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The effect of green tea supplementation on some physiological markers of anxiety following a high-intensity interval exercise in anxious young women

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Abstract

Introduction: Green tea supplementation and exercise, including high-intensity interval exercise, can be effective in improving anxiety accordingly, the aim of the present study was to determine the effects of green tea supplementation on some physiological markers of anxiety following a high-intensity interval exercise in anxious young women.

Methods: Forty anxious young women with a mean age of 20.1±4.41 years were selected based on the criteria of the Spielberger Anxiety Questionnaire and randomly divided into four groups: control group, green tea supplement group, high-intensity interval exercise group, and high-intensity interval exercise plus green tea supplement group. Participants in the supplement and exercise+supplement groups consumed 1,000 mg of green tea daily for one week. The exercise groups then performed a session of high-intensity interval exercise. The double product and serum cortisol and serotonin hormones were assessed before and after the research protocol.

Results: The findings showed that taking green tea supplements alone significantly increased serotonin levels ($P = 0.002$) but had no significant effect on the double product and cortisol levels ($p < 0.05$). Also, one session of intense interval training significantly increased the double product but did not show a significant effect on the hormones cortisol and serotonin ($p<0.05$). Finally, no significant interaction effect was observed between exercise and supplementation ($p<0.05$).

Conclusions: Overall, it seems that short-term consumption of green tea is effective in reducing anxiety and invigorating anxious young women by increasing the hormone serotonin, but it does not have an interactive effect with a high-intensity interval exercise.

Key Words: Green tea, High-intensity interval exercise, Double product, Cortisol, Serotonin.

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1. Introduction

According to recent estimates, approximately 60 million individuals in Europe are affected by anxiety disorders. Data from a survey conducted in the United States indicated that women are twice as likely as men to develop panic disorder or phobia during their lifetime (1). Although only minor sex-related differences have been reported, evidence suggests that the prevalence of anxiety among women is increasing. Some studies have proposed that anxiety disorders in women may be strongly influenced by genetic factors (1).

Anxiety activates the sympathetic nervous system and affects several physiological parameters, including heart rate and blood pressure, leading to elevations in both variables (2). Stress and anxiety play significant roles in the onset and progression of coronary artery disease (3). Chronic stress may exacerbate this condition through environmental interactions or psychological changes in individuals. Previous studies have demonstrated that stress stimulates the release of adrenaline and noradrenaline, resulting in elevated levels of free fatty acids and reduced vascular elasticity. These alterations contribute to vasoconstriction and increased platelet adhesion, ultimately promoting the formation of atherosclerotic plaques and aggravating coronary artery disease (3).

In recent years, exercise and physical activity have gained considerable attention as effective non-pharmacological approaches for the prevention and treatment of mood disorders such as depression and anxiety. Exercise is a low-cost, accessible intervention with minimal side effects and has been shown to be particularly effective in alleviating anxiety symptoms, demonstrating superiority over control interventions. In this context, high-intensity interval training (HIIT) has emerged as a popular exercise modality among athletes, coaches, and exercise scientists (4). HIIT consists of relatively short, intermittent bouts of exercise performed at near-maximal or maximal effort. Furthermore, HIIT has been introduced as a time-efficient alternative to improve the effectiveness of exercise training sessions (5).

High-intensity interval exercise typically involves repeated exercise bouts performed at 80–100% of maximum heart rate and induces several physiological adaptations, including improvements in maximal oxygen uptake and favorable changes in body composition. This type of training has also been shown to enhance adherence to exercise programs and improve cardiovascular health (6). Nevertheless, limited evidence is available regarding the effects of HIIT on anxiety-related markers, particularly among anxious women.

Considering the aforementioned evidence, one of the approaches to coping with anxiety and stress involves enhancing nervous system function and psychological relaxation through the use of natural dietary supplements. Among these, green tea has attracted considerable attention (7). This beverage is highly popular in countries such as China and Japan and accounts for approximately 20% of global tea consumption (7). Green tea is widely recognized for its pleasant taste and numerous health benefits, including antioxidant, neuroprotective, and cholesterol-lowering properties. Derived from the leaves of *Camellia sinensis*, green tea contains several bioactive compounds, including catechins, flavonoids, theanine, and antioxidants. Among these constituents, L-theanine and epigallocatechin gallate (EGCG) have received particular attention due to their potential anxiolytic and relaxation-promoting effects (7).

