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The Effect of Interval Training Based on Heart Rate Variability (HRV) on Sleep Quality After Aerobic Exercise

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ABSTRACT

Background: Sleep quality is an essential component of post-exercise recovery, particularly following high-intensity physical activities such as aerobic exercise. Autonomic nervous system regulation, commonly assessed through Heart Rate Variability (HRV), has been associated with recovery efficiency and sleep regulation. However, empirical evidence on the application of HRV-based interval training as a recovery strategy to improve sleep quality after aerobic exercise remains limited, particularly among adult women participating in community-based exercise programs. Objectives: This study aimed to analyze the effect of HRV-based interval training on sleep quality following aerobic exercise among members of the Bunda Antang aerobic exercise group. Methods: This study employed a quantitative approach using a Pre-Experimental One Group Pretest-Posttest Design. The participants consisted of 25 women aged 35–45 years selected through purposive sampling from the Bunda Antang aerobic exercise community. The intervention was conducted over six weeks using HRV-based interval training, in which exercise intensity and recovery intervals were individually adjusted according to real-time HRV monitoring. Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI), while HRV parameters were measured using a chest-strap heart rate sensor connected to HRV analysis software. Data were analyzed using descriptive statistics, the Shapiro-Wilk normality test, and Paired Sample t-Test at a significance level of $\alpha = 0.05$. Results: The findings revealed significant improvements in sleep quality and HRV parameters following the intervention. PSQI global scores decreased from 11.84 ± 2.31 to 7.12 ± 2.04, representing a 39.86% improvement ($p = 0.000$). RMSSD values increased from 28.46 ± 6.72 ms to 41.93 ± 7.85 ms, representing a 47.33% improvement ($p = 0.000$). The largest improvement in PSQI components was observed in sleep latency, while RMSSD showed the most substantial increase among HRV parameters. Conclusions: HRV-based interval training significantly improves sleep quality and autonomic recovery following aerobic exercise. These findings indicate that HRV-based interval training is an effective recovery strategy for enhancing sleep quality among adult women engaged in community-based aerobic exercise programs.

Keywords: Heart Rate Variability; Interval Training; Sleep Quality; Aerobic Exercise; Autonomic Recovery.

INTRODUCTION

Sleep quality is a fundamental physiological component that contributes to the recovery, health, and overall well-being of individuals who engage in regular physical activity (Fullagar et al., 2015; Suwardi et al., 2026). For adults who participate in structured aerobic exercise programs, sleep does not merely serve as a passive resting state but functions as an active recovery process involving hormonal regulation, autonomic restoration, and tissue repair (Walker, 2017; Arga, 2025a). Adequate sleep following exercise allows the body to restore energy balance, regulate metabolic processes, and prepare the cardiovascular and musculoskeletal systems for subsequent physical demands (Driver & Taylor, 2000).

One of the key physiological mechanisms underlying the relationship between exercise and sleep is the regulation of the autonomic nervous system, which can be quantitatively assessed through Heart Rate Variability (HRV). HRV reflects the balance between sympathetic and parasympathetic nervous system activity, where higher HRV values generally indicate better autonomic flexibility and recovery capacity (Task Force of the European Society of Cardiology, 1996; Plews et al., 2013). Exercise-induced physiological stress activates the sympathetic nervous system, while adequate recovery, including sleep, is largely dependent on parasympathetic reactivation (Stanley et al., 2013).

Aerobic exercise, despite its well-documented benefits for cardiovascular health and metabolic function, can also impose considerable physiological stress on the autonomic nervous system, particularly when performed at moderate-to-vigorous intensities without individualized recovery management (Buchheit, 2014). For middle-aged women who often experience hormonal transitions, increased stress sensitivity, and a higher prevalence of sleep disturbances, inappropriate exercise intensity regulation may exacerbate sleep difficulties rather than improve them (Baker et al., 2007; Mallampalli & Carter, 2014). Consequently, exercise programming that incorporates physiological monitoring is increasingly considered essential for this population.

Interval training, which alternates between periods of high-intensity exertion and recovery, has been widely applied in fitness and rehabilitation settings due to its time efficiency and cardiovascular benefits (Gibala et al., 2012). However, conventional interval training protocols often apply standardized work-to-rest ratios without considering individual physiological readiness. HRV-based interval training addresses this limitation by using real-time HRV monitoring to individually adjust exercise intensity and recovery duration, ensuring that training load remains aligned with the participant's autonomic capacity (Kiviniemi et al., 2007; Vesterinen et al., 2016). This individualized approach is theorized to optimize the balance between training stimulus and recovery, thereby reducing excessive autonomic strain that may otherwise impair sleep quality.

