. Graph of Average Change in HRV Parameters

Attention Scores: Significant improvements in attention were observed in the stimulation group, as evidenced by the reduction in omission errors (29.33 ± 21.89 pre-test vs. 1 ± 1.20

post-test, $p < 0.001$), while the control group showed no significant change (22.87 ± 17.38 pre-test vs. 2.00 ± 1.81 post-test, $p = 0.594$) (Table 3). This suggests that binaural beats enhance sustained attention, which is critical for cognitive performance in shift workers (Febrian, 2022). These findings align with previous research showing that beta wave stimulation can improve attention and cognitive processing speed (Santoso et al., 2020).

The increase in commission errors in the stimulation group (5.87 ± 7.48 pre-test vs. 9.27 ± 10.21 post-test, $p = 0.083$) may indicate increased impulsivity (Table 2), a common trade-off when enhancing attention (Towey et al., 2019). The control group's lack of significant changes in omission and commission errors suggests that white noise does not notably affect cognitive functions. This highlights the specificity of binaural beats in modulating attention, confirming their potential as a cognitive enhancement tool (Reedijk, 2013).

Table 3. Comparison of Pre and Post Attention Functions

Attention Function	Time	n	Mean ± SD	P Value
Control				
Omission error (OE)	Pre	15	22.87 ± 17.38	0.594[a]
	Post	15	20.07 ± 18.11	
Commission error (CE)	Pre	15	2.87 ± 2.29	0.177[a]
	Post	15	3.87 ± 3.85	
Stimulation				
Omission error (OE)	Pre	15	29.33 ± 21.89	<0.001[*a]
	Post	15	1 ± 1.20	
Commission error (CE)	Pre	15	5.87 ± 7.48	0.083[a]
	Post	15	9.27 ± 10.21	

[a]Wilcokson, *Significant at $p<0.05$
Source: Primary data

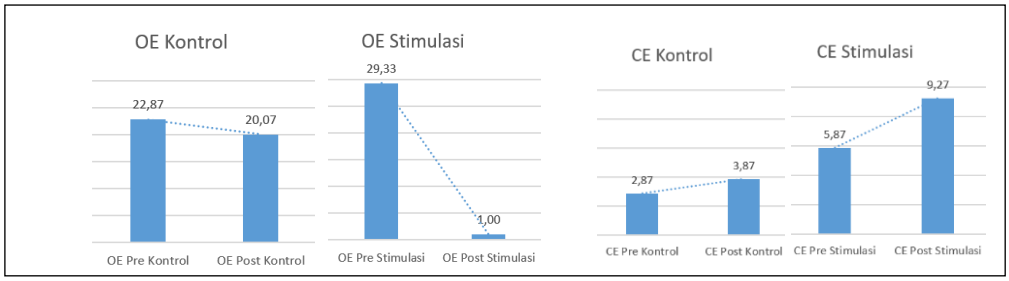

Figure 2. Graph of Average Change in OE and CE

Based on Table 4, each parameter was subjected to unpaired comparative analysis, pre-mean RR value test in the control group and stimulation group with a p value of 0.494, post-mean RR value test in the control group and stimulation group with a p value of 0.864, delta mean RR value test in the control group and stimulation group with a p value of 0.015. For the

average SNS index value, test the average value of the SNS index pre-test in the control group and stimulation group with a p value of 0.663, test the average value of the SNS index post-test in the control group and stimulation group with a p value of 0.671, test the average value of the Delta SNS index in the control group and stimulation group with a p value of 0.740. For the average value of PNS index, test the average value of PNS index pre-test in the control group and stimulation group with a p value of 0.756, test the average value of PNS index post-test in the control group and stimulation group with a p value of 0.319, test the average value of Delta PNS index in the control group and stimulation group with a p value of 0.125.

For the average value of OE, test the average value of OE pre-test in the control group and stimulation group with a p value of 0.468, test the average value of OE post-test in the control group and stimulation group with a p value <0.001, test the average value of Delta OE in the control group and stimulation group with a p value of 0.004. For the average CE value, the test of the average value of the pre-test CE value in the control group and the stimulation group with a p value of 0.283, the test of the average value of the post-test OE value in the control group and the stimulation group with a p value of 0.063, the test of the average value of the Delta CE value in the control group and the stimulation group with a p value of 0.259.

