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Original Article

Effects of Cigarette Smoking and Vaping on Blood Glucose and Cardiopulmonary Endurance in Young Males, A Comparative Longitudinal Study Thesis

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ABSTRACT

Background: Cigarette smoking and vaping are common nicotine-delivery practices among young adults, but their comparative effects on metabolic and cardiopulmonary indicators remain insufficiently defined. Objective: To compare the effects of cigarette smoking and vaping on random blood glucose, cardiopulmonary endurance, and selected physiological parameters among young males. Methods: This comparative longitudinal study included 158 young males aged 18–30 years, with 79 participants in the cigarette-smoking group and 79 in the vaping group. Random blood glucose, estimated VO_2max, systolic and diastolic blood pressure, oxygen saturation, heart rate, recovery heart rate, and respiratory rate were assessed at baseline, immediately after exposure, at 1 month, and at 2 months. Between-group comparisons were performed using the Mann–Whitney U test, and longitudinal changes were assessed using repeated-measures and mixed ANOVA. Results: Baseline physiological variables were comparable between groups. Immediately after exposure, random blood glucose increased more in the vaping group than in the cigarette-smoking group (124.56 ± 15.91 mg/dL vs 118.08 ± 18.55 mg/dL). At 1 month, oxygen saturation was lower in the vaping group (88.82 ± 8.64%) than in the cigarette-smoking group (93.70 ± 6.88%), while respiratory rate was higher in the cigarette-smoking group (19.03 ± 2.21 breaths/min) than in the vaping group (17.01 ± 2.93 breaths/min). VO_2max showed modest longitudinal improvement in both groups. Conclusion: Vaping was associated with a stronger immediate glycemic response and transient oxygen-saturation reduction, whereas cigarette smoking showed a greater early respiratory-rate response. Both exposures produced measurable physiological changes, supporting the need for cautious counseling of young users. Keywords: Cigarette smoking; Vaping; Blood glucose; VO_2max; Cardiopulmonary endurance; Oxygen saturation; Young males.

INTRODUCTION

Cigarette smoking and vaping remain major public health concerns because both deliver nicotine and expose users to inhaled toxicants that may alter metabolic and cardiopulmonary function. Cigarette smoking continues to contribute substantially to preventable morbidity and mortality worldwide, with tobacco-related disease affecting cardiovascular, respiratory, metabolic, and oncological outcomes. Pakistan also carries a considerable tobacco-use burden, particularly among males, making tobacco-related physiological effects especially relevant in young populations (1,2). Although conventional cigarettes and electronic nicotine delivery systems differ in their chemical composition and mode of

aerosol generation, both practices can expose users to nicotine and other biologically active substances capable of influencing vascular tone, oxygen transport, autonomic activity, and glucose regulation (3,4).

Young adulthood is a clinically important period for evaluating these effects because physiological reserve is usually high, overt chronic disease is often absent, and early metabolic or cardiopulmonary alterations may remain subclinical. Cigarette smoking has been associated with endothelial dysfunction, increased sympathetic nervous system activity, impaired pulmonary function, altered oxygen delivery, and reduced exercise capacity, all of which may compromise cardiopulmonary endurance over time (5,6). Nicotine may also affect glucose homeostasis by stimulating catecholamine release, increasing hepatic glucose output, promoting insulin resistance, and modifying peripheral glucose uptake, thereby linking smoking exposure with dysregulated blood glucose levels even before the development of clinically apparent diabetes (7,8).

Vaping has frequently been promoted as a less harmful alternative to cigarette smoking because it avoids direct tobacco combustion and may reduce exposure to tar and carbon monoxide. However, electronic cigarette aerosols may still contain nicotine, aldehydes, volatile compounds, flavoring chemicals, particulate matter, and metals, depending on device characteristics, e-liquid composition, heating temperature, and user behavior (9,10). Emerging evidence suggests that vaping may produce acute cardiovascular, respiratory, inflammatory, and autonomic responses that are not necessarily benign, particularly when used regularly by young adults (11,12). Despite growing research on toxicological and cardiovascular outcomes, fewer studies have directly compared vaping and cigarette smoking in relation to short- and medium-term changes in blood glucose and field-based cardiopulmonary endurance among young male users (13-17).

The key knowledge gap is therefore not whether cigarette smoking is harmful, but whether vaping produces distinct or comparable physiological changes in young habitual users when assessed using clinically measurable outcomes such as random blood glucose, estimated maximal oxygen uptake, blood pressure, heart rate, oxygen saturation, respiratory rate, and recovery heart rate. This distinction is important because young users may perceive vaping as safer than cigarette smoking, while clinicians and public health professionals require comparative evidence to guide counseling, prevention, and risk communication. A longitudinal comparison of habitual cigarette smokers and habitual vape users can help identify whether either exposure pattern is associated with measurable changes in metabolic and cardiopulmonary indicators over time.