L-theanine has been reported to reduce stress by increasing alpha brain wave activity. Furthermore, both L-theanine and EGCG may alleviate stress and anxiety by modulating brain activity and influencing neurotransmitter systems (8–10). In general, stress and anxiety can alter the concentrations of several hormones, including cortisol, commonly referred to as the stress hormone, and serotonin, which is associated with mood regulation and psychological well-being. Chronic stress increases cortisol levels through activation of the hypothalamic–pituitary–adrenal (HPA) axis, and prolonged activation of this pathway may contribute to anxiety disorders. Conversely, stress may reduce serotonin levels, a monoamine neurotransmitter involved in the regulation of anxiety, mood, and various psychiatric disorders (11).

It has been suggested that both physical activity and green tea may alleviate anxiety symptoms by stimulating the norepinephrine neurotransmitter system or by activating the serotonergic system, thereby enhancing serotonin release and producing anxiolytic effects (11). However, the acute effects of green tea supplementation and high-intensity interval exercise have not been

adequately investigated. Given the importance of non-pharmacological approaches to anxiety management, the present study was conducted to investigate the effects of a single session of high-intensity interval exercise, with and without green tea supplementation, on selected cardiovascular functional indices and the hormones cortisol and serotonin in young women with anxiety.

2. Methods

2.1. Participants

The present study employed a semi-experimental, double-blind design with measurements performed at two time points. The study population consisted of 40 healthy, non-athletic young women with anxiety, aged 18–22 years, who were selected from a pool of 80 volunteers through screening using the Spielberger State–Trait Anxiety Inventory (STAI), which includes 20 items assessing trait anxiety and 20 items assessing state anxiety.

Each item was scored on a four-point scale ranging from 1 to 4. For positively worded items, scores ranged from 4 (very low) to 1 (very high), whereas negatively worded items were reverse-scored from 1 (very low) to 4 (very high). The total score for each subscale ranged from 20 to 80. Scores of 20–40, 41–60, and 61–80 indicated mild, moderate, and severe anxiety, respectively. The reliability coefficients of the questionnaire, assessed using Cronbach's alpha, were $\alpha = 0.78$ for state anxiety and $\alpha = 0.84$ for trait anxiety (12).

Participants were randomly assigned to four homogeneous groups (n = 10 per group): exercise plus supplementation, exercise plus placebo, supplementation alone, and control. The exercise plus supplementation group received two capsules containing 500 mg of green tea leaf powder and 50 mg of total polyphenols daily, whereas the exercise plus placebo group consumed two 500-mg dextrose capsules. Cardiovascular functional indices, including heart rate, systolic blood pressure, and rate-pressure product, as well as serum cortisol and serotonin concentrations, were measured before the supplementation period and 30 minutes after completion of the experimental protocol (5).

Potential confounding variables, including sex, age, body weight, exercise history, occupation, supplement use, medical conditions, measurement time and location, ambient temperature, and examiner effects, were controlled. Information regarding age, body weight, occupation, exercise history, supplement use, and the presence of physical or psychological disorders was obtained through questionnaires completed by the participants. Individuals who did not meet the study inclusion criteria were excluded.

To enhance measurement reliability, all assessments were performed by the same examiner using standardized procedures. In addition, to minimize the potential influence of diurnal variation, all measurements were conducted at the same time of day. Furthermore, the menstrual cycles of the participants were carefully monitored, and blood sampling was performed during the post-ovulatory (luteal) phase, approximately between days 17 and 25 of the menstrual cycle.

2.2. Supplementation protocol

Participants received the prescribed supplement doses daily and were instructed to adhere strictly to the supplementation protocol throughout the study period. The supplement contained 500 mg of green tea leaf powder and 50 mg of total polyphenols per capsule. Participants in the supplementation and exercise plus supplementation groups consumed two capsules daily for one week, resulting in a total daily green tea dose of 1,000 mg.

The selected dosage was based on previous studies investigating the effects of green tea supplementation (14). Furthermore, the timing and method of supplement administration were carefully monitored by the researcher to ensure compliance with the supplementation protocol. Following completion of the supplementation period, blood samples were collected again for subsequent analyses.