A growing body of evidence supports the relationship between HRV, exercise training load, and sleep outcomes. Stanley et al. (2013) demonstrated that HRV-guided training adjustments improved recovery markers among athletes compared to fixed training programs. Similarly, Plews et al. (2013) emphasized that HRV monitoring provides valuable insight into an individual's readiness to train, which can be used to prevent overtraining and its associated negative effects on sleep and recovery. Nevertheless, most existing studies have focused on competitive athletes, leaving a significant gap in understanding how HRV-based training approaches affect sleep quality among non-athlete adult populations, particularly women participating in community-based aerobic exercise programs (Bellenger et al., 2016).

In the Indonesian context, community-based aerobic exercise groups have become increasingly popular among adult women as a means of maintaining physical fitness, social engagement, and overall health (Ridwan et al., 2025). The Bunda Antang aerobic exercise group, based in Makassar, represents one such community in which members regularly participate in aerobic sessions but commonly report difficulties with post-exercise sleep, including delayed sleep onset, frequent nighttime awakenings, and non-restorative sleep. Despite these reported concerns, structured interventions that integrate physiological monitoring to optimize exercise-induced recovery and sleep quality have not been examined within this population.

Several research gaps remain unresolved in the current literature. First, although HRV-based training has demonstrated efficacy in athletic populations, its application among middle-aged women engaged in recreational aerobic exercise remains largely unexplored (Vesterinen et al., 2016). Second, while numerous studies have examined the relationship between exercise and sleep using general intensity measures, few have specifically investigated whether individualized, HRV-guided interval training produces measurable improvements in both autonomic function and subjective sleep quality (Driver & Taylor, 2000; Hottenrott et al., 2012). Third, empirical studies examining this relationship within Indonesian community exercise settings are particularly scarce, limiting the contextual applicability of international findings to local populations.

Based on the background and research gaps identified above, this study was conducted to analyze the effect of HRV-based interval training on sleep quality following aerobic exercise among members of the Bunda Antang aerobic exercise group. The findings of this study are expected to provide empirical evidence supporting the integration of physiological monitoring into community-based exercise programming, with the aim of enhancing recovery quality, sleep health, and overall well-being among adult women engaged in regular aerobic exercise.

METHODS

This study employed a quantitative approach using a Pre-Experimental One Group Pretest-Posttest Design. This design was selected to determine the effect of HRV-based interval training on sleep quality and HRV parameters among participants before and after the intervention. In this design, all participants underwent a pretest to determine baseline sleep quality and autonomic function, followed by a six-week intervention using HRV-based interval training, and concluded with a posttest to identify the changes that occurred following the intervention.

The research population consisted of all active members of the Bunda Antang aerobic exercise group in Makassar, totaling 60 women. The research sample was determined using purposive sampling technique by considering several criteria, namely: women aged 35–45 years, actively participating in aerobic exercise sessions at least twice per week for the previous three months, not suffering from cardiovascular disease, sleep disorders requiring clinical treatment, or musculoskeletal conditions that could hinder participation in interval training, and willing to participate in the entire research process including HRV monitoring and sleep assessment. Based on these criteria, 25 women with an age range of 35–45 years were obtained as the research sample.

The intervention was carried out over six weeks with a frequency of three sessions per week, resulting in a total of 18 intervention sessions. The HRV-based interval training protocol was implemented immediately following each aerobic exercise session. Each participant wore a chest-strap heart rate sensor (Polar H10) connected to an HRV analysis application (Elite HRV) to monitor real-time HRV parameters, specifically the Root Mean Square of Successive Differences (RMSSD). Exercise intensity during the interval phase and the duration of recovery intervals were individually adjusted based on each participant's HRV readiness score measured prior to each session, following the individualized HRV-guided training protocol described by Kiviniemi et al. (2007). Participants with lower HRV readiness on a given day were assigned reduced training intensity and extended recovery intervals, whereas participants with higher HRV readiness were permitted to undertake higher-intensity intervals.

Data collection was carried out using two primary instruments. Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI), a validated questionnaire consisting of 19 items covering seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction (Buysse et al., 1989). A global PSQI score above 5 indicates poor sleep quality, while lower scores reflect better sleep quality. HRV parameters, specifically RMSSD, were measured using the chest-strap sensor and HRV analysis software described above, with measurements taken each morning upon waking under standardized resting conditions for five minutes, following procedures recommended by the Task Force of the European Society of Cardiology (1996).

The research data were analyzed using descriptive statistics and inferential statistics. Descriptive analysis was used to determine the mean, standard deviation, minimum value, maximum value, and percentage change of each research variable. Prior to hypothesis testing, the data were tested for normality using the Shapiro-Wilk test to ensure that the data distribution met the assumptions required for parametric analysis. Subsequently, hypothesis testing was conducted using the Paired Sample t-Test at a significance level of α = 0.05 to determine the difference in PSQI scores and RMSSD values between pretest and posttest. Effect size was calculated using Cohen's d to determine the magnitude of the effect of HRV-based interval training on the two research variables. The entire data analysis process was carried out using IBM SPSS Statistics software version 26.

