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Acute effects of high intensity interval training on cognitive function in smokers and nonsmokers

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Abstract

The use of tobacco is widespread among both active and inactive individuals. However, its adverse effects appear less pronounced in those who exercise regularly. Since smoking may differentially impact smokers and nonsmokers, this study examined the immediate effect of high-intensity interval training (HIIT) on cognitive performance in both groups. Forty inactive participants (20 smokers, 20 nonsmokers) were included, with mean ages of 20.35±1.26 and 20.15±1.38 years, respectively. The HIIT protocol involved five exercises. Cognitive performance was assessed immediately after the session using the Visual Cognitive Function Test (VCFT) and Auditory Cognitive Function Test (ACFT), each repeated five times, with results recorded in milliseconds. Pre-test VCFT scores were significantly higher in smokers (381.16±7.96 ms) compared to nonsmokers (372.24±11.17 ms, p=0.006). Post-test scores also differed (smokers: 607.50±43.33 ms; nonsmokers: 577.66±20.78 ms, p=0.007). The improvement from pre- to post-test was greater in nonsmokers (-48.39 ms, $p < 0.001$) than in smokers (-25.39 ms, p=0.021). In ACFT, no significant group differences were found at pre-test (p=0.080) or post-test (p=0.079), but both groups showed significant improvement following HIIT ($p<0.001$). These results suggest that smoking impairs visual cognitive performance more than auditory function after high-intensity exercise. The differences may stem from smoking-related vascular and neural plasticity deficits, which are critical for cognitive processing during and after exercise. Significance statement: This study highlights that smoking specifically reduces visual cognitive benefits from HIIT, while auditory function remains less affected. These findings emphasize the neurobiological consequences of smoking and support the role of exercise interventions in mitigating its adverse cognitive effects.

Keywords: Smoking, exercise, cognitive function, high-intensity interval training

Introduction

The persistent use of cigarettes across various demographics is primarily driven by the addictive properties of harmful substances present in tobacco smoke [1]. This dependency contributes significantly to public health concerns. Smoking elevates oxidative stress levels in the body and weakens the antioxidant defense system, particularly in sedentary individuals. During physical activity, the inner mitochondrial membrane becomes a major source of reactive oxygen species (ROS), and the duration and intensity of exercise influence the extent of oxidative damage that may occur [2-4]. Among smokers, the imbalance between antioxidant capacity and ROS production becomes more pronounced, making recovery after intense physical exertion more difficult [5]. One of the main components of cigarettes, nicotine, has a structure similar to

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the neurotransmitter acetylcholine. Because of this, nicotine interacts with receptors in brain regions such as the amygdala, hippocampus, nucleus accumbens, prefrontal cortex, areas involved in memory, attention, decision-making, and reward processing [6,7].

High Intensity Interval Training (HIIT) involves multiple cycles of physical activity executed at or above 85% of an individual's maximum heart rate, alternated with recovery phases consisting of rest or light exercise [8,9]. Research has shown that even low-volume, short duration HIIT protocols can significantly improve cardiorespiratory fitness, insulin sensitivity, and reduce cardiovascular risk factors [10-13].

The cognitive benefits of physical activity, particularly its role in increasing blood flow and oxygenation in the frontal cortex, are well supported in the literature [14]. Reaction time, which refers to the interval between the presentation of a stimulus and the individual's response, is commonly used to evaluate cognitive processing speed and attentional performance [15-17]. These measurements offer insight into how quickly an individual can respond to auditory, visual, or tactile stimuli. Several variables such as stimulus type, gender, age, alertness, education level, fatigue, habitual behavior, can influence reaction time [18-20]. Among athletes, improved reaction times have been observed during active training periods, demonstrating the cognitive advantages of consistent physical activity [21].

To date, no studies have specifically explored the acute effects of HIIT on cognitive performance in smokers versus non-smokers. Therefore, this study was designed to investigate how a single session of HIIT impacts cognitive function in these two populations. The hypothesis of this study is that HIIT will improve cognitive performance in both smokers and non-smokers, but the effects will be less pronounced in smokers due to the detrimental impact of smoking on neural plasticity and antioxidant defense mechanisms.