Accordingly, this study aimed to compare the effects of cigarette smoking and vaping on random blood glucose levels and cardiopulmonary endurance among young males aged 18–30 years, while also evaluating associated changes in blood pressure, heart rate, oxygen saturation, respiratory rate, and recovery heart rate. The study was guided by the research question: among young male habitual users, do cigarette smoking and vaping differ in their longitudinal effects on blood glucose and cardiopulmonary endurance over the follow-up period? It was hypothesized that cigarette smoking and vaping would produce significantly different physiological effects on blood glucose regulation and cardiopulmonary endurance in young males.

MATERIAL AND METHODS

A prospective comparative longitudinal observational study was conducted to evaluate and compare the effects of cigarette smoking and vaping on blood glucose level, cardiopulmonary endurance, and selected cardiopulmonary vital parameters among young males. The study was carried out at Spine Care Physiotherapy and Rehabilitation Center, Peshawar, after approval from the research committee of Riphah International University. The study population consisted of young male habitual cigarette smokers and habitual vape users aged 18–30 years. Participants were selected using non-probability purposive sampling according to predefined eligibility criteria and were followed across repeated measurement points to assess short-term and follow-up physiological changes. The two exposure groups

were defined as the cigarette-smoking group and the vaping group; the vaping group was not treated as a non-exposed control group because both groups represented active nicotine or aerosol exposure categories.

Participants were eligible if they were male, aged 18–30 years, and had a history of habitual cigarette smoking or habitual vaping for at least 6 months, with use of one or more cigarettes per day in the cigarette-smoking group or regular vape use in the vaping group. Individuals were excluded if they had a known history of cardiovascular, respiratory, or renal disease, were unable to provide written informed consent, or had a history of allergy to any component of e-liquid, including nicotine, propylene glycol, vegetable glycerol, vanillin, furaneol, or ethyl vanillin. Eligible participants were screened according to these criteria, informed about the study procedures, and enrolled only after written informed consent was obtained. A total sample of 158 participants was included, with 79 participants in the cigarette-smoking group and 79 participants in the vaping group. The sample size was calculated using G*Power version 3.1.9.7 for comparison between two independent groups, using an alpha level of 0.05, statistical power of 95%, and equal allocation between groups (1:1), resulting in 79 participants per group.

Data were collected using a structured data collection form that recorded demographic and clinical characteristics, including age, height, weight, body mass index, educational status, occupation, allergy history, and family history of chronic disease. Body mass index was calculated from measured height and weight and categorized according to standard BMI categories. Physiological outcomes were assessed at baseline, immediately after cigarette smoking or vaping exposure, at 1-month follow-up, and at 2-month follow-up. The main outcome variables were random blood glucose and cardiopulmonary endurance, while secondary variables included systolic blood pressure, diastolic blood pressure, heart rate, recovery heart rate, oxygen saturation, and respiratory rate. Random blood glucose was measured in mg/dL using an Accu-Chek Active blood glucose meter, which has been reported to meet international clinical accuracy requirements and demonstrate acceptable precision for blood glucose assessment (13,14). Cardiopulmonary endurance was assessed through the Queen's College Step Test, using a 16.25-inch step, a standardized stepping cadence of 24 steps per minute for 3 minutes, and post-exercise heart rate measurement to estimate VO_2max using the formula: $VO_2\text{max} = 111.33 - (0.42 \times \text{recovery heart rate in beats per minute})$. Higher estimated VO_2max values indicated better cardiopulmonary endurance (15,16).

Blood pressure was measured in mmHg using a calibrated sphygmomanometer according to standardized procedures by trained personnel. Systolic and diastolic blood pressure were recorded after appropriate participant positioning and rest to reduce measurement variability. Oxygen saturation and heart rate were measured using a pulse oximeter, with SpO_2 recorded as percentage saturation and heart rate recorded in beats per minute. Respiratory rate was measured in breaths per minute using a respiratory rate monitoring procedure, with the same assessment approach applied across participants and time points to maintain consistency. Recovery heart rate was recorded after completion of the Queen's College Step Test and was used both as an independent cardiopulmonary response variable and as part of the VO_2max estimation procedure. All devices were used according to standard operating procedures, and repeated assessments were performed using consistent measurement methods across follow-up points to improve reproducibility.

At baseline, eligible participants underwent demographic assessment and initial measurement of random blood glucose, systolic and diastolic blood pressure, heart rate, respiratory rate, oxygen saturation, recovery heart rate, and estimated VO_2max. Participants in the cigarette-smoking group then underwent assessment immediately after cigarette smoking exposure, while participants in the vaping group underwent assessment immediately after vaping exposure. The same outcome variables were reassessed at 1 month and 2 months. This repeated-measures approach allowed evaluation of both acute post-exposure changes and longitudinal changes within and between the cigarette-smoking and vaping groups. To reduce information bias, the same operational definitions, measurement instruments, timing

structure, and testing procedures were applied to both groups. To reduce measurement bias, standardized testing instructions were used, trained assessors performed the measurements, and instruments were maintained and calibrated where applicable. Potential confounding was addressed at the design stage by restricting the study population to young males within a narrow age range and excluding participants with known cardiovascular, respiratory, or renal disease; additional confounding by BMI, baseline physiological status, exposure intensity, diet, caffeine use, physical activity, and timing of last meal should be considered during adjusted analysis.

