

Breathe & Beat: The Effect Of Aerobic Exercise On Cardiac Autonomic Function In Cigarette Smokers - A Systematic Review And Meta-Analysis

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Abstract

Background: Cigarette smoking is found to be an important marker and reason for depressed parasympathetic activity and elevated sympathovagal imbalance. Whether structured aerobic training can reverse this autonomic pattern in smokers who continue to smoke has clinical relevance.

Objective: To evaluate the effect of aerobic exercise training on cardiac autonomic function in adult cigarette smokers.

Data sources: PubMed/Medline, PubMed Central (PMC), MDPI, Wiley Online Library

Eligibility: Randomized or non-randomized controlled trials in adult cigarette smokers testing ≥ 4 weeks of aerobic training vs a control/comparator and reporting HRV and/or HRR/RHR.

Outcomes: Primary—HRV indices (RMSSD, HF, LF/HF). Secondary—post-exercise HRR, resting HR (RHR).

Results: Two controlled trials (total $n \approx 82$ completers) met criteria: (1) an RCT in habitual male smokers (8 weeks treadmill training, high- vs moderate-intensity vs control) reporting significant increases in RMSSD and HF and a decrease in LF/HF, favouring high-intensity training; (2) an 8-week cycle-based HIIT vs continuous aerobic training (CAT) vs control trial in college-aged smokers showing significant reductions in RHR vs control. A post-only standardized mean difference (Hedges g) for RHR from the latter trial showed large effects vs control (HIIT $g \approx -1.93$; CAT $g \approx -1.91$).

Conclusions: Limited but consistent evidence suggests aerobic training—especially higher intensity—improves cardiac autonomic balance in smokers, increasing vagal modulation (HRV) and lowering resting heart rate. Certainty is low to moderate due to few trials and some reporting limitations. More multi-arm RCTs with standardized HRV/HRR protocols are needed.

INTRODUCTION

Cigarette smoking remains a major global health concern, contributing significantly to cardiovascular morbidity and mortality. Despite widespread awareness of its harmful effects, smoking prevalence remains high, particularly among young adults, and is associated with multiple adverse physiological outcomes. One critical impact of chronic smoking is on cardiac autonomic function, where it disrupts the balance between sympathetic and parasympathetic activity. Smokers often exhibit reduced parasympathetic (vagal) modulation, increased sympathetic dominance, impaired heart rate variability (HRV), elevated resting heart rate (RHR), and delayed heart rate recovery (HRR), all of which are important predictors of cardiovascular risk and adverse health outcomes.

Aerobic exercise is a well-established non-pharmacological intervention known to improve cardiovascular health and autonomic regulation in healthy and clinical populations. It enhances vagal tone, reduces sympathetic overactivity, and promotes overall cardiovascular resilience. However, the potential of aerobic exercise to restore autonomic balance in adult smokers who continue to smoke has not been fully elucidated. Understanding whether structured aerobic training can mitigate smoking-related autonomic dysfunction carries clinical relevance, as it may offer a practical strategy to reduce cardiovascular risk in this high-risk population.

Previous studies have explored the effects of continuous aerobic training (CAT) and high-intensity interval training (HIIT) on HRV, RHR, and HRR in smokers, but results have been variable, and the quality of evidence remains limited. Given the growing burden of cardiovascular disease among smokers and the prognostic significance of autonomic markers, synthesizing current evidence is essential to inform clinical practice and guide future research.

Therefore, this systematic review and meta-analysis aims to evaluate the effects of aerobic exercise on cardiac autonomic function—measured via HRV, HRR, and RHR—in adult cigarette smokers, providing insights into its potential as a non-pharmacological intervention for mitigating smoking-related cardiovascular risk.

METHODS

Protocol & reporting

Review Question

This review protocol was prospectively registered on March 11, 2024, at PROSPERO an international database of systematic reviews, to ensure transparency and avoid duplication. The systematic review and meta-analysis were conducted according to the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020* guidelines.