2.3. Exercise protocol

The high-intensity interval exercise protocol consisted of a 15-minute warm-up, a 20-minute exercise session with a work-to-rest ratio of 1:3, and a 10-minute cool-down period. The main exercise session comprised repeated bouts of 30 seconds of high-intensity running performed at 85–90% of maximum heart rate, followed by 90 seconds of low-intensity running at 45–50% of maximum heart rate (13).

Exercise intensity was prescribed based on the percentage of maximum heart rate and was continuously monitored using a Polar heart rate monitor. Following completion of the main exercise session, participants performed stretching exercises during the cool-down period to facilitate recovery and return physiological parameters to baseline levels (5).

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Table 1 Details of the High-Intensity Interval Training Protocol

Phase	Intensity	Duration (s)	Number of Repetitions	Total Time (min)
High-intensity interval	85–90% of heart rate reserve (HRR)	30	10	5
Low-intensity interval	45–50% of heart rate reserve (HRR)	90	10	15

2.4. Statistical analysis

The normality of data distribution was initially assessed using the Shapiro–Wilk test. Subsequently, the changes from pre- to post-intervention within each group were calculated. A two-way analysis of variance (Two-way ANOVA) was performed to examine the interaction effects between exercise and green tea supplementation, as well as the independent effects of exercise and green tea supplementation on the selected outcome variables.

All statistical analyses were performed using SPSS software (version 26.0). Statistical significance was established at $P \leq 0.05$.

3. Results

3.1. Participants' characteristics and compliance

Table 2 presents the participants' baseline characteristics as mean ± standard deviation. According to the results of the Shapiro–Wilk test, the collected data were normally distributed ($P > 0.05$). Table 3 presents the mean ± standard deviation values of the rate-pressure product and serum cortisol (Figure 1) and serotonin levels (Figure 2) at the pre- and post-intervention measurements.

3.2. Primary outcomes

According to the results presented in Table 4, a single session of high-intensity interval exercise significantly increased the rate-pressure product ($P = 0.001$). However, no significant effects were observed on serum cortisol or serotonin levels ($P > 0.05$).

Furthermore, green tea supplementation alone significantly increased serum serotonin levels ($P = 0.001$), whereas no significant effects were found on the rate-pressure product or cortisol concentrations ($P > 0.05$).

Finally, no significant interaction effect was observed between exercise and green tea supplementation on any of the measured variables ($P > 0.05$).

Table 2 Participant Characteristics in the Study Groups (Mean ± SD).

Variable	Control	Green Tea	HIIT	Green Tea + HIIT
Age (years)	20.6±1.89	20.3±1.25	20.7±2.07	20.2±0.91
Height (cm)	162.1±7.2	160.9±7.54	163.9±5.97	164.1±7.24
Body weight (kg)	59.75±12.54	62.25±13.86	64.19±13.76	64.05±12.14
Body mass index (kg/m²)	23.04±4.15	24.6±5.19	24.44±5.64	23.78±3.89
Body fat (%)	27.44±5.77	28.43±6.07	30.63±6.96	29.6±6.24
Anxiety score	52.7±8.9	54.75±5.58	49.8±9.36	51.8±6.37

Table 3 Mean ± SD of the Assessed Variables in the Study Groups Before and After the Intervention.

Variable	Time Point	Control	Green Tea	HIIT	Green Tea + HIIT
Rate-Pressure Product (HR × SBP)	Pre-test	8733.9±1297.87	9122.8±1128.41	8853.8±1511.7	8988.5±1120.7
	Post-test	8896.1±1124.33	9038.9±1268.65	10373.9±1592.2	10816.1±1359.2
Serum Cortisol (µg/dL)	Pre-test	8.5±3.09	9.2±2.77	8.3±3.23	7.2±2.02
	Post-test	8.4±2.75	9.1±1.88	9.1±2.64	8.1±3.83
Serum Serotonin (ng/mL)	Pre-test	139.4±26.58	132.6±18.43	141.7±26.89	144.3±19.45
	Post-test	138.3±25.11	145.8±21.89	145.9±31.36	149.6±25.69

Table 4 Results of the Two-Way Analysis of Variance (Two-Way ANOVA).