Data were entered, coded, cleaned, and analyzed using SPSS version 26. Continuous variables were summarized using mean and standard deviation where appropriate, and categorical variables were summarized using frequencies and percentages. Normality of continuous outcome variables was assessed using the Kolmogorov–Smirnov test. Because the tested physiological variables showed significant deviation from normal distribution, non-parametric analysis was used for between-group comparisons where appropriate. The Mann–Whitney U test was applied to compare cigarette-smoking and vaping groups at each measurement point for random blood glucose, VO_2max, systolic blood pressure, diastolic blood pressure, oxygen saturation, heart rate, recovery heart rate, and respiratory rate. Longitudinal within-group changes across repeated measurements were assessed using repeated-measures analysis, and group-by-time interaction effects were examined using mixed ANOVA for overall temporal comparison between cigarette-smoking and vaping groups. Statistical significance was set at $p < 0.05$. Exact p-values were reported where possible, and p-values smaller than 0.001 were interpreted as $p < 0.001$. Effect sizes, including eta squared for mixed ANOVA, were used to support interpretation of the magnitude of longitudinal effects. Cases with incomplete outcome data were reviewed during data cleaning, and analyses were conducted using available complete measurements for the relevant outcome and time point.

Ethical considerations were maintained throughout the study. Institutional approval was obtained before participant recruitment, and all participants provided written informed consent before data collection. Participants were informed about the study purpose, procedures, voluntary participation, and their right to withdraw without penalty. Confidentiality was maintained by using coded data and limiting access to study records. Data integrity was supported through standardized data collection forms, uniform measurement procedures, consistent device use, careful data entry, and verification of statistical outputs against tabulated results. These procedures were intended to ensure that the study could be reproduced by other researchers using the same population criteria, measurement tools, exposure grouping, follow-up schedule, and statistical analysis plan.

RESULTS

A total of 158 young male participants were included in the study, with 79 participants in the cigarette-smoking group and 79 participants in the vaping group. The mean age of participants was 26.6 ± 2.7 years, mean height was 1.6 ± 0.12 m, mean weight was 64.5 ± 13.2 kg, and mean BMI was 23.1 ± 4.1 kg/m². Most participants had a normal BMI category, while smaller proportions were underweight, overweight, or obese. Baseline demographic findings are summarized in Table 1.

Table 1. Demographic Characteristics of Participants

Variable	Mean ± SD
Age, years	26.6 ± 2.7
Height, m	1.6 ± 0.12
Weight, kg	64.5 ± 13.2
BMI, kg/m²	23.1 ± 4.1

The frequency distribution showed that 100 participants had normal BMI, representing 63.3% of the sample, while 22 participants were underweight, 29 were overweight, 3 had class I obesity, and 4 had class II obesity. Educational status was dominated by postgraduate-level participants, who represented 53.8% of the sample, followed by bachelor-level participants at 45.6%. Most participants were employed

full-time, while 29.7% were students and 16.5% were employed part-time. Allergy history was reported by 18.4% of participants, and 27.8% reported a family history of chronic disease. These categorical characteristics are presented in Table 2.

Table 2. Frequency Distribution of Participant Characteristics

Variable	Category	Frequency, n	Percentage, %
BMI category	Underweight	22	13.9
	Normal	100	63.3
	Overweight	29	18.4
	Obesity class I	3	1.9
	Obesity class II	4	2.5
Education	High school	1	0.6
	Bachelor's degree	72	45.6
	Postgraduate	85	53.8
Occupation	Student	47	29.7
	Full-time employment	85	53.8
	Part-time employment	26	16.5
Allergy history	Yes	29	18.4
	No	129	81.6
Family history of chronic disease	Yes	44	27.8
	No	113	72.2

At baseline, the cigarette-smoking and vaping groups were broadly comparable across all measured physiological variables. Random blood glucose was nearly identical between the cigarette-smoking group and vaping group, with values of 114.30 ± 17.85 mg/dL and 114.63 ± 18.87 mg/dL, respectively. Estimated VO_2max was also similar between groups, measuring 37.24 ± 2.41 mL/kg/min in the cigarette-smoking group and 37.39 ± 2.28 mL/kg/min in the vaping group. Baseline oxygen saturation, heart rate, recovery heart rate, and respiratory rate also showed no statistically significant between-group differences. These findings indicate that the two groups were physiologically comparable before acute exposure assessment and follow-up evaluation. Baseline comparisons are shown in Table 3.