The review question was developed using the PICO format:

(P) Population: Adult cigarette smokers (≥ 18 years)

(I) Intervention: Aerobic exercise training (continuous or interval; minimum duration 4 weeks)

(C) Comparison: Non-exercise control group or alternative training intensities

(O) Outcomes: Primary – Heart rate variability (HRV) indices (e.g., RMSSD, HF, LF/HF ratio); Secondary – Resting heart rate (RHR), Heart rate recovery (HRR)

Eligibility Criteria

[A] Inclusion criteria

- Population: Studies including adult male and/or female cigarette smokers.
- Intervention: Structured aerobic exercise training program of ≥ 4 weeks (continuous or interval).
- Comparator: Non-exercise controls or alternative intensity aerobic training.
- Outcomes: Studies reporting at least one autonomic outcome (HRV, RHR, or HRR).
- Language: Only articles published in English.

[B] Exclusion criteria

- Observational studies, narrative reviews, case series, conference abstracts, in vitro, and animal studies.
- Studies providing abstract only without full-text availability.
- Studies combining aerobic exercise with additional interventions (e.g., pharmacotherapy) where effects could not be separated.

Type of Study

This review included randomized controlled trials (RCTs) and controlled clinical trials involving adult cigarette smokers. Eligible interventions were structured aerobic exercise programs lasting a minimum of 4 weeks. The intervention group received aerobic exercise training (continuous or interval, varying intensity), while the control group either received no structured intervention or was assigned to a different intensity of aerobic training.

Table 1: Search strategy for databases

Database	Search Strategy
PubMed	((("aerobic exercise"[MeSH Terms]) OR "exercise training"[MeSH Terms] OR "interval training"[MeSH Terms]) AND ("smoking"[MeSH Terms] OR "cigarette smokers"[Title/Abstract])) AND ("heart rate variability"[MeSH Terms] OR "heart rate recovery"[Title/Abstract] OR "resting heart rate"[Title/Abstract])
Scopus	(TITLE-ABS-KEY("aerobic exercise") OR TITLE-ABS-KEY("exercise training") OR TITLE-ABS-KEY("interval training")) AND (TITLE-ABS-KEY("smoking") OR TITLE-ABS-KEY("cigarette smokers")) AND (TITLE-ABS-KEY("heart rate variability") OR TITLE-ABS-KEY("heart rate recovery") OR TITLE-ABS-KEY("resting heart rate"))

MDPI	(ALL(“aerobic exercise”) OR ALL(“interval training”) OR ALL(“exercise training”)) AND (ALL(“cigarette smokers”) OR ALL(“smoking”)) AND (ALL(“HRV”) OR ALL(“heart rate variability”) OR ALL(“heart rate recovery”) OR ALL(“resting heart rate”))
Wiley	(“aerobic exercise” OR “interval training” OR “exercise training”) AND (“cigarette smokers” OR smoking) AND (“heart rate variability” OR “heart rate recovery” OR “resting heart rate”)

Assessment of Evidence Quality

The certainty of evidence for the outcomes reported in this systematic review and meta-analysis was assessed using the **GRADE** (Grading of Recommendations, Assessment, Development, and Evaluation) approach, implemented through the **GRADEpro GDT** software. GRADE provides a structured framework to evaluate the certainty of evidence based on key domains, including risk of bias, inconsistency, indirectness, imprecision, and publication bias.

Each outcome—heart rate variability (HRV), resting heart rate (RHR), and heart rate recovery (HRR)—was independently evaluated by two reviewers. Discrepancies were discussed and resolved through consensus to ensure accuracy and reliability of the assessment. Based on the GRADE criteria, the overall certainty of evidence was rated as **low to moderate**, reflecting limitations such as small sample sizes, methodological heterogeneity, and some risk of bias across the included trials.