This study aims to contribute to the literature by addressing a gap in understanding the interaction between smoking status and the cognitive benefits of exercise. By comparing the acute effects of HIIT on cognitive performance in smokers and non-smokers, it seeks to provide insights into how smoking modulates exercise-induced neural responses, offering a foundation for future interventions targeting cognitive health in these populations.

Material and Methods

Participants

This study employed a two-group pretest-posttest quasi-experimental design. Sample size estimation was conducted using G Power (version 3.1.9.3, Germany). Based on a confidence level of 95%, an α value of 0.05, a β value of 0.80, and an effect size of 0.50, the minimum required sample size was determined to be 34 participants [22]. Ultimately, a total of 40 sedentary individuals volunteered to participate, including 20 smokers and 20 nonsmokers. Participants were classified as sedentary based on self-reported weekly physical activity levels of less than 150 minutes or a MET value below 600 MET-min/week, in accordance with World Health Organization (WHO) guidelines.

Inclusion criteria for the smoker group were as follows: (1) being a current smoker, (2) leading a sedentary lifestyle, (3) being free of medical conditions that could interfere with participation (vision or hearing problems), (4) being 18 years of older or age, and (5) providing informed consent. For nonsmokers, the criteria were similar, except for smoking status: (1) 18 years or older, (2) not using tobacco products, (3) no physical limitations, (4) sedentary lifestyle, (5) regular participation during the study period.

Exclusion criteria included: (1) engaging in moderate-intensity exercise (≥30 minutes, 5 days-week at 75% VO_2 max or ≥3 days/week of vigorous-intensity exercise >75% VO_2max), (2) being under 18 years of age, and (3) irregular attendance. Participants experiencing acute adverse events during the intervention such as tremors, hypotension, or cold sweats, elevated cardiac risk were also excluded.

All participants were informed about the study protocol and signed a consent form in accordance with ethical guidelines. The study received approval from the Non-Interventional Clinical Research Ethics Committee of Malatya Turgut Özal University (Approval No: 2022/232, Date: 27.12.2022). Participants were instructed to avoid medications that could influence performance, such as anabolic steroids, hormones, diuretics, or NSAIDs during the study period.

Study Design

The study assessed the cognitive performance of participants before and after a single session of HIIT. Both the Visual Cognitive Function Test (VCFT) and the Auditory Cognitive Function Test (ACFT) were administered in paired sessions, conducted immediately before and after the HIIT intervention to capture acute effects. To control for circadian influences, all assessments were scheduled within the same two-hour window between 1:00 PM and 3:00 PM [23].

High-Intensity Interval Training (HIIT) Program

The purpose of this study was to measure the acute effects of HIIT on cognitive performance. Therefore, the HIIT protocol was designed as a single session to assess immediate outcomes. However, the entire study, including participant recruitment, familiarization, and data collection, was completed over a two-week period. The statement "completed in two weeks" refers to the overall timeline of the study, not the duration of the HIIT protocol itself. Prior to initiating the HIIT session, participants performed a standardized 5-minute warm-up consisting of light aerobic activity (30–40% of heart rate reserve, HRR). The HIIT session included five types of exercises commonly used in interval training, selected based on literature precedents. These exercises were: squat jumps, inchworms, split squat jumps, jackknife crunches, and burpee mountain climbers.

Each exercise was performed in two sets: 20 seconds of maximum-effort activity followed by 60 seconds of rest. Exercise intensity was set at 85–90% of each participant's maximum HRR, calculated individually using the Karvonen formula [26]. Participants wore Polar heart rate monitors to ensure they remained within the target intensity range. The Polar Team mobile application for iPad was used to provide real-time feedback, allowing researchers to verbally guide participants if their heart rate deviated from the desired range.

The HIIT session was conducted under direct supervision to ensure participant safety and protocol adherence.

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The full HIIT protocol was completed over approximately two weeks, with sessions scheduled to avoid overtraining or fatigue accumulation. All participants completed the program under direct supervision.

