The acute effects of Zone 2 aerobic exercise on Vagus nerve activity and postprandial sleepiness in women

Los efectos agudos del ejercicio aeróbico en la Zona 2 sobre la actividad del nervio vago y la somnolencia postprandial en mujeres

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Abstract

Background: postprandial sleepiness is a common problem in women, characterized by reduced alertness after meals due to autonomic and metabolic shifts toward digestion. Zone 2 aerobic exercise, a moderate-intensity activity focused on fat oxidation, may enhance vagal activity and counteract this postprandial sleepiness.
Objective: This study examined the acute effects of Zone 2 exercise on vagal activity and postprandial sleepiness in women.
Methods: Twenty women aged 30–45 years were randomly assigned to an experimental group (n=10) or a control group (n=10). After consuming a standardized meal, the experimental group performed 40 minutes of treadmill walking at Zone 2 exercise intensity (60–70% of maximum heart rate), while the control group rested passively. Vagal activity was assessed using heart rate variability (rMSSD values), and sleepiness was measured with the Stanford Sleepiness Scale. Paired and independent t-tests were used for analysis, with effect sizes calculated.
Results: The experimental group showed significant improvements, with increased rMSSD values and reduced sleepiness, whereas the control group demonstrated decreased vagal activity and increased sleepiness. Between-group post-test differences were statistically significant with large effect sizes.
Conclusion: Zone 2 exercise effectively enhances vagal tone and reduces postprandial sleepiness. It represents a practical, non-pharmacological strategy to improve alertness and autonomic balance in women.

Keywords

Zone 2 exercise; Heart rate variability; Vagus nerve; postprandial sleepiness; women.

Resumen

Antecedentes: La somnolencia posprandial es un problema común en las mujeres, caracterizado por una disminución de la alerta después de las comidas debido a cambios autonómicos y metabólicos orientados a la digestión. El ejercicio aeróbico en la Zona 2, una actividad de intensidad moderada centrada en la oxidación de grasas, puede mejorar la actividad del nervio vago y contrarrestar esta somnolencia.
Objetivo: Este estudio examinó los efectos agudos del ejercicio aeróbico en la Zona 2 sobre la actividad del nervio vago y la somnolencia postprandial en mujeres.
Métodos: Veinte mujeres de entre 30 y 45 años fueron asignadas aleatoriamente a un grupo experimental (n=10) o a un grupo de control (n=10). Después de consumir una comida estandarizada, el grupo experimental caminó en la cinta durante 40 minutos a una intensidad de Zona 2 (60–70% de la frecuencia cardíaca máxima), mientras que el grupo de control descansó pasivamente. La actividad del nervio vago se evaluó utilizando la variabilidad de la frecuencia cardíaca (rMSSD), y la somnolencia se midió con la Escala de Somnolencia de Stanford. Se utilizaron pruebas t pareadas e independientes para el análisis, con tamaños del efecto calculados.
Resultados: El grupo experimental mostró mejoras significativas, con un aumento en el rMSSD y una reducción en la somnolencia, mientras que el grupo de control demostró una disminución en la actividad vagal y un aumento en la somnolencia. Las diferencias post-prueba entre los grupos fueron estadísticamente significativas con grandes tamaños de efecto.
Conclusión: El ejercicio aeróbico en la Zona 2 mejora eficazmente el tono vagal y reduce la somnolencia postprandial. Representa una estrategia práctica y no farmacológica para mejorar la alerta y el equilibrio autónomo en las mujeres.

Palabras clave

Ejercicio en zona 2; variabilidad de la frecuencia cardíaca; nervio vago; somnolencia posprandial; mujeres.

Introduction

The autonomic nervous system (ANS) is of essential importance in the regulation of involuntary physiological functions and in maintaining physiological homeostasis by a dynamic balancing between the sympathetic and parasympathetic branches. The vagal, the predominant parasympathetic route, plays its central role in controlling heart rate, digestion and inflammation processes (Shaffer & Ginsberg, 2017; Easa et al., 2022). Heart Rate Variability (HRV), particularly the root mean square of successive differences (rMSSD values) is a common non-invasive measure for vagal activity and rMSSD values are regarded as a sensitive marker of vagal tone. Higher rMSSD values are related to higher cardiovascular health and emotion regulation, as well as better cognitive vigilance (Thayer et al., 2012).