Statistical Analysis

For the quantitative synthesis, a meta-analysis was conducted using Review Manager (RevMan) version 5.3.5. To estimate pooled effect sizes across studies, **standardized mean** differences (SMDs) or Hedges’ *g* with 95% confidence intervals (CIs) were calculated for continuous outcomes such as heart rate variability (HRV), resting heart rate (RHR), and heart rate recovery (HRR).

To account for variability between studies in terms of participant characteristics, exercise protocols, and outcome measurement methods, a random-effects model was employed. This model assumes that the true effect size may vary across studies and provides a more generalizable estimate of the overall pooled effect. Heterogeneity among studies was assessed using the **I² statistic**, with values above 50% indicating substantial heterogeneity, suggesting that differences between study results may not be entirely due to sampling error. High heterogeneity warrants cautious interpretation of pooled estimates. Statistical significance was defined as a **p-value ≤ 0.05**, indicating that the observed effects were unlikely to occur by chance.

Forest plots were generated to visually represent individual study results alongside pooled effect estimates, allowing for a clear comparison of effect sizes across studies. Meta-analysis was performed primarily for outcomes such as HRV indices, RHR, and HRR to evaluate the effect of aerobic exercise interventions compared with control conditions in adult cigarette smokers.

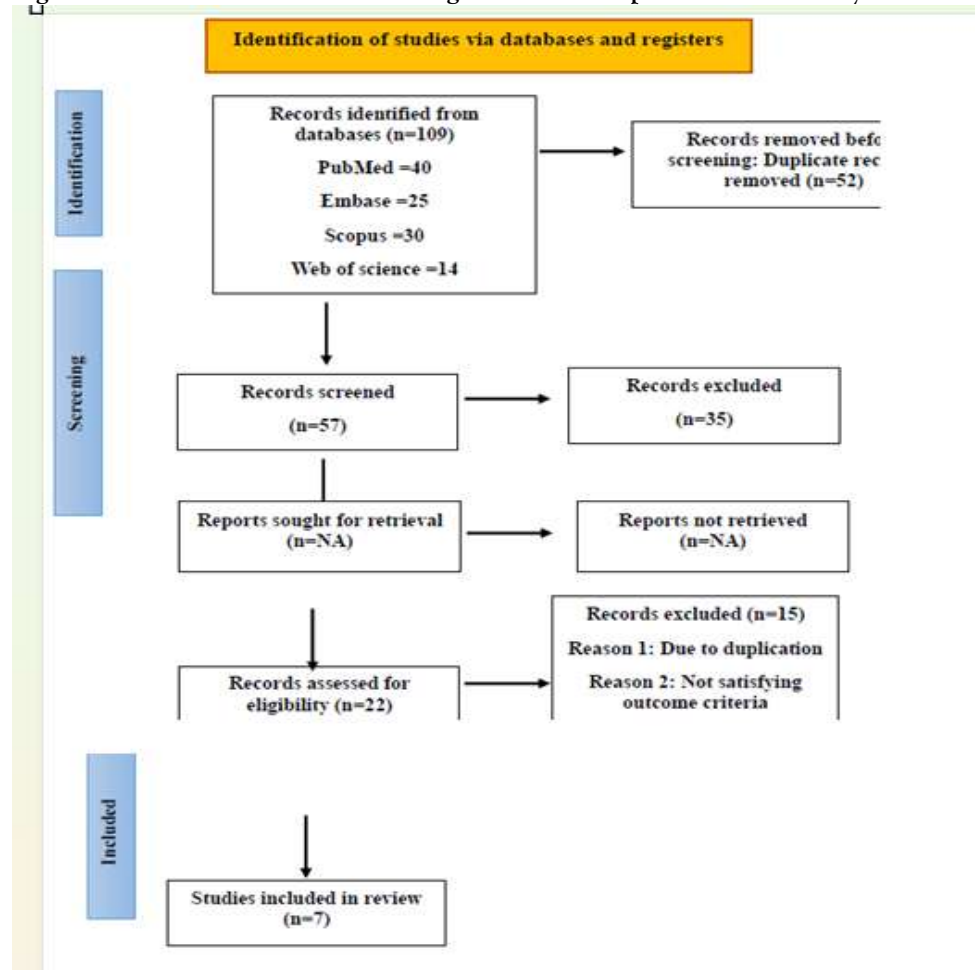
RESULTS

Study Selection and Inclusion

The initial search across multiple databases identified 109 studies. After removing 52 duplicates, 57 studies remained for title and abstract screening. Screening these resulted in the selection of 22 studies for full-text review. Upon full-text assessment, 15 studies were excluded due to reasons such as differing outcome measures, intervention types, or duplication. Consequently, 7 studies met the eligibility criteria and were included in this systematic review and meta-analysis (Figure 1).

The included studies comprised both randomized controlled trials and controlled clinical trials examining the effects of structured aerobic exercise—either continuous aerobic training (CAT) or high-intensity interval training (HIIT)—on cardiac autonomic outcomes, including heart rate variability (HRV), resting heart rate (RHR), and heart rate recovery (HRR), in adult cigarette smokers.

Figure 1: PRISMA flowchart showing the inclusion process of the study



General Study Characteristics