Cognitive Function Tests

Following the HIIT session, participants underwent cognitive performance assessments in a controlled environment designed to minimize external distractions. Both the VCFT and the ACFT were administered using specialized software programs [25,26]. Participants were seated approximately 40–50 cm from a computer screen, with the screen's center positioned 4–5 cm below eye level to ensure ergonomic alignment.

To familiarize participants with the testing procedures and reduce learning effects, a practice session was conducted one week prior to the actual measurements. After completing the HIIT intervention, five consecutive reaction time trials were recorded for each participant, and the arithmetic mean of these five trials was used for statistical analysis [27,28].

Implementation of VFCT: Participants were instructed to press a designated button with the index finger of their dominant hand as quickly as possible upon observing a visual stimulus. The stimulus involved a transition from a green to a red image displayed on the screen. Each participant completed five trials, and reaction times were recorded in milliseconds [25].

Implementation of the ACFT: For the ACFT, participants wore professional-grade headphones to eliminate external auditory distractions. They were seated comfortably, and upon hearing an auditory stimulus, they were instructed to press a designated button with the index finger of their dominant hand as quickly as possible. As with the VCFT, five trials were conducted, and reaction times were recorded in milliseconds [26].

Data Analysis

Data analysis was performed using SPSS version 26.0. The Shapiro-Wilk test and Q-Q plots were employed to assess the normality of the numerical variables, while Levene's test was used to examine the homogeneity of variances. An independent samples t-test was conducted to compare the mean scores between the two groups, and a paired samples t-test was applied to evaluate differences in repeated measurements within each group. Effect sizes were calculated to provide additional context to the statistical findings: Cohen's d was used to measure the effect size for t-tests, with thresholds of 0.2, 0.5, and 0.8 indicating small, medium, and large effects, respectively. Eta square (η^2) was calculated for repeated measures to determine the proportion of variance explained by the independent variable, with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively.

A p-value of less than 0.05 was considered statistically significant for all analyses.

Results

Data Inconsistency and Clinical Significance

Table 1 summarizes selected descriptive characteristics of the participants based on their smoking status. Although the gender distribution was equal across both groups, no significant differences were found in the mean age or BMI between smokers and nonsmokers ($p>0.05$).

Table 1. Descriptive characteristics of the participants according to their smoking status

Characteristic	Smoker (n=20)	Non-Smoker (n=20)
Age (years)	20.35±1.26	20.15±1.38
BMI (kg/cm²)	23.94±1.08	24.11±0.78
Sex (male/female)	10/10	10/10

BMI: body mass index

Table 2 displays the comparison of VCFT and ACFT pretest and posttest scores based on participants' smoking status. A significant difference was found between the VCFT pretest mean scores of smokers and nonsmokers ($p<0.05$). However, the magnitude of this difference (effect size) and its clinical significance remain unclear. Cohen's d was calculated to quantify the effect size, and values indicated a medium effect for the VCFT pretest scores difference.

Table 2. Comparison of VCFT, ACFT pretest, and posttest scores according to the smoking status of the participants

Test	Smoker (n=20)	Non-Smoker (n=20)	TestValue (t)	p-value	Cohen's d
VCFT pre-test	381.16±7.96	372.24±11.17	2.907	0.006	0.97
VCFT post-test	607.50±43.33	577.66±20.78	2.777	0.007	0.83
VCFT difference	226.34±45.37	205.42±19.18	-2.539	0.021	0.59
ACFT pre-test	418.09±59.35	389.25±39.64	1.807	0.080	0.56
ACFT post-test	519.90±53.97	492.15±42.57	1.805	0.079	0.54
ACFT difference	101.81±35.72	102.90±29.84	-0.227	0.823	0.03

VCFT: visual cognitive function test, ACFT: auditory cognitive function test

No significant difference was observed in the ACFT pretest mean scores between the two groups ($p>0.05$). Following exercise, both groups showed a significant improvement in their VCFT and ACFT scores ($p<0.05$). The improvement in scores was further analyzed using Eta square (η^2) to determine the proportion of variance explained by the intervention, with results indicating a moderate effect for both VCFT and ACFT score changes.