Table 3. Between-Group Comparison of Physiological Variables at Baseline

Variable	Cigarette-Smoking Group, Mean ± SD	Vaping Group, Mean ± SD	Cigarette Mean Rank	Vaping Mean Rank	p-value
RBS, mg/dL	114.30 ± 17.85	114.63 ± 18.87	80.20	78.80	0.847
VO_2max, mL/kg/min	37.24 ± 2.41	37.39 ± 2.28	76.34	82.66	0.675
Systolic BP, mmHg	118.35 ± 5.70	117.53 ± 8.87	78.87	80.13	0.489
Diastolic BP, mmHg	80.63 ± 2.70	82.15 ± 8.19	77.81	88.19	0.120
SpO_2, %	97.15 ± 1.42	97.22 ± 1.36	78.65	80.35	0.775
HR, bpm	78.33 ± 5.19	77.75 ± 5.04	82.66	76.34	0.475
RHR, bpm	69.58 ± 5.26	69.51 ± 5.27	79.93	79.07	0.928
RR, breaths/min	13.87 ± 1.44	13.76 ± 1.54	81.46	77.54	0.632

Immediately after smoking or vaping exposure, random blood glucose increased in both groups, but the rise was greater in the vaping group. The cigarette-smoking group had an immediate post-exposure RBS of 118.09 ± 18.55 mg/dL, while the vaping group had a higher value of 124.57 ± 15.92 mg/dL. This between-group difference was statistically significant, with a higher mean rank in the vaping group. VO_2max, systolic blood pressure, diastolic blood pressure, and oxygen saturation did not show statistically significant immediate between-group differences. The available immediate post-exposure findings are presented in Table 4; however, the manuscript source table appears incomplete for some variables, so only clearly available values are reported here.

Table 4. Between-Group Comparison of Physiological Variables Immediately After Smoking or Vaping

Variable	Cigarette-Smoking Group, Mean ± SD	Vaping Group, Mean ± SD	Cigarette Mean Rank	Vaping Mean Rank	p-value
RBS, mg/dL	118.09 ± 18.55	124.57 ± 15.92	66.27	92.73	<0.001
VO_2max, mL/kg/min	38.16 ± 2.21	37.66 ± 2.21	76.34	82.66	0.382
Systolic BP, mmHg	117.59 ± 5.30	116.77 ± 8.84	78.85	80.15	0.479
Diastolic BP, mmHg	80.51 ± 2.61	81.90 ± 6.85	76.99	80.26	0.093
SpO_2, %	97.14 ± 1.44	97.23 ± 1.37	78.24	—	0.692

At the 1-month follow-up, most physiological variables remained statistically comparable between the cigarette-smoking and vaping groups, but two clinically important differences emerged. Oxygen saturation was significantly lower in the vaping group, with a mean SpO_2 of 88.82 ± 8.64%, compared with 93.71 ± 6.89% in the cigarette-smoking group. Respiratory rate was significantly higher in the cigarette-smoking group, measuring 19.03 ± 2.21 breaths/min compared with 17.01 ± 2.93 breaths/min in the vaping group. Random blood glucose, VO_2max, systolic and diastolic blood pressure, heart rate, and recovery heart rate did not show statistically significant between-group differences at this time point. These findings are presented in Table 5.

Table 5. Between-Group Comparison of Physiological Variables at 1 Month

Variable	Cigarette-Smoking Group, Mean ± SD	Vaping Group, Mean ± SD	Cigarette Mean Rank	Vaping Mean Rank	p-value
RBS, mg/dL	109.51 ± 12.32	110.00 ± 19.18	81.91	77.09	0.503
VO_2max, mL/kg/min	37.69 ± 2.42	37.45 ± 2.35	81.15	77.85	0.532
Systolic BP, mmHg	117.03 ± 5.46	116.08 ± 8.76	79.39	79.61	0.415
Diastolic BP, mmHg	80.70 ± 2.74	82.09 ± 6.82	77.02	81.98	0.094
SpO_2, %	93.71 ± 6.89	88.82 ± 8.64	90.37	68.63	0.002
HR, bpm	77.38 ± 4.95	77.63 ± 4.91	77.85	81.15	0.747
RHR, bpm	69.70 ± 5.32	69.51 ± 5.27	80.46	78.54	0.822
RR, breaths/min	19.03 ± 2.21	17.01 ± 2.93	94.42	64.48	0.001

At the 2-month follow-up, between-group differences were no longer statistically significant for any measured physiological variable. Random blood glucose declined in both groups, reaching 103.62 ± 8.01 mg/dL in the cigarette-smoking group and 101.29 ± 14.43 mg/dL in the vaping group. Estimated VO_2max was slightly higher in the cigarette-smoking group at 38.83 ± 1.29 mL/kg/min compared with 38.49 ± 1.61 mL/kg/min in the vaping group, but this difference was not statistically significant. Oxygen saturation improved compared with the 1-month values, particularly in the vaping group, reaching 96.08 ± 4.70%. Respiratory rate was almost identical between groups at 2 months. These findings suggest that the most prominent between-group differences were observed immediately after exposure for RBS and at 1 month for SpO_2 and respiratory rate. The 2-month comparisons are presented in Table 6.