RESULTS RESULTS

Characteristics of Samples

Table 1. Characteristics of the Research Sample (n=25)

Variable	Mean ± SD
Age (years)	39,6 ± 3,2
Height (cm)	156,8 ± 5,4
Weight (kg)	62,3 ± 8,1
BMI (kg/m²)	25,4 ± 2,9
Aerobic exercise experience (years)	2,7 ± 1,4

Based on Table 1, the characteristics of the study sample show that the average age of participants was 39.6 ± 3.2 years, which falls within the targeted 35–45 age range. The average height of participants was recorded at 156.8 ± 5.4 cm, while the average weight was 62.3 ± 8.1 kg, resulting in an average BMI of 25.4 ± 2.9 kg/m², indicating that participants were, on average, within the overweight category according to Asian BMI classification. The average duration of participation in the Bunda Antang aerobic exercise group was 2.7 ± 1.4 years, suggesting that most participants had moderate familiarity with regular aerobic exercise prior to the intervention.

Table 2. Normality Test Results (Shapiro-Wilk)

Variable	Sig.
PSQI Pretest	0,312
PSQI Posttest	0,287
RMSSD Pretest	0,358
RMSSD Posttest	0,406

Based on Table 2, the significance value (Sig.) for the PSQI Pretest variable was 0.312, while the PSQI Posttest was 0.287. The RMSSD Pretest variable showed a significance value of 0.358, and the RMSSD Posttest showed 0.406. All variables analyzed had significance values above 0.05, indicating that all data were normally distributed and therefore suitable for parametric statistical analysis.

Changes in Sleep Quality and HRV Parameters

Table 3. Paired Sample t-Test Results

Variable	Pretest	Posttest	Change (%)	Sig.
PSQI Global Score	11,84 ± 2,31	7,12 ± 2,04	-39,86	0,000
RMSSD (ms)	28,46 ± 6,72	41,93 ± 7,85	+47,33	0,000

Based on Table 3, the average PSQI global score decreased from 11.84 ± 2.31 during the pretest to 7.12 ± 2.04 during the posttest, representing a decrease of 39.86% with a significance value of 0.000. A lower PSQI score reflects improved sleep quality, indicating that participants experienced substantially better sleep following the intervention. Conversely, the average RMSSD value increased from 28.46 ± 6.72 ms in the pretest to 41.93 ± 7.85 ms in the posttest, representing an increase of 47.33% with a significance value of 0.000. An increase in RMSSD reflects enhanced parasympathetic activity and improved autonomic recovery capacity.

Overall, both research variables showed significant changes from pretest to posttest following the implementation of HRV-based interval training. The significance value obtained for each variable was 0.000, indicating that the observed changes were statistically significant at the $\alpha = 0.05$ level. Effect size analysis using Cohen's d produced values of 1.92 for PSQI and 1.78 for RMSSD, both of which are categorized as large effect sizes, further confirming the substantial impact of the intervention.

Sleep Quality Improvement Profile

Table 4. PSQI Component Scores

Component	Pretest	Posttest	Improvement (%)
Subjective sleep quality	1,92	1,08	43,8
Sleep latency	2,24	1,12	50,0
Sleep duration	1,76	1,16	34,1
Habitual sleep efficiency	1,68	1,04	38,1
Sleep disturbances	1,84	1,24	32,6
Use of sleep medication	0,88	0,52	40,9
Daytime dysfunction	1,52	0,96	36,8

Based on Table 4, all components of the PSQI showed a decrease in score from pretest to posttest, reflecting improvement across every dimension of sleep quality. The sleep latency component showed the greatest improvement, decreasing from 2.24 to 1.12, representing a 50.0% reduction. This was followed by the use of sleep medication component, which improved by 40.9%, and subjective sleep quality, which improved by 43.8%.

Sleep duration showed the smallest, though still meaningful, improvement at 34.1%, followed by sleep disturbances at 32.6%. The highest improvement was found in the sleep latency component at 50.0%, while the lowest improvement was found in the sleep disturbances component at 32.6%. All components demonstrated a positive change between the initial and final measurements, indicating a comprehensive improvement in sleep quality following the intervention.

HRV Improvement Profile

Table 5. HRV Parameter Indicators

Indicator	Pretest	Posttest	Increase (%)
RMSSD (ms)	28,46	41,93	47,3
SDNN (ms)	34,12	47,68	39,7
Resting heart rate (bpm)	76,4	70,2	-8,1

HRV readiness score	58,3	74,6	27,9

DISCUSSION

The results of this study show that HRV-based interval training significantly improves sleep quality among members of the Bunda Antang aerobic exercise group. The 39.86% decrease in PSQI global scores indicates that individualizing exercise intensity and recovery intervals according to real-time autonomic readiness substantially enhances post-exercise recovery and subjective sleep experience.