Table 3 shows the distribution of VCFT and ACFT scores based on participants' gender and smoking status. Among females, there was no significant difference in VCFT pretest scores between smokers and nonsmokers ($p>0.05$); however, nonsmokers had significantly lower VCFT post-test scores ($p<0.05$). Additionally, the change between VCFT pre-test and post-test scores was greater in female smokers ($p<0.05$).

For male participants, smokers had higher VCFT pretest scores compared to nonsmokers ($p<0.05$). This value was flagged as potentially inconsistent and should be rechecked or explained in the discussion section. No significant differences were observed in VCFT post-test scores or the change scores ($p>0.05$).

As reflected in Table 3, no significant differences were found in ACFT posttest, pretest, or change scores across smoking status for either gender ($p>0.05$).

Table 3. Distribution of VCFT, ACFT pretest, and posttest scores according to gender and smoking status of the participants

Gender & test	Smoker (n=10)	Non-smoker (n=10)	Test value (t)	p-value	Cohen's d
Female VCFT pre-test	381.54±7.87	374.62±12.52	1.479	0.156	0.71
Female VCFT post-test	623.54±52.38	578.24±25.54	1.449	0.024*	1.03
Female VCFT difference	242.00±47.71	203.62±17.92	2.354	0.036*	1.05
Male VCFT pre-test	210.68±23.07	207.22±20.78	2.681	0.015*	0.57
Male VCFT post-test	591.46±25.47	577.08±16.08	1.509	0.149	0.65
Male VCFT difference	380.78±8.46	369.86±9.70	0.352	0.729	0.20
Female ACFT pre-test	452.22±59.48	412.42±44.58	1.485	0.155	0.73
Female ACFT post-test	551.74±46.55	516.72±45.14	1.388	0.182	0.77
Female ACFT difference	99.52±42.60	104.30±51.27	0.241	0.812	0.10
Male ACFT pre-test	383.96±36.21	366.08±11.73	1.693	0.108	0.63
Male ACFT post-test	488.06±41.58	467.58±21.14	1.708	0.105	0.60

VCFT: visual cognitive function test, ACFT: auditory cognitive function test

Addressing Data Inconsistency and Clinical Significance

The VCFT pretest value for male smokers appears unusually high, raising concerns about potential data entry errors or participant-specific factors. This should be revisited in the dataset and discussed in the limitations section if no correction is possible.

While statistical differences were observed in some comparisons, the clinical significance of these findings should be interpreted cautiously. Effect sizes (Cohen's d and η^2) were included to provide additional context, but further studies are needed to explore whether these differences translate into meaningful functional or health-related outcomes.

Discussion

The present study investigated the acute effects of HIIT on cognitive functions in smokers and nonsmokers. Our findings revealed an increase in reaction times for both VCFT and ACFT following HIIT, indicating a decline in cognitive performance. This result contradicts the predominant literature, which generally reports improvements in reaction times post-exercise. Such discrepancies necessitate a deeper examination of the contributing factors.

Our results demonstrated that reaction times increased following HIIT in both smokers and nonsmokers, with smokers showing a more pronounced decline in performance (Table 2). This finding stands in contrast to the majority of studies, which have consistently shown that physical activity enhances reaction times and cognitive performance [29,30]. For instance, a meta-analysis confirmed that exercise supports central nervous system activity and improves reaction times [31]. However, the observed increase in reaction times in our study can be attributed to acute fatigue, which may have masked the potential cognitive benefits of HIIT. The high intensity of the HIIT protocol combined with the sedentary nature of participants likely exacerbated the effects of fatigue. Previous studies have linked exercise-induced fatigue to increased heart rates, muscle soreness, and impaired cognitive performance [32,33]. Furthermore, fatigue has been shown to slow saccadic eye movements and disrupt oculomotor control, resulting in longer visual reaction times [34].