Table 6. Between-Group Comparison of Physiological Variables at 2 Months

Variable	Cigarette-Smoking Group, Mean ± SD	Vaping Group, Mean ± SD	Cigarette Mean Rank	Vaping Mean Rank	p-value
RBS, mg/dL	103.62 ± 8.01	101.29 ± 14.43	80.72	78.28	0.732
VO_2max, mL/kg/min	38.83 ± 1.29	38.49 ± 1.61	79.93	79.47	0.145
Systolic BP, mmHg	117.53 ± 5.77	116.33 ± 9.12	80.34	78.64	0.323
Diastolic BP, mmHg	80.82 ± 2.46	81.20 ± 4.45	79.43	79.57	0.508
SpO_2, %	96.97 ± 1.44	96.08 ± 4.70	81.36	77.64	0.106
HR, bpm	74.87 ± 2.25	75.37 ± 3.11	77.49	81.51	0.254
RHR, bpm	68.90 ± 3.75	69.61 ± 5.03	75.91	83.00	0.317
RR, breaths/min	18.84 ± 2.19	18.75 ± 2.19	79.90	78.09	0.800

Within the cigarette-smoking group, repeated assessment showed statistically significant temporal changes in random blood glucose, heart rate, recovery heart rate, VO_2max, and oxygen saturation. Random blood glucose increased immediately after cigarette smoking from 114.30 ± 17.85 mg/dL to 118.08 ± 18.55 mg/dL and then declined to 109.51 ± 12.32 mg/dL at 1 month and 103.62 ± 8.01 mg/dL at 2 months. Heart rate declined from 78.32 ± 5.19 bpm at baseline to 74.87 ± 2.24 bpm at 2 months. Estimated VO_2max increased from 37.23 ± 2.40 mL/kg/min at baseline to 38.82 ± 1.29 mL/kg/min at 2 months. Systolic and diastolic blood pressure remained statistically stable over time. These within-group findings are summarized in Table 7.

Table 7. Longitudinal Changes in Physiological Variables Within the Cigarette-Smoking Group

Variable	Baseline, Mean ± SD	Immediate Post-Smoking, Mean ± SD	1 Month, Mean ± SD	2 Months, Mean ± SD	p-value
RBS, mg/dL	114.30 ± 17.85	118.08 ± 18.55	109.51 ± 12.32	103.62 ± 8.01	0.001
Systolic BP, mmHg	118.35 ± 5.70	117.59 ± 5.30	117.02 ± 5.46	117.53 ± 5.76	0.605

Variable	Baseline, Mean ± SD	Immediate Post-Smoking, Mean ± SD	1 Month, Mean ± SD	2 Months, Mean ± SD	p-value
Diastolic BP, mmHg	80.63 ± 2.69	80.50 ± 2.60	80.69 ± 2.74	80.82 ± 2.45	0.426
HR, bpm	78.32 ± 5.19	76.35 ± 4.25	77.37 ± 4.95	74.87 ± 2.24	0.002
RHR, bpm	69.58 ± 5.26	68.79 ± 3.66	69.69 ± 5.32	68.89 ± 3.75	0.001
VO_2max, mL/kg/min	37.23 ± 2.40	38.15 ± 2.20	37.68 ± 2.42	38.82 ± 1.29	0.001
SpO_2, %	97.15 ± 1.42	97.13 ± 1.43	93.70 ± 6.88	96.97 ± 1.44	0.001

Within the vaping group, random blood glucose showed a significant temporal pattern, rising from 114.63 ± 18.86 mg/dL at baseline to 124.56 ± 15.91 mg/dL immediately after vaping, followed by a reduction to 110.00 ± 19.17 mg/dL at 1 month and 101.29 ± 14.43 mg/dL at 2 months. Heart rate also decreased over time, from 77.74 ± 5.03 bpm at baseline to 75.36 ± 3.13 bpm at 2 months. VO_2max increased from 37.39 ± 2.28 mL/kg/min at baseline to 38.48 ± 1.60 mL/kg/min at 2 months. Oxygen saturation showed the most notable fluctuation, declining from 97.21 ± 1.35% at baseline to 88.82 ± 8.64% at 1 month before improving to 96.07 ± 4.69% at 2 months. Systolic blood pressure remained stable, whereas diastolic blood pressure showed a statistically significant temporal change. These findings are shown in Table 8.

Table 8. Longitudinal Changes in Physiological Variables Within the Vaping Group

Variable	Baseline, Mean ± SD	Immediate Post-Vaping, Mean ± SD	1 Month, Mean ± SD	2 Months, Mean ± SD	p-value
RBS, mg/dL	114.63 ± 18.86	124.56 ± 15.91	110.00 ± 19.17	101.29 ± 14.43	0.001
Systolic BP, mmHg	117.53 ± 8.87	116.77 ± 8.84	116.32 ± 9.11	116.07 ± 8.75	0.819
Diastolic BP, mmHg	82.15 ± 8.19	81.89 ± 6.85	82.08 ± 6.82	81.20 ± 4.45	0.001
HR, bpm	77.74 ± 5.03	77.16 ± 4.63	77.63 ± 4.91	75.36 ± 3.13	0.002
RHR, bpm	69.50 ± 5.27	—	69.50 ± 5.27	69.60 ± 5.03	0.001
VO_2max, mL/kg/min	37.39 ± 2.28	37.65 ± 2.21	37.44 ± 2.34	38.48 ± 1.60	0.006
SpO_2, %	97.21 ± 1.35	97.22 ± 1.36	88.82 ± 8.64	96.07 ± 4.69	0.001