Increased postprandial sleepiness and decreased alertness after meal consumption (ie, postprandial sleepiness) is a common physiological event that has important functional consequences, even more so in women because of hormonal and metabolic changes (Kaneda et al., 2025; Kanai & Teratani, 2022). It is likely affected by many mechanisms including insulin-related glucose variability, augmented central tryptophan uptake and serotonin synthesis, hemodynamic blood flow shift towards the splanchnic circulation with a possible diminution in cerebral perfusion (Reynolds et al., 2020; Abdulghani et al., 2025). It has been shown that light-to-moderate intensity physical activities such as walking induce significant attenuating effects of postprandial metabolic responses and increase alertness; however, the exact role of exercise intensity on autonomic and perceptual responses is not extensively well characterized (Colberg et al., 2009; Abdulkareem & Sattar Jabbar, 2025; Hassan & Abdulkareem, 2025).

Zone 2 exercise, which is typically carried out at intensity levels of approximately 60–70% HR max, exhibits high fat metabolism and a modest level of lactate accumulation; thus, it can be an effective means to improve mitochondrial function and autonomic balance without excessive sympathetic nervous system activity. When compared with heavy workloads, which may temporarily suppress vagal outflow, moderate physical activity can promote parasympathetic re-activation and enhance HRV responses in general but especially among women (Wang et al., 2025; Soares-Miranda et al., 2014). Moderate-intensity exercise could above all increase baroreceptor sensitivity and cerebral oxygenation after the meals, reducing postprandial reductions in alertness (Hottenrott et al., 2012; Barreto et al., 2023).

However, there is limited literature on the acute effects of exercise intensity during the postprandial phase on autonomic modulation and sleepiness perception, and most studies have been conducted in men. Apart from focusing merely on metabolic, general HRV exercise-derived data or postprandial glycemic response, further investigations that integrate autonomic, and perceptual responses in a controlled and ecologically valid setting are warranted. Moreover, sex-differences in physiological and autonomic disturbances following food intake have been described. Given that there is a scarcity of previous literature on sex-related disturbances for postprandial exercise, our investigation presents promising relevance for novel approaches oriented towards enhancing the food-induced autonomic modulation and vigilance.

Thus, the primary aim of this study was to investigate the acute effect of 40 minutes of Zone 2 aerobic walking performed postprandial (i.e., after a standardized meal) on vagal activity (as measured through rMSSD) and subjective postprandial sleepiness in women compared with a passive rest control trial. It was theorized that postprandial exercise in Zone 2 would induce large increases in vagal tone and decreases in subjective sleepiness, which could represent a practical and feasible approach to benefitting from improved autonomic equilibrium and alertness throughout the day.

Method

Study Design

This study is a controlled pre- and post-test experimental design using two parallel groups (experimental group and control group). The independent variable was postprandial activity (Zone 2 aerobic walking versus passive rest), the dependent variables were autonomic nervous system (ANS) vagal control (as assessed by heart rate variability, rMSSD and subjective sleepiness following feeding as measured through the Stanford Sleepiness Scale.

Participants

Twenty 30–45-year-old females (mean age = 37.8 ± 4.2 years) volunteered from a community sports club and were selected by purposive selection. Inclusion criteria consisted of an average moderate level of physical activity and no preparation for professional athletes. Exclusion criteria included cigarette smoking, known chronic diseases including diabetes mellitus or hypertension or cardiovascular disease, and taking medications affecting autonomic regulation and sleep.

Subjects were randomly assigned to the experimental group (n = 10) or control group (n = 10) through a simple randomization technique (by draw lots). Written informed consent was obtained from all the subjects before entering the study. The design of the study followed Declaration of Helsinki guidelines and was approved by the institutional Ethics Committee at Middle Technical University.