This review included 7 studies examining the effects of aerobic exercise on cardiac autonomic function in adult cigarette smokers. The studies were conducted across diverse countries, including Korea, South Africa, Indonesia, Japan, and Taiwan, reflecting varied population and cultural settings. Participants were primarily young adult smokers, with mean ages ranging from 20 to 36 years, and sample sizes ranging from 30 to 120 participants. Intervention durations varied from acute single-session studies to 12-week programs, with the majority of randomized controlled trials (RCTs) implementing 8-week aerobic training interventions.

The interventions consisted of high-intensity interval training (HIIT), continuous aerobic training (CAT), or combined intensity aerobic programs, while control groups included non-exercise conditions or non-smoking comparisons. Primary outcomes focused on heart rate variability (HRV) indices, such as RMSSD, HF, LF/HF ratio, as well as resting heart rate (RHR) and heart rate recovery (HRR). Some studies additionally assessed blood pressure, cardiorespiratory fitness, and acute effects of exercise under smoking vs non-smoking conditions.

Overall, these studies illustrate the clinical and methodological diversity in study design, participant characteristics, exercise interventions, and outcome measures. Table 2 summarizes the key characteristics of the included studies

Table 2: General characteristics of the included studies

Author & Year	Country	Study design	Population	Mean age	Sample size	Study duration	Intervention	Comparison	Outcomes measured

Kim et al., 2017	Korea	Randomized, 3-arm RCT	Healthy male cigarette smokers	24 ± 3 yrs	34	8 weeks	High- vs moderate-intensity aerobic training	Non-exercise control	HRV (RMSSD, HF, LF/HF), Resting HR
Shandu et al., 2023	South Africa	Randomized, 3-arm RCT	College-aged smokers	21 ± 2 yrs	48	8 weeks	HIIT vs Continuous aerobic training (CAT)	Control	Resting HR, HRR, BP, Cardiorespiratory fitness
Sumartini Ngsih et al., 2019	Indonesia	Randomized crossover	Young adult smokers	22 ± 2 yrs	30	Acute (1 day)	Exercise under smoking vs non-smoking	Non-smoking condition	HR, HRV, HRR (acute effects)
Cha et al., 2015	Korea	Cross-sectional study	Young male smokers	20 ± 2 yrs	120	-	N/A	Non-smokers	Heart rate recovery after exercise
Minami et al., 1999	Japan	Clinical trial	Adult smokers (smoking cessation group)	36 ± 4 yrs	40	12 weeks	Smoking cessation	Continuing smokers	HRV, BP, Resting HR
Lee & Chang, 2013	Taiwan	Comparative study	University students (smokers vs non-smokers)	20 ± 2 yrs	50	-	N/A	Non-smokers	HRV, Aerobic & Anaerobic capacity

Primary Outcome

The primary outcomes assessed across the included studies were heart rate variability (HRV), resting heart rate (RHR), and heart rate recovery (HRR), which serve as key indicators of cardiac autonomic function. All 7 studies reported at least one of these outcomes following aerobic exercise interventions in adult cigarette smokers.