Mixed ANOVA demonstrated a statistically significant time effect for random blood glucose, diastolic blood pressure, recovery heart rate, VO_2max, and oxygen saturation. Random blood glucose showed a significant temporal change with $F = 51.37$, $p < 0.001$, and $\eta^2 = 0.250$, indicating a moderate-to-large effect over time. Diastolic blood pressure also changed significantly over time with $F = 24.255$, $p = 0.001$, and $\eta^2 = 0.136$. VO_2max demonstrated the largest temporal effect, with $F = 188.726$, $p < 0.001$, and $\eta^2 = 0.548$, indicating a large change across repeated measurements. Oxygen saturation also showed a significant temporal effect, with $F = 20.042$, $p < 0.001$, and $\eta^2 = 0.239$. In contrast, systolic blood pressure and heart rate did not show significant overall time effects in the mixed ANOVA model. These findings are presented in Table 9.

Table 9. Mixed ANOVA Summary for Time Effects Across Physiological Variables

Variable	F-value	df	p-value	η^2
RBS	51.37	2.548	<0.001	0.250
Systolic BP	0.201	3.000	0.895	0.001
Diastolic BP	24.255	2.961	0.001	0.136
HR	0.039	2.725	0.985	0.000
RHR	11.585	2.338	<0.001	0.059
VO_2max	188.726	2.725	<0.001	0.548
SpO_2	20.042	1.209	<0.001	0.239

Overall, the results indicate that the cigarette-smoking and vaping groups were comparable at baseline for all measured variables. The vaping group showed a greater immediate rise in random blood glucose compared with the cigarette-smoking group, while the cigarette-smoking group showed a higher respiratory rate at 1 month. The vaping group demonstrated a marked reduction in oxygen saturation at 1 month, followed by partial recovery at 2 months. Blood pressure remained relatively stable between groups across follow-up, while VO_2 max showed small but statistically significant longitudinal improvement within both groups. These findings suggest that cigarette smoking and vaping may produce different short-term physiological response patterns, particularly for blood glucose, oxygen

saturation, and respiratory rate, while showing broadly similar trends for blood pressure, heart rate, and cardiopulmonary endurance over the observed follow-up period.

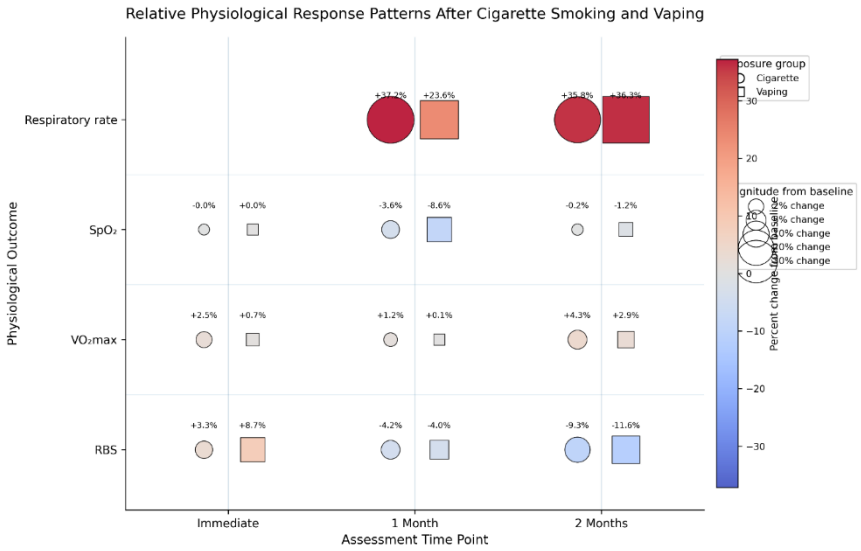

Figure 1. Relative Physiological Response Patterns After Cigarette Smoking and Vaping

The derived response-pattern figure shows that vaping produced the larger immediate glycemic response, with random blood glucose increasing by 8.7% from baseline compared with 3.3% after cigarette smoking. By 2 months, RBS declined below baseline in both groups, with a larger relative reduction in the vaping group (−11.6%) than in the cigarette-smoking group (−9.3%). The most prominent respiratory divergence occurred at 1 month, where SpO_2 decreased by 8.6% from baseline in the vaping group compared with 3.6% in the cigarette-smoking group, while respiratory rate increased more sharply in the cigarette-smoking group (+37.2%) than in the vaping group (+23.6%). At 2 months, respiratory rate remained elevated in both groups, increasing by 35.8% in the cigarette-smoking group and 36.3% in the vaping group, whereas VO_2max showed only modest improvement, rising by 4.3% and 2.9%, respectively. This pattern suggests that vaping was associated with a stronger acute metabolic shift and a larger transient oxygen-saturation reduction, while cigarette smoking showed a stronger early respiratory-rate response; however, both exposures demonstrated persistent respiratory-rate elevation over follow-up.