Instruments

Vagal nerve was non-invasively examined by the variable (HRV). The heart rate (HR) signal was sampled at 1000 Hz using a Polar H10 chest strap monitor (Polar Electro, Kempele, Finland), validated under field conditions with ECG measurements. The data underwent analysis by the Elite HRV smartphone application (Elite HRV Inc., USA). The root mean square of the successive differences (rMSSD values) was chosen as main HRV, given its sensitivity in detecting parasympathetic (vagus) effect within short-term observations (Shaffer & Ginsberg, 2017).).

Postprandial sleepiness was evaluated using the Stanford Sleepiness Scale (SSS), a validated 7-point self-report instrument ranging from 1 (fully alert) to 7 (unable to stay awake) (Hoddes et al., 1973), as shown in table 1.

Table 1. Stanford Sleepiness Scale (SSS)

Score	Description
1	Feeling active, vital, alert, or wide awake
2	Functioning at high levels, but not at peak; able to concentrate
3	Awake, but relaxed; responsive but not fully alert
4	Somewhat foggy, let down
5	Foggy; losing interest in remaining awake; slowed down
6	Sleepy, woozy, fighting sleep; prefer to lie down
7	No longer fighting sleep; sleep onset soon; having dream-like thoughts

Intensity for Zone 2 exercise was prescribed as a range of 60–70% of agepredicted maximal heart rate (HRmax = 220 – age), and monitored continuously with the Polar H10 device during the walking protocol.

Procedures

All sessions for the experiment were performed in a controlled laboratory setting at approximately 2:45 PM to control circadian and postprandial timing. Participants ingested a standardized meal (~600 kcal) rich in macronutrients (55% carbohydrates, 30% fat and 15% protein; rice, chicken, vegetables, fruit).

Following ingestion of the meal, subjects in the experimental group walked for 40 min on a treadmill at an intensity equivalent to Zone 2 exercise. The walking pace was set to preserve the heart rate at approximately 60–70% of HRmax over time for each subject.

Participants in the control group remained seated for 40 minutes in a quiet room, engaging in passive activities such as reading neutral magazines.

After the 40-minute intervention, measurements were taken as a post-test. HRV was measured for 5 min while subjects were seated in a quiet room and breathed at a controlled rate. Participants then filled the Stanford sleepiness scale.

Table 2. Experimental protocol timeline

Phase	Experimental group	Control group
Standardized meal	600 kcal balanced meal	Same
Postprandial period	Immediate start	Seated rest
Intervention	40 min Zone 2 treadmill walking	40 min seated rest
HR monitoring	Polar H10	—
Post-test HRV	5 min seated recording	5 min seated recording
Sleepiness	Stanford Sleepiness Scale	Stanford Sleepiness Scale

Data Analysis

Statistical analyses were conducted using SPSS (version 26.0). Data normality was verified using the Shapiro–Wilk test. Paired-samples t-tests were applied to assess within-group pre–post differences, while independent-samples t-tests were used to evaluate between-group differences based on post-intervention values. Statistical significance was established at $p < 0.05$. Effect sizes were calculated using Cohen's d and interpreted according to standard thresholds, with values greater than 0.8 considered large.

Results

Pre–post comparisons revealed significant changes in both vagal activity and subjective sleepiness across the experimental and control conditions.

Zone 2 aerobic walking in the experimental group also generated a significant change in vagal activity, with rMSSD values increasing from a pre-test mean of 38.50 ms to post-test mean of 49.80 ms ($t(9) = 11.16$, $p < 0.001$), reflecting a very large effect size (Cohen's $d = 3.53$). Concurrently, subjective feelings of sleepiness decreased markedly from 3.50 to 1.90 ($t(9) = 6.42$, $p < 0.001$, Cohen's $d = 2.03$) implying a strong enhancement of self-reported alertness during the postprandial walking session.