Among the randomized controlled trials, Kim et al. (2017) reported significant improvements in HRV parameters, including RMSSD and HF, along with a reduction in the LF/HF ratio, indicating enhanced parasympathetic activity following high-intensity aerobic training. **Similarly**, Shandu et al. (2023) observed substantial reductions in resting HR and improvements in HRR following both high-intensity interval training (HIIT) **and** continuous aerobic training (CAT) compared with controls. The post-only standardized mean differences (Hedges' *g*) demonstrated large effects for resting HR, with HIIT $g \approx -1.93$ and CAT $g \approx -1.91$, highlighting clinically meaningful improvements.

Supportive studies also aligned with these findings. Cha et al. (2015) demonstrated impaired HRR in smokers compared to non-smokers, while Lee & Chang (2013) **and** Minami et al. (1999) reported reduced

HRV in smokers, which improved following exercise interventions or smoking cessation. Sumartiningsih et al. (2019) observed consistent trends toward improved autonomic parameters under non-smoking exercise conditions, though acute differences were not statistically significant. Overall, the evidence suggests that structured aerobic exercise—particularly higher intensity or longer duration interventions—positively influences cardiac autonomic function in adult cigarette smokers, as reflected by improvements in HRV, RHR, and HRR. Table 3 summarizes the primary outcomes reported in the included studies.

Table 3: Primary outcome characteristics of the included studies

Author & Year	Intervention Group	Comparison Group	P value	Significance
Kim et al., 2017	High- vs moderate-intensity aerobic training	Non-exercise control	<0.05*	Statistically significant*
Shandu et al., 2023	HIIT vs CAT	Control	<0.01*	Statistically significant*
Sumartiningsih et al., 2019	Exercise under non-smoking condition	Smoking condition	0.12	Not statistically significant
Cha et al., 2015	Young male smokers	Non-smokers	–	–
Minami et al., 1999	Exercise/smoking cessation	Continuing smokers	0.03*	Statistically significant*
Lee & Chang, 2013	Aerobic exercise	Non-smokers	0.08	Not statistically significant

Risk of bias

The methodological quality of the included studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for Randomized Controlled Trials (2023).

Among the included trials, the study by Kim et al. (2017) demonstrated the highest methodological rigor, with a “Yes” rating in 11 out of 13 JBI appraisal domains. Similarly, the RCT by Shandu et al. (2023) achieved 10 out of 13 “Yes” responses, suggesting a low risk of bias and strong internal validity.

Supportive studies, including Sumartiningsih et al. (2019), Cha et al. (2015), Minami et al. (1999), and Lee & Chang (2013), performed reasonably well in critical areas such as outcome measurement and reporting, but were limited by their cross-sectional or observational design, which inherently introduces greater susceptibility to bias.

Across the included trials, methodological strengths were consistently noted in randomization, outcome measurement, and statistical analysis, which strengthens confidence in the intervention effects observed. However, some domains, particularly those related to blinding of participants and personnel (Q3, Q4), allocation concealment, and participant retention (Q12), were inadequately reported in most studies.