DISCUSSION

The present study compared longitudinal changes in blood glucose and cardiopulmonary parameters between young male cigarette smokers and vape users. At baseline, both groups were broadly comparable across random blood glucose, estimated VO_2max, blood pressure, oxygen saturation, heart rate, recovery heart rate, and respiratory rate, indicating that the subsequent differences were less likely to be explained by major baseline physiological imbalance. The most notable immediate finding was the greater post-exposure rise in random blood glucose among vape users compared with cigarette smokers, with values increasing from 114.63 ± 18.86 mg/dL to 124.56 ± 15.91 mg/dL in the vaping group, compared with an increase from 114.30 ± 17.85 mg/dL to 118.08 ± 18.55 mg/dL in the cigarette-smoking group. This suggests that vaping may be associated with a stronger acute glycemic response in this sample, although interpretation should remain cautious because random blood glucose is influenced by meal timing, physical activity, stress, caffeine intake, and time since last nicotine exposure. Nicotine-mediated sympathetic activation may explain this acute increase, as catecholamine release can increase hepatic glucose output and reduce insulin sensitivity, producing short-term elevations in circulating glucose (15–17).

The immediate rise in random blood glucose after vaping is clinically relevant because e-cigarettes are often perceived as metabolically safer than conventional cigarettes. Although vaping avoids tobacco

combustion, it may still deliver nicotine efficiently and expose users to aerosolized compounds that can influence autonomic and metabolic function. Previous work has shown that e-cigarette exposure can produce acute vascular, oxidative, and autonomic changes, although the magnitude and direction of these changes vary according to nicotine concentration, device characteristics, user behavior, and exposure duration (13,18,19). In the present study, random blood glucose declined below baseline by 2 months in both groups, reaching 103.62 ± 8.01 mg/dL in cigarette smokers and 101.29 ± 14.43 mg/dL in vape users. This downward trend should not be interpreted as a beneficial metabolic effect of smoking or vaping; rather, it may reflect variability in random glucose measurement, differences in recent dietary intake, adaptation, regression toward the mean, or unmeasured behavioral factors during follow-up (18-23).

Cardiopulmonary endurance, estimated through VO_2max, showed small but statistically significant longitudinal changes within both groups. In the cigarette-smoking group, VO_2max increased from 37.23 ± 2.40 mL/kg/min at baseline to 38.82 ± 1.29 mL/kg/min at 2 months, while in the vaping group it increased from 37.39 ± 2.28 mL/kg/min to 38.48 ± 1.60 mL/kg/min. Although the mixed ANOVA indicated a large time effect for VO_2max, the absolute magnitude of change was modest, and between-group comparisons were not statistically significant at any time point. Therefore, these findings should be interpreted as small longitudinal variation in estimated aerobic capacity rather than evidence that either cigarette smoking or vaping improves cardiopulmonary endurance. Because the Queen's College Step Test estimates VO_2max using recovery heart rate, changes in autonomic tone, test familiarity, motivation, and recovery response may affect calculated VO_2max values. Prior studies have linked habitual smoking with poorer cardiopulmonary function and reduced exercise capacity, but the short follow-up duration and absence of a non-smoking/non-vaping control group in the present study limit causal interpretation (24-29).

Blood pressure remained relatively stable between groups across the study period. Systolic blood pressure showed no significant longitudinal effect, and between-group differences were non-significant at baseline, immediately after exposure, 1 month, and 2 months. Diastolic blood pressure demonstrated a statistically significant temporal effect in the mixed analysis, but the absolute values remained within a narrow range, suggesting limited clinical change over the observed period. These findings partly align with studies reporting that smoking and vaping may produce acute cardiovascular responses, including changes in heart rate, blood pressure, arterial stiffness, and vascular function, but such effects may be transient and influenced by nicotine dose, exposure timing, and participant characteristics (30-36). The present findings therefore suggest that in young males without known cardiovascular disease, resting blood pressure may remain relatively stable over short follow-up, even when other physiological variables fluctuate (37-43).

Oxygen saturation showed one of the most clinically striking findings. At 1 month, the vaping group had a markedly lower mean SpO_2 of 88.82 ± 8.64%, compared with 93.71 ± 6.89% in the cigarette-smoking group, while baseline values were nearly identical between groups at approximately 97%. By 2 months, oxygen saturation improved in both groups, reaching 96.97 ± 1.44% in cigarette smokers and 96.08 ± 4.70% in vape users. This transient reduction in SpO_2 among vape users may indicate short-term respiratory compromise, airway irritation, ventilation-perfusion mismatch, or measurement variability. Because a mean SpO_2 below 90% is unexpectedly low in young adults without known respiratory disease, this finding requires verification through raw-data checking, outlier analysis, device calibration review, and confirmation of whether participants had acute respiratory illness or measurement artifacts during the 1-month assessment. Nevertheless, the observation is consistent with concerns raised in previous literature that e-cigarette aerosol exposure may affect respiratory physiology and pulmonary function, even when long-term consequences remain incompletely defined (44-51).