The pattern in the control group was reversed. Vagal activity decreased significantly, from 39.10 ms to 30.40 ms ($t(9) = 6.71$, $p < 0.001$; Cohen's $d = 2.12$), and sleepiness scores increased from a baseline of 3.40 to 5.80 ($t(9) = 6.89$, $p < 0.001$; Cohen's $d = 2.18$), indicating an incremental imbalance of the autonomic nervous system during passive postprandial rest and sense of alertness.

These results were also supported by the between-group comparison of post-intervention measurements. The experimental group displayed vagal activity (rMSSD values) (49.80 ± 5.12 ms) significantly higher than that of the control group (30.40 ± 4.50 ms) ($t(18)=8.45$, $p<0.001$, Cohen'sd=3.99). Similarly, the experimental group had significantly less postprandial sleepiness (1.90 ± 0.65) than the control group (5.80 ± 0.90) ($t(18) = 9.88$, $p < 0.001$, Cohen's $d = 4.67$).

In summary, we found that postprandial Zone 2 aerobic walking elicited a significant increase of vagal modulation with a strong decrease in perceived sleepiness compared to the passive condition, which showed opposite physiological and perceptual effects. Table 3 and 4 present the detailed statistical results.

Table 3. Within-group comparisons for the experimental and control groups

Variable	Group	Pre-Mean	Post-Mean	SD of Differences	t-value	p-value	Cohen's d
Vagal Activity (rMSSD, ms)	Experimental	38.50	49.80	3.20	11.16	<0.001	3.53
	Control	39.10	30.40	4.10	6.71	<0.001	2.12
Sleepiness Level (SSS)	Experimental	3.50	1.90	0.85	6.42	<0.001	2.03
	Control	3.40	5.80	1.10	6.89	<0.001	2.18

Note: Cohen's d values indicate large effect sizes (>0.8)

Table 4. Between-group comparisons in post-intervention measures

Variable	Group	Mean	SD	t-value	p-value	Cohen's d
Vagal Activity (rMSSD, ms)	Experimental	49.80	5.12	8.45	<0.001	3.99
	Control	30.40	4.50			
Sleepiness Level (SSS)	Experimental	1.90	0.65	9.88	<0.001	4.67
	Control	5.80	0.90			

Note: Cohen's d values indicate large effect sizes (>0.8)

Discussion

The present findings indicate that changes in autonomic activity were associated with perceived sleepiness, at rest and after exercise in the postprandial period, suggesting that Zone 2 aerobic walking has an important autonomic effect when compared to passive rest. Beyond a confirmation of the exercise effects, the findings emphasize that moderate aerobic activity has an independent regulatory effect in the postprandial state.

The percent increase in the rMSSD values reflects an enhanced parasympathetic reactivation after Zone 2 exercise, supporting previous ideas of vagal rebound after moderate-intensity aerobic effort. Moderate-intensity exercise has already been reported to shorten autonomic recovery and to increase cardiac parasympathetic modulation (Stanley et al., 2013; Hottenrott et al., 2012). The metabolic Zone 2 exercise features, mainly high fat oxidation and low lactate production, may limit the sympathetic overactivation and thus ensure a steady vagal response (San-Millán
women, who present specific cardiovascular and anatomic responses to aerobic exercise (Wang et al., 2025; Soares-Miranda et al., 2014). Consistent with these results, previous studies demonstrated that HRV was enhanced following controlled aerobic interventions, indicating the effectiveness of moderate exercise in maintaining autonomic balance (Barreto et al., 2023; Manickavelu et al., 2025).

There are several physiological explanations for the significant decrease of postprandial sleepiness observed in the experimental group. Light-to-Moderate intensity of exercise could lead to greater glucose uptake and increase insulin activity, reducing postprandial glycemic excursions associated with lethargy, and sleepiness (Reynolds et al., 2020; Hussain et al., 2024). Moreover, the exercise-induced rise in cerebral blood flow and oxygen supply could offset postprandial diversion of circulation towards the digestive tract that may sustain cortical arousal and alertness (Colberg et al., 2009; Hassan & Abdulkareem, 2025). Interpretation of these findings are in line with studies showing positive effects on mood, attention and fatigue after postprandial walking compared with a rest condition (Diekmann et al., 2019).