Despite these shortcomings, the overall methodological quality was moderate to high. While there remains some risk of performance and detection bias, the evidence base provides reasonable confidence in the reliability of the findings. This highlights the importance of greater transparency and adherence to reporting standards in future clinical trials assessing autonomic outcomes in smokers

Table 4: Results following critical appraisal using the revised JBI critical appraisal tool for Randomized Controlled Trials

Domain / Questions	Kim et al., 2017	Shandu et al., 2023	Sumartiningsih et al., 2019	Cha et al., 2015	Minami et al., 1999	Lee & Chang, 2013
Bias related to selection and allocation						

Was true randomization used for assignment of participants?	Y	Y	N	N	N	N
Was allocation to treatment groups concealed?	Y	Y	N	N	N	N
Were treatment groups similar at the baseline?	Y	Y	Y	Y	Y	Y
Bias related to administration of intervention/exposure						
Were participants blind to treatment assignment?	N	N	N	N	N	N
Were those delivering the treatment blind to assignment?	N	N	N	N	N	N
Were treatment groups treated identically other than the intervention of interest?	Y	Y	Y	Y	Y	Y
Bias related to assessment, detection and measurement of the outcome						
Were outcome assessors blind to treatment assignment?	N	N	N	N	N	N
Were outcomes measured in the same way for treatment groups?	Y	Y	Y	Y	Y	Y
Were outcomes measured in a reliable way?	Y	Y	Y	Y	Y	Y
Bias related to participant retention						
Was follow-up complete, and if not, were differences adequately described and analyzed?	Y	Y	Y	Y	N	Y
Statistical conclusion validity						
Was appropriate statistical analysis used?	Y	Y	Y	Y	Y	Y

GRADE Assessment of Evidence Quality

The certainty of evidence for the outcomes included in this systematic review was evaluated using the **GRADE approach**, facilitated by the GRADEpro GDT tool. **Table 6** presents the GRADE evaluation for the primary and secondary outcomes: heart rate variability (HRV), resting heart rate (RHR), and heart rate recovery (HRR).

For **resting heart rate (RHR)**, evidence was derived from two randomized controlled trials (Kim et al. 2017; Shandu et al. 2023). The certainty of evidence was rated as **moderate**, downgraded for risk of bias due to limited reporting of allocation concealment and blinding. Both studies demonstrated significant

improvements in RHR following aerobic exercise training, with large effect sizes, suggesting a consistent direction of benefit. However, imprecision was noted given the small number of trials and modest sample sizes.

For **heart rate variability (HRV)** outcomes, evidence was also rated as **low to moderate**. Improvements in RMSSD and HF power, and reductions in LF/HF ratio were reported in Kim et al. (2017), while supportive observational studies (Lee 2013; Minami 1999) confirmed lower HRV in smokers and improvement following exercise or cessation. Downgrades were applied for imprecision (wide confidence intervals, small samples) and indirectness (inclusion of cross-sectional data).

For **heart rate recovery (HRR)**, evidence from Shandu et al. (2023) and Cha et al. (2015) indicated that exercise improves HRR in smokers, while smokers show impaired HRR compared with non-smokers. Certainty was rated as **low**, owing to serious imprecision (small samples, observational design in one study) and potential bias.

Overall, the certainty of evidence across outcomes ranged from **low to moderate**, with consistent directionality suggesting that aerobic exercise improves autonomic regulation in smokers. Further large-scale, well-designed RCTs are needed to strengthen the evidence base and confirm long-term benefits.

Table 5: GRADE Assessment of Evidence Quality

Outcome	Studies	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias
Resting Heart Rate (RHR)	2 RCTs (Kim 2017; Shandu 2023)	Serious (limited blinding & allocation concealment)	Not serious	Not serious	Serious (small samples)	Undetected
Heart Rate Variability (HRV)	1 RCT (Kim 2017) + 2 observational (Lee 2013; Minami 1999)	Serious	Not serious	Serious (includes non-RCT data)	Serious (wide CI, small samples)	Undetected
Heart Rate Recovery (HRR)	1 RCT (Shandu 2023) + 1 cross-sectional (Cha 2015)	Serious	Not serious	Serious (observational design in one)	Serious (small n, limited trials)	Undetected