Variable	Source	F	P value
Rate-Pressure Product (HR × SBP)	EXE	12.9	0.001
	SUP	0.22	0.63
	EXE×SUP	0.26	0.61

Serum Cortisol (µg/dL)	EXE	1.15	0.57
	SUP	0.65	0.42
	EXE×SUP	0.003	0.98
Serum Serotonin (ng/mL)	EXE	0.55	0.46
	SUP	11.71	0.001
	EXE×SUP	1.56	0.21

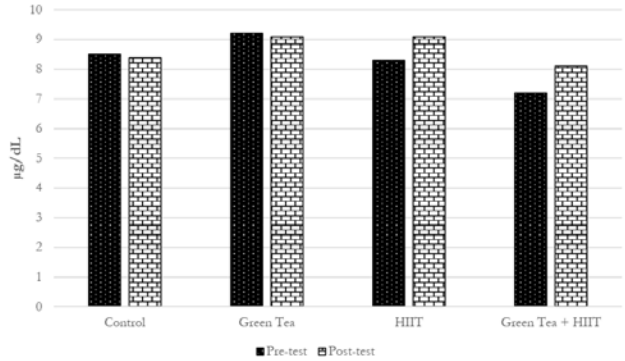

Figure 1. Serum Cortisol Levels at Pre- and Post-Intervention in the Four Study Groups

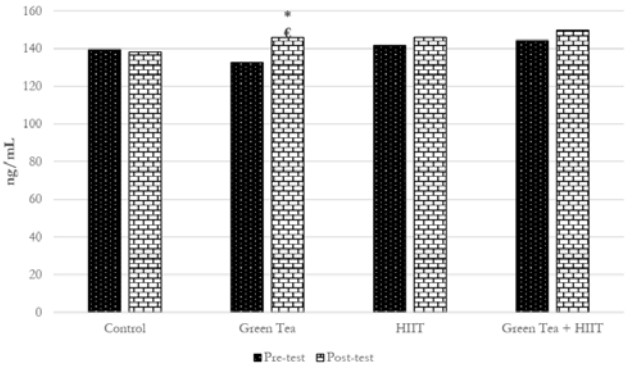

Figure 2. Serum Serotonin Levels at Pre- and Post-Intervention in the Four Study Groups

*P<0.05: Significant difference compared to pre-test; **€** P<0.05: Significant difference compared to other groups

4. Discussion

The present study was conducted to investigate the effects of green tea supplementation on selected physiological markers of anxiety following a single session of high-intensity interval training (HIIT) in young women with anxiety. The findings demonstrated that a single session of HIIT significantly increased the rate-pressure product (RPP) and serum serotonin levels but had no significant effect on serum cortisol concentrations.

The observed increase in RPP is consistent with the findings of Zar et al. (15) and Mohebi et al. (16), but contrasts with those reported by Mirzaei et al. (17). Consistent with the present results, Zar et al. (2018) reported a significant increase in RPP following a single session of HIIT in 11 physical education students (15). Similarly, Mohebi and Rezaei (2014) found a significant increase in RPP after 51 minutes of continuous aerobic exercise performed at 61% of heart rate reserve in untrained overweight men (16). In contrast, Mirzaei et al. (2012) observed no significant changes in RPP immediately following a 40-minute interval running and swimming protocol (six 5-minute exercise bouts at 65–85% of heart rate reserve interspersed with 2-minute recovery periods) in trained young male runners and swimmers (17). These discrepancies may be attributed to differences in participants' fitness levels, exercise intensity, and training modality. Unlike the trained athletes included in the study by Mirzaei et al., the participants in the present study, as well as those in the supporting studies, were physically active but non-athletic individuals. Therefore, differences in cardiovascular

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adaptations to exercise may account for the inconsistent findings.

The rate-pressure product is an important indicator of the relationship between coronary blood flow and myocardial metabolic demand, ventricular function, and myocardial workload, and is closely correlated with directly measured myocardial oxygen consumption (17). During exercise, increases in heart rate and systolic blood pressure elevate the rate-pressure product, reflecting the increased cardiac workload required to meet the oxygen demands of the active myocardium (17).