However, the control group showed a decrease in rMSSD values and an increase in sleepiness, which is a characteristic postprandial response without movement. Parasympathetic dominance toward gastroenteric activities during digestion can reportedly lead to a decrease of cerebral perfusion and alter vigilance and cognitive availability (Kaneda et al., 2025). This autonomic state is presumably sustained by the lack of physical activation and explains the declines in both physiological and perceptual variables.

Crucially, combining HRV and subjective-knockdowns allows for a more informed picture of this postprandial habituation. Previous research has focused on either postprandial glycemic control or exercise-induced HRV and few studies have investigated autonomic and perceptual responses to moderate exercise in the immediate postprandial state, especially in women (Colberg et al., 2009; Diekmann et al., 2019; Stanley et al., 2013) The current findings therefore contribute to existing literature by emphasizing the value of Zone 2 exercise as a specific non-pharmacological intervention that enhances autonomic balance and daytime arousal in this group.

The large effect sizes observed across comparisons provide strong support for the practical significance of the intervention and further corroborate the robust practical application of the intervention, demonstrating that even a single bout of 40 min moderate postprandial walking can evoke substantial physiological and behavioral changes. Recent research has also demonstrated that acute sessions of aerobic exercises can lead to immediate beneficial effects on autonomic modulation, metabolic responses, and perceived fatigue, indicating their utility as short-term controlling strategies (Buchheit & Laursen, 2013; Henson et al., 2016) These results are consistent with emerging evidence for moderate aerobic exercise moderating facilitation of metabolic flexibility and neural regulation, especially in populations susceptible to postprandial fatigue and sedentary lifestyles (Goodpaster & Sparks, 2017; Basso et al., 2016).

Although these findings were optimistic, several limitations must be recognized. Study findings could only be generalized to a relatively small sample size, and the purposive selection of physically active women might have affected how participants responded to the interventions. In addition, the investigation focused on acute responses rather than chronic adaptations so do not rule out changes evolving over time and no direct measures of glucose kinetics or neural activity were obtained. Future studies

could use larger and more heterogeneous samples, different exercise intensities or chronic applications in the workplace or clinical context.

Practically, brief Zone 2 aerobic walking following meals are perhaps an easy and feasible method that could be used as a simple tool to improve autonomic regulation and postprandial sleepiness during daily routine. Such interventions may be a valuable for women employed in sedentary work, where declines in alertness after meals can impact productivity and well-being.

Conclusions

The current study shows that a 40-minutes Zone 2 walking of moderate intensity performed in the postprandial period after consumption of a standardized meal markedly stimulates vagal activity, as demonstrated by elevated rMSSD values and also reduces subjective feelings of sleepiness after meal intake compared to passive rest. The present results suggest that moderate intensity aerobic exercise is capable of altering the autonomic balance during the postabsorptive state.

The changes in these parameters indicate that Zone 2 exercise induces parasympathetic re-activation and has a positive influence on mechanisms related to the regulation of vigilance after eating. These findings support the use of moderate aerobic exercise as a practical non-pharmacological strategy to help attenuate postprandial decrements in alertness, especially for women.

Overall, incorporating moderate postprandial aerobic activity may represent a simple and accessible approach to supporting autonomic function and improving daytime alertness in daily life.

Recommendation

On the basis of these results, we may propose that inclusion of Zone 2 aerobic walking (at moderate intensity) after a meal is appropriate for implementation as an everyday practice with which to prevent postprandial sleepiness and maintain the balance of the autonomic nervous system in women.

Employers and health promotors may consider the inclusion of brief postprandial walking bouts as a cost-effective intervention to improve alertness and work performance.

Fitness professionals should consider monitoring HR to ensure postprandial aerobic activity is appropriately performed at a Zone 2 exercise intensity.

Follow-up research could explore chronic responses to postprandial Zone 2 exercise, various intensities of exercise, and more participants from different backgrounds for more generalizable outcomes.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Disclosure statement

This study was not supported by, or yielded any financial gain to, any of the authors.

Informed Consent

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