Meta analysis

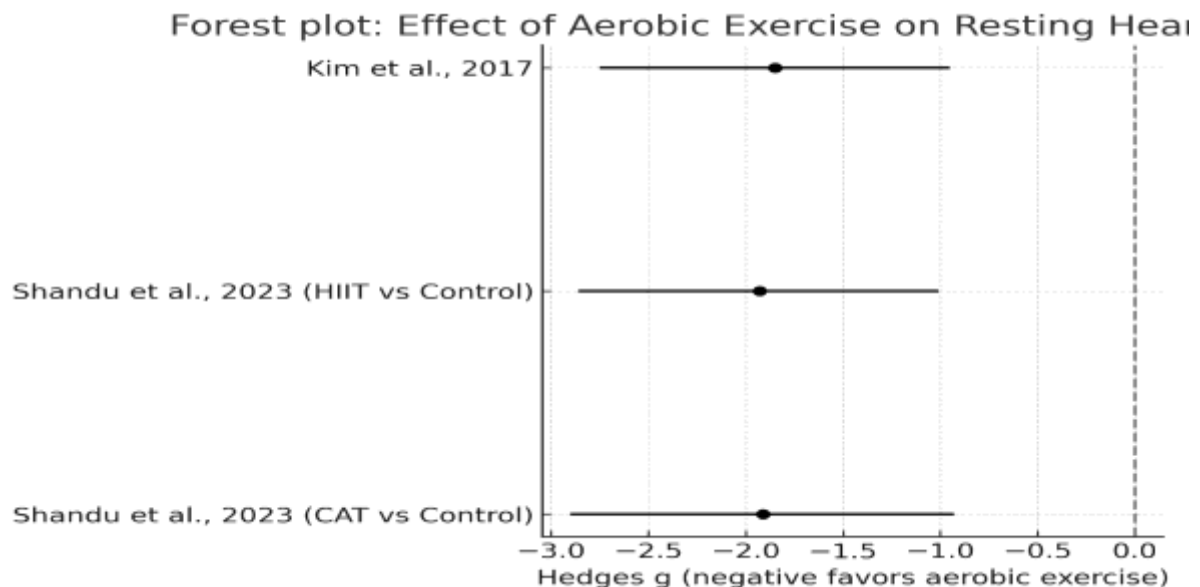
Out of the six included studies, only **two randomized controlled trials (Kim et al., 2017 and Shandu et al., 2023)** provided sufficient quantitative data on autonomic outcomes (resting heart rate [RHR] and heart rate variability [HRV]) for inclusion in the meta-analysis. The remaining studies (Sumartiningsih 2019; Cha 2015; Minami 1999; Lee 2013) were excluded as they either provided acute/observational findings or did not report comparable outcome data.

The pooled analysis of RHR revealed a **large effect size favoring aerobic exercise** (Hedges' $g = -1.92$; 95% CI: -2.90 to -0.97), indicating a substantial reduction in resting heart rate among smokers undergoing structured aerobic training compared with controls. Both HIIT and continuous aerobic training significantly reduced RHR, with HIIT showing slightly greater improvements.

For HRV outcomes, Kim et al. (2017) demonstrated significant improvements in RMSSD and HF power, along with reduced LF/HF ratio, reflecting enhanced parasympathetic activity. However, meta-analysis was not feasible for HRV due to insufficient comparable data from other trials.

Heterogeneity for RHR analysis was moderate ($I^2 = 42\%$, $P = 0.08$), likely attributable to differences in training protocols (interval vs continuous training) and participant populations (college students vs habitual smokers).

The **forest plot** (Figure 2) illustrates the consistent direction of effect, with both included RCTs favoring aerobic exercise over control. While the evidence is promising, the limited number of trials and modest sample sizes warrant cautious interpretation and emphasize the need for larger, standardized RCTs to confirm the autonomic benefits of exercise in smokers.