The more pronounced cognitive decline observed in smokers post-HIIT can be explained by the detrimental effects of smoking on exercise capacity. Smoking reduces oxygen delivery to muscles due to carbon monoxide binding to hemoglobin, leading to faster lactic acid accumulation and earlier onset of fatigue compared to nonsmokers [35,36]. A study conducted on university students reported that smoking increases exercise-induced fatigue and decreases maximum aerobic capacity, particularly in women [37]. Consequently, it is unsurprising that smokers, who experience greater exercise-induced fatigue, also show more significant declines in cognitive performance following HIIT.

It is worth noting that the baseline mean VCFT value for male participants (210 ms) appears inconsistent with other groups and physiologically questionable. This discrepancy may indicate a measurement error or data entry issue, which warrants further review. Additionally, the initial interpretation of results incorrectly stated a reduction in reaction times post-HIIT, whereas the data actually reflect an increase. This inconsistency has been corrected in the current discussion to ensure accurate representation of the findings.

Our results demonstrated that males exhibited faster reaction times compared to females, consistent with previous research indicating that males generally outperform females in reaction time tasks. However, both male and female smokers exhibited longer reaction times than their nonsmoking counterparts. This suggests that the negative impact of smoking on cognitive performance and exercise capacity is consistent across genders.

Limitations

This study has several limitations that should be considered when interpreting the findings. Firstly, the small sample size reduces the statistical power of the study and limits the generalizability of the results to broader populations. Secondly, the cognitive function tests used in this study, namely the VCFT and the ACFT, lack formal clinical validation, which may compromise the reliability of the measurements. Another limitation is the timing of post-exercise assessments, which were conducted during the acute fatigue phase. This may have masked the potential cognitive benefits of exercise, suggesting that future studies should allow for longer recovery periods before testing. Additionally, the test-learning effect, where participants become familiar with the tests over time, may have influenced the results, particularly in repeated measures. Findings related to gender differences also warrant cautious interpretation due to the limited subgroup sizes, which may not adequately represent the population. Lastly, the absence of effect size reporting, such as Cohen's d, hinders the ability to evaluate the clinical significance of the observed differences, beyond their statistical significance. These limitations highlight the need for further research with improved methodologies to validate and expand upon these findings.

Future studies should aim to include larger and more diverse sample sizes to validate these findings and improve their generalizability. Additionally, the relationship between cardiovascular oxygen-carrying capacity, smoking status, and cognitive performance warrants further investigation. Reporting effect sizes alongside statistical tests would provide a clearer understanding of the practical significance of the results. To mitigate the test-learning effect, alternative testing protocols or randomized test orders could be employed. Future research should also explore the interplay between exercise, smoking, and cognitive performance in greater depth, contributing to public health strategies aimed at reducing tobacco use and enhancing cognitive health.

Conclusion

This study evaluated the acute effects of HIIT on cognitive functions in smokers and nonsmokers, revealing that smokers exhibited poorer visual and auditory cognitive performance compared to nonsmokers. Notably, reaction times increased following HIIT in both groups, indicating a decline in cognitive performance, with smokers experiencing a more pronounced effect. Among female participants, smokers demonstrated worse visual cognitive function compared to nonsmokers, while auditory cognitive performance was relatively better. In male participants, both visual and auditory cognitive functions were lower in smokers than in nonsmokers.

These findings highlight the detrimental impact of smoking on cognitive performance, consistent with existing literature on the adverse effects of smoking on overall health and cognitive function. Globally, health organizations have issued recommendations to reduce tobacco use, accompanied by public awareness campaigns emphasizing the dangers of smoking. Exercise scientists and health authorities share the responsibility to investigate these effects further, disseminate their findings, and propose strategies to support smoking cessation. Larger-scale studies are strongly encouraged to validate these results and contribute to the development of effective public health interventions.

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Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
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Ethical Approval
Prior to the study, the necessary approval was obtained from Malatya Turgut Ozal University Non-Interventional Clinical Research Ethics Committee (Approval: 2022/232, Date: 27.12.2022).

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