Table 4. Unpaired Sample Parameter Test

Parameter	Control Group		Stimulation Group		P Value
	n	Mean ± SD	n	Mean ± SD	
Mean RR					
Pre	15	714.87 ± 58.86	15	758.33 ± 109.79	0.494[b]
Post	15	734.07 ± 69.88	15	728.47 ± 103.78	0.864[a]
Delta	15	19.20 ± 60.28	15	-29.87 ± 44.93	0.015[*b]
SNS					
Pre	15	0.80 ± 0.60	15	0.61 ± 1.21	0.663[b]
Post	15	0.90 ± 0.97	15	0.73 ± 1.18	0.671[a]
Delta	15	0.09 ± 0.87	15	0.12 ± 0.77	0.740[b]
PNS					
Pre	15	0.05 ±1.72	15	0.286 ± 5.36	0.756[b]
Post	15	0.21 ± 7.47	15	0.292 ± 2.05	0.319[b]
Delta	15	0.16 ± 6.28	15	0.01 ± 5.22	0.125[b]
OE					
Pre	15	22.87 ± 17.38	15	29.33 ± 21.89	0.468[b]
Post	15	20.07 ± 18.11	15	1 ± 1.20	<0.01[*b]
Delta	15	-2.80 ± 22.03	15	-28.33 ± 21.30	0.004[*b]
CE					
Pre	15	2.87 ± 2.29	15	5.87 ± 7.48	0.283[b]

Post	15	3.87 ± 3.85	15	9.27 ± 10.21	0.063[b]
Delta	15	1.00 ± 2.85	15	3.40 ± 6.58	0.259[b]

[a]Independent T-Test, [b]Mann Whitney, *Significant at $p<0.05$
Source: Primary data

The reduction in omission errors, indicating improved attention, supports the use of binaural beats as an effective intervention for cognitive enhancement in shift workers. These improvements can be attributed to increased neural synchronization and heightened alertness facilitated by beta wave stimulation, which directly influences attention networks in the brain (Schuman et al., 2020). This neural synchronization is critical for shift workers, who often experience deficits in sustained attention due to disrupted circadian rhythms (Suliani et al., 2016).

Binaural beats work through a mechanism known as brainwave entrainment, which stimulates the auditory cortex and subsequently affects neural pathways involved in cognitive functions. This study confirms that binaural beats at beta frequencies can enhance neural oscillations associated with alertness and cognitive processing, particularly in the frontal cortex, where attention is regulated (Sharma et al., 2017). The results align with previous studies showing that beta wave entrainment improves attention and reaction times, supporting its application in occupational settings with high cognitive demands (Ingendoh et al., 2023).

These findings are particularly relevant in the context of shift work, where cognitive deficits, especially in attention, pose significant safety risks. Improved attention through binaural beats could enhance occupational performance and reduce the likelihood of errors, benefiting both individual health and workplace safety (Kecklund et al., 2016). The enhanced sympathetic activity, as evidenced by HRV changes, also suggests a potential role for binaural beats in managing the stress response in shift workers, contributing to overall well-being (Torquati et al., 2018).

However, the study also highlights some limitations. The short intervention period limits the generalizability of these findings to long-term effects. Future research should explore extended exposure to binaural beats to determine whether these cognitive and physiological benefits are sustainable over time (Basu & Banerjee, 2020). Additionally, exploring different binaural beat frequencies could provide insights into tailoring cognitive interventions for specific occupational needs, such as those requiring high alertness or relaxation (Garcia-Argibay et al., 2019).

Overall, the study contributes to the growing evidence supporting the efficacy of binaural beats in enhancing cognitive and physiological functions among shift workers. These findings

suggest that binaural beats, particularly at beta frequencies, are a promising non-invasive intervention to mitigate the cognitive deficits associated with shift work, thereby enhancing performance and safety in demanding work environments (Azam et al., 2021).

CONCLUSION

The study concludes that binaural auditory beats with beta wave frequencies significantly enhance sympathetic nervous system activity and improve sustained attention among shift workers experiencing sleep disorders. These findings highlight the potential of binaural beats as a non-invasive intervention to mitigate cognitive deficits associated with shift work, thereby enhancing workplace performance and safety. It is recommended that future studies explore the long-term effects of binaural beats, test various frequencies for targeted cognitive enhancement, and investigate their impact on different populations and work environments to optimize their application for broader occupational health benefits.

Conflict of Interest: The authors declare no conflicts of interest.

Author's Contribution: All authors contributed to data collection, analysis, presentation, and discussion.

Data Availability Statement: Not applicable

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