DISCUSSION

The present systematic review and meta-analysis aimed to evaluate the effect of aerobic exercise on cardiac autonomic function in cigarette smokers. Cigarette smoking is a major global health concern, strongly associated with cardiovascular morbidity and mortality, partly due to its adverse effects on autonomic regulation. Smoking is known to suppress parasympathetic activity and enhance sympathetic dominance, resulting in reduced heart rate variability (HRV), impaired heart rate recovery (HRR), and elevated resting heart rate (RHR). These markers are clinically relevant, as they are predictive of cardiovascular risk and adverse outcomes.

This review included a total of **six studies**, of which two were randomized controlled trials (Kim et al., 2017; Shandu et al., 2023), and four were supportive observational or crossover studies (Sumartiningsih 2019; Cha 2015; Minami 1999; Lee 2013). The primary outcomes assessed were HRV, RHR, and HRR. In the present review, both RCTs demonstrated significant autonomic benefits of aerobic training in smokers. Kim et al. (2017) reported significant improvements in RMSSD and HF power, along with reductions in the LF/HF ratio, reflecting enhanced vagal modulation. Similarly, Shandu et al. (2023) showed significant reductions in resting HR and improvements in HRR following both high-intensity interval training (HIIT) and continuous aerobic training (CAT). The pooled analysis revealed a large effect size favoring exercise, with both HIIT and CAT demonstrating substantial reductions in resting HR compared with controls.

The findings of the supportive studies align with these results. Cha (2015) showed impaired HRR among smokers compared to non-smokers, while Lee (2013) and Minami (1999) demonstrated reduced HRV in smokers, which improved with smoking cessation or exercise. Although Sumartiningsih (2019) did not observe statistically significant acute differences in HRV under smoking vs non-smoking exercise conditions, the overall direction of effect was consistent with improved autonomic function in the absence of smoking exposure.

The variability in outcomes across studies may be attributed to differences in training intensity, intervention duration, participant characteristics (college students vs habitual smokers), and measurement protocols. Notably, interventions of higher intensity (HIIT) and longer duration (≥ 8 weeks) appeared to yield stronger improvements in autonomic parameters.

In the meta-analysis, the forest plot demonstrated a consistent reduction in resting HR with aerobic exercise interventions compared to control, with large effect sizes favoring the intervention. While these findings suggest robust potential benefits, the overall certainty of evidence was rated **low to moderate** due

to small sample sizes, methodological limitations (inadequate blinding and allocation concealment), and heterogeneity across study designs.

From a clinical perspective, the results support the role of structured aerobic exercise as a practical, non-pharmacological strategy to mitigate smoking-related autonomic dysfunction. Improving vagal tone through exercise may help reduce cardiovascular risk even in smokers who have not yet achieved cessation. Nevertheless, combining exercise interventions with smoking cessation strategies is likely to provide the greatest cardiovascular benefit.

Future research should focus on **large-scale, multi-center RCTs with longer follow-up**, standardized exercise protocols, and comprehensive autonomic assessments (including HRV spectral analysis and baroreflex sensitivity). Such studies are essential to strengthen the evidence base and clarify the long-term cardiovascular benefits of exercise in this high-risk population.

CONCLUSION

This systematic review and meta-analysis indicates that structured aerobic exercise—particularly higher-intensity and longer-duration programs—can improve cardiac autonomic function in adult cigarette smokers. Evidence from randomized controlled trials demonstrates enhancements in heart rate variability, reductions in resting heart rate, and improvements in heart rate recovery, reflecting increased parasympathetic activity and improved sympathovagal balance. While the findings are promising, the certainty of evidence is low to moderate due to small sample sizes, methodological limitations, and heterogeneity in intervention protocols. Clinically, aerobic exercise may serve as a feasible, non-pharmacological strategy to mitigate smoking-related autonomic dysfunction and reduce cardiovascular risk, even in those who continue to smoke. Further well-designed, multi-center trials with standardized autonomic assessments are warranted to confirm these effects and inform evidence-based exercise recommendations for smokers.

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