Respiratory rate showed a different response pattern. At baseline, both groups had similar respiratory rates, but at 1 month the cigarette-smoking group had a significantly higher respiratory rate than the

vaping group, with values of 19.03 ± 2.21 versus 17.01 ± 2.93 breaths/min. By 2 months, respiratory rate remained elevated in both groups and became nearly identical, measuring 18.84 ± 2.19 breaths/min in cigarette smokers and 18.75 ± 2.19 breaths/min in vape users. This pattern suggests that cigarette smoking may be associated with a stronger early respiratory-rate response, while both exposures may be associated with sustained respiratory activation over follow-up. Cigarette smoke contains combustion products, particulate matter, carbon monoxide, oxidants, and airway irritants that can increase respiratory drive and contribute to airway inflammation. Vaping aerosols may contain fewer combustion-related toxicants but can still expose the respiratory tract to nicotine, flavoring agents, aldehydes, and fine particles, which may explain overlapping respiratory effects between the two groups (17,22,23, 52-56).

Heart rate and recovery heart rate did not show meaningful between-group differences, although both demonstrated some within-group temporal variation. In the vaping group, heart rate decreased from 77.74 ± 5.03 bpm at baseline to 75.36 ± 3.13 bpm at 2 months, while in the cigarette-smoking group it decreased from 78.32 ± 5.19 bpm to 74.87 ± 2.24 bpm. Recovery heart rate remained within a narrow range in both groups. These findings are consistent with reports that vaping and cigarette smoking may influence autonomic function, although measured heart-rate responses vary according to acute versus chronic exposure, nicotine concentration, and timing of assessment (19). In the present study, the small absolute differences suggest limited clinical separation between cigarette smoking and vaping for resting heart rate and recovery heart rate over the short follow-up period (9, 57, 58).

When considered together, the findings suggest that cigarette smoking and vaping were associated with different physiological response profiles rather than a uniform pattern across all outcomes. Vaping was associated with a greater immediate rise in random blood glucose and a marked transient decrease in oxygen saturation at 1 month, whereas cigarette smoking was associated with a higher respiratory rate at 1 month. Blood pressure, heart rate, recovery heart rate, and estimated VO_2max were broadly similar between groups across most time points. These results support the view that vaping should not be considered physiologically inert, especially among young users who may perceive it as a harmless alternative to cigarettes. At the same time, the findings do not establish that vaping is uniformly more harmful than cigarette smoking; instead, they indicate that each exposure may affect different cardiometabolic and respiratory parameters in distinct ways.

The study has several strengths. It addressed a timely clinical and public health question in a young male population, used repeated measurements rather than a single cross-sectional assessment, and compared multiple physiological outcomes, including glucose, oxygen saturation, respiratory rate, blood pressure, heart rate, recovery heart rate, and estimated VO_2 max. The equal group sizes also improved balance for between-group comparison. However, several limitations must be acknowledged. The study did not include a non-smoking and non-vaping control group, which limits the ability to distinguish exposure-related changes from natural variation over time. Exposure classification depended on reported smoking or vaping behavior, and nicotine exposure was not biochemically verified using cotinine or similar biomarkers. Important confounders such as nicotine concentration, cigarette quantity, vaping device type, e-liquid composition, dual use, caffeine intake, recent food intake, physical activity, sleep, stress, and time of day were not fully controlled. The use of random blood glucose rather than fasting glucose or HbA1c limits metabolic interpretation. The follow-up duration was short, and longer observation is needed to determine whether the observed changes persist, worsen, or normalize over time.

Another important methodological consideration is the statistical approach. Because the data were reported as non-normally distributed, non-parametric methods were appropriate for between-group comparisons; however, repeated-measures and mixed ANOVA require careful assumption checking or robust alternatives. Future analyses should consider linear mixed-effects models or generalized estimating approaches that can incorporate repeated measurements, baseline adjustment, missing data

handling, and confounder control. Reporting confidence intervals and effect sizes for all group differences would also improve clinical interpretability. The unexpectedly low SpO_2 values in the vaping group at 1 month should be specifically examined through sensitivity analysis, including analysis with and without extreme values (54).

CONCLUSION

In conclusion, this comparative longitudinal study showed that cigarette smoking and vaping were associated with distinct short-term physiological response patterns among young males. Both groups were comparable at baseline, but vaping produced a greater immediate increase in random blood glucose, rising from 114.63 ± 18.86 mg/dL to 124.56 ± 15.91 mg/dL, whereas cigarette smoking showed a smaller increase from 114.30 ± 17.85 mg/dL to 118.08 ± 18.55 mg/dL. At 1 month, the vaping group demonstrated a marked reduction in oxygen saturation (88.82 ± 8.64%) compared with the cigarette-smoking group (93.71 ± 6.89%), while the cigarette-smoking group showed a higher respiratory rate (19.03 ± 2.21 breaths/min) than the vaping group (17.01 ± 2.93 breaths/min). Blood pressure, heart rate, recovery heart rate, and estimated VO_2 max remained broadly similar between groups across most time points, although both groups showed significant longitudinal variation in selected outcomes. These findings suggest that vaping should not be considered physiologically harmless, as it may be associated with acute metabolic disturbance and transient oxygenation changes, while cigarette smoking may exert a stronger early respiratory-rate response. However, because the study lacked a non-user control group and did not fully control nicotine dose, dietary timing, physical activity, or vaping-device characteristics, the findings should be interpreted cautiously and confirmed through larger controlled studies with longer follow-up and biochemical verification of nicotine exposure.

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