Theoretically, the improvement in sleep quality observed in this study can be explained through the autonomic nervous system's role in regulating both exercise recovery and sleep architecture. According to prior HRV research, increased parasympathetic activity, as reflected by elevated RMSSD values, facilitates the physiological transition from a sympathetically dominant, alert state to a parasympathetically dominant, restful state necessary for sleep onset and maintenance (Stanley et al., 2013; Plews et al., 2013). In the context of this study, the individualized adjustment of training intensity based on HRV readiness likely prevented excessive sympathetic activation that might otherwise persist into the evening hours and disrupt sleep onset.

The highest improvement was found in the sleep latency component (50.0%). This suggests that the autonomic recalibration achieved through HRV-based training enabled participants to transition into sleep more readily, likely due to reduced residual sympathetic arousal following exercise sessions. This finding is consistent with Hottenrott et al. (2012), who reported that HRV-guided training adjustments were associated with faster sleep onset compared to non-individualized training protocols among recreational exercisers.

The 47.33% increase in RMSSD values further substantiates the physiological basis for the observed sleep improvements. RMSSD is widely regarded as a reliable indicator of parasympathetic nervous system activity and overall autonomic flexibility (Task Force of the European Society of Cardiology, 1996). The substantial increase observed in this study aligns with findings from Vesterinen et al. (2016), who demonstrated that HRV-guided training over several weeks produced measurable improvements in autonomic recovery markers among non-elite exercisers. The concurrent decrease in resting heart rate (-8.1%) further supports the interpretation that participants experienced genuine improvements in cardiovascular autonomic regulation rather than mere subjective perception of recovery.

From a practical perspective, these findings have particular relevance for middle-aged women, a population often characterized by heightened stress sensitivity and increased vulnerability to sleep disturbances due to hormonal transitions associated with perimenopause (Baker et al., 2007; Mallampalli & Carter, 2014). The individualized nature of HRV-based interval training appears to accommodate the physiological variability inherent in this population more effectively than fixed-intensity exercise protocols, as training load was continuously matched to each participant's daily autonomic readiness rather than applied uniformly across all participants.

Improvements were also observed across all PSQI components, including sleep disturbances (32.6%) and daytime dysfunction (36.8%), suggesting that the benefits of HRV-based interval training extended beyond sleep onset to encompass broader dimensions of sleep quality and daytime functioning. This comprehensive pattern of improvement is consistent with Driver and Taylor (2000), who emphasized that exercise-induced improvements in sleep quality typically manifest across multiple sleep dimensions simultaneously, rather than being confined to a single component.

The findings of this study also reinforce the work of Bellenger et al. (2016), who found that HRV-guided training adjustments were associated with improved recovery outcomes compared to non-individualized training approaches in non-athlete populations. Thus, HRV-based interval training can be seen as an effective recovery-oriented strategy that simultaneously enhances autonomic function and sleep quality among adult women participating in community-based aerobic exercise programs.

Despite these encouraging findings, several limitations should be acknowledged. The absence of a control group in this pre-experimental design limits the ability to fully attribute the observed improvements solely to the HRV-based intervention, as factors such as natural adaptation to regular exercise routines or seasonal variations in sleep patterns cannot be entirely ruled out. Additionally, sleep quality was assessed using a subjective self-report instrument (PSQI), which, although validated, may be influenced by recall bias. Future studies incorporating objective sleep measures such as actigraphy, alongside randomized controlled designs, are recommended to strengthen the causal inference of these findings.

CONCLUSIONS AND SUGGESTIONS

Conclusion

Based on the results of the study, it can be concluded that HRV-based interval training has a significant influence on improving sleep quality and autonomic recovery among members of the Bunda Antang aerobic exercise group following aerobic exercise. PSQI global scores decreased by 39.86%, while RMSSD values increased by 47.33% after six weeks of intervention. These results show that HRV-based interval training is effectively used to enhance both subjective sleep quality and objective autonomic recovery markers among adult women engaged in community-based aerobic exercise programs.

Suggestions

1. Aerobic exercise instructors and community fitness program coordinators are advised to consider incorporating HRV monitoring as a recovery-management tool, particularly for middle-aged participants who are more susceptible to sleep disturbances.
2. Community exercise groups need to support the implementation of HRV-based training through the provision of accessible and affordable HRV monitoring devices.
3. Further research is recommended using randomized controlled designs with a comparison group receiving standardized, non-individualized interval training to obtain stronger empirical evidence regarding the specific contribution of HRV-based individualization.
4. Subsequent research can examine the influence of HRV-based interval training on other recovery-related outcomes such as perceived fatigue, mood states, and long-term cardiovascular health among community-based exercise populations.

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