Regarding serum cortisol, the present study found that a single session of HIIT did not significantly affect cortisol concentrations in young women with anxiety. Cortisol, a primary biomarker of hypothalamic–pituitary–adrenal (HPA) axis activation, is influenced by several factors, including exercise intensity and duration, psychological status, sampling time, and individual fitness level (18,19). Previous studies have suggested that short-duration interval exercise, particularly in physically active but non-athletic individuals, may not provide sufficient stimulation to elicit a significant cortisol response because activation of the HPA axis is relatively brief and hormone levels rapidly return to baseline (19).

Furthermore, chronic anxiety may alter the sensitivity of HPA axis receptors, resulting in an attenuated cortisol response to acute stressors. Consequently, the absence of significant changes in cortisol observed in the present study may reflect partial adaptation of the neuroendocrine system in young women with anxiety or may be related to the timing of post-exercise blood sampling. In addition, previous evidence indicates that cortisol responses to HIIT are generally less pronounced in women than in men and may be influenced by fluctuations in sex hormones, which could also explain the present findings (18).

Numerous studies have demonstrated that green tea exerts beneficial effects on health, including reductions in obesity, stress, and depression, as well as improvements in neurological and metabolic function (8–10). One proposed mechanism underlying these effects involves modulation of serotonin, a neurotransmitter that plays a central role in the regulation of mood, appetite, sleep, and cognition. Consistent with this mechanism, the present study demonstrated that green tea supplementation alone significantly increased serum serotonin levels in young women with anxiety. These findings are in agreement with those of Li et al. (2019) (18) and Mirza et al. (2013) (19), but are inconsistent with the findings reported by Irandoust and Taheri (2019) (4).

Mirza et al. (2013) demonstrated in an experimental study using rats that green tea extract increased brain serotonin concentrations, which may contribute to improved appetite regulation, arousal, memory, and reduced anxiety. Their findings further suggested that green tea may represent a promising strategy for the prevention and management of obesity, stress, depression, and neurological disorders (19). In contrast, Irandoust and Taheri (2019) reported that one week of HIIT significantly reduced serum serotonin levels in middle-aged women with obesity, whereas no significant changes were observed in the control group (4). These discrepancies may be explained by differences in participant characteristics, including age, obesity status, psychological condition, exercise protocol, and supplementation regimen.

Overall, the findings of the present study support previous evidence suggesting that green tea supplementation may exert anxiolytic effects by enhancing serotonergic neurotransmission. In addition to increasing serotonin availability, green tea has been reported to reduce blood pressure and improve cardiovascular function. Nevertheless, further well-designed clinical studies are warranted to confirm these mechanisms and to clarify the interaction between green tea supplementation, high-intensity interval exercise, and neuroendocrine responses in individuals with anxiety.

5. Conclusion

The findings of the present study demonstrated that a single session of high-intensity interval training (HIIT) significantly increased cardiovascular functional indices, particularly the rate-pressure product, in young women with anxiety, while producing no significant effect on serum cortisol levels. In addition, green tea supplementation (1,000 mg/day) significantly increased serum serotonin concentrations, suggesting a potential role in alleviating anxiety symptoms.

Taken together, these findings indicate that HIIT and green tea supplementation may influence physiological and psychological stress responses through distinct mechanisms. While HIIT appears to primarily affect cardiovascular function, green tea supplementation may exert its anxiolytic effects by enhancing serotonergic activity. Nevertheless, further studies are warranted to clarify the underlying hormonal mechanisms, particularly the cortisol response, using longer intervention periods and carefully controlled blood sampling protocols.

6. Highlights

Overall, the findings suggest that: 1. High-intensity interval training (HIIT) exerts a distinct effect on resting rate-pressure product, particularly in young women with anxiety. 2. Short-term green tea supplementation may contribute to anxiety reduction and improved psychological well-being by increasing serum serotonin levels in this population.

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Conflicts of Interest#
The authors declare that they have no conflicts of interest regarding the publication of this paper.

Authors' Contributions#
All authors contributed substantially to the conception and design of the study, data collection, data analysis and interpretation, manuscript preparation, and critical revision of the manuscript. All authors read and approved the final version of the manuscript.

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