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Physiological Responses to KN95 Masks Use After Moderate-Intensity Activity (5-Minute Recovery): A Randomized Controlled Trial

Machrumnizar Machrumnizar, Rulliana Agustin, Nurul Amalia

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International Journal of TROPICAL DISEASE & Health

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Physiological Responses to KN95 Masks Use After Moderate-Intensity Activity (5-Minute Recovery): A Randomized Controlled Trial

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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Abstract

Aims: To evaluate the cardiopulmonary effects of wearing KN95 respirators compared with a standard surgical mask during moderate-intensity outdoor cycling, and to explore potential sex-based differences in physiological responses.
Study Design: This was a randomized parallel-group controlled trial conducted in an outdoor field environment at the Sudirman Central Business District (SCBD), Jakarta, Indonesia, from October to November 2022.
Methodology: Thirty-two healthy, physically active adults were randomly assigned (1:1) to wear either a KN95 mask (n = 16) or a standard surgical mask (n = 16) while cycling 8 km at a constant speed of 15 km/h

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(~30 minutes). Heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2) were measured five minutes post-exercise. Independent t-tests compared groups, and ANCOVA adjusted for age, sex, and body mass index (BMI). Effect sizes were calculated using Cohen's d and partial η^2. Gender-stratified analyses were conducted exploratorily.
Results: Compared with a standard surgical mask, KN95 use significantly increased HR (+14.4 bpm; $p = 0.003$; $d = 1.15$) and RR (+5.1 breaths/min; $p = 0.013$; $d = 0.94$), and reduced SpO_2 (–0.8%; $p = 0.019$; $d = 0.88$). Adjusted analyses confirmed these associations (partial η^2 range: 0.189–0.295). All effect sizes were large. Oxygen saturation remained within clinically acceptable ranges in both groups. Exploratory subgroup analyses suggested sex-related trends in physiological responses; however, no statistically significant interaction effects were observed, and these findings should be interpreted cautiously given the limited sample size.
Conclusion: KN95 respirators impose measurable cardiopulmonary strain during moderate-intensity cycling compared with standard surgical masks. While these effects were physiologically tolerable for healthy adults during short-duration activity, the findings have implications for individuals with limited cardiopulmonary reserves and for public health guidance in contexts requiring both infection control and physical activity promotion.

Keywords: KN95 mask; physical activity physiology; cardiopulmonary response; cycling; oxygen saturation; public health.

1. Introduction

Global public health policies were reshaped by the COVID-19 pandemic, including widespread recommendations for mask usage in both community and physical activity settings (Vito et al., 2022). Despite their effectiveness in preventing the spread of viruses, face masks have aroused controversy when worn during physical activity due to possible effects on breathing, oxygen exchange, and performance during physical activity (Boulos et al., 2023; Howard et al., 2021). Cycling and other aerobic physical activities require a high ventilatory capacity, raising concern about the possibility that airflow resistance from masks may change cardiopulmonary physiological responses (Han et al., 2023).

Several studies have examined the impact of face mask use on cardiopulmonary responses during exercise. Fikenzer et al. (2020) demonstrated that surgical and FFP2/N95 masks were associated with reduced cardiopulmonary exercise capacity during graded exercise testing, while do Prado et al. (2022) reported alterations in cardiorespiratory parameters during aerobic exercise with protective mask use. Nevertheless, existing studies largely focus on laboratory-based exercise protocols or peak performance outcomes, leaving limited evidence on physiological responses during moderate-intensity activity conducted under applied, real-world conditions relevant to public health and occupational safety.

Previous research on mask use during physical activity has yielded inconsistent findings. Some studies report increased dyspnea, elevated heart rate, and reduced oxygen saturation during moderate-intensity exercise, whereas others suggest minimal physiological effects (Lott et al., 2022; Zheng et al., 2023; Asín-Izquierdo et al., 2022). Moreover, most investigations have focused on surgical or cloth masks. Evidence regarding respirator-type masks, particularly KN95 masks with higher filtration efficiency and tighter fit, remains limited. This gap is critical, as KN95 masks may impose greater breathing resistance compared to non-KN95 masks, potentially influencing physical activity tolerance in active individuals. Understanding these effects is essential not only for infection prevention during pandemics, but also for broader contexts such as air pollution exposure and protection of vulnerable populations (Lai et al., 2024; Duncan et al., 2021). Public health recommendations must balance protective efficacy with physiological safety and user comfort, particularly in active adults who may regularly engage in physical activity while wearing masks.

To our knowledge, few studies have directly compared the physiological impact of KN95 versus non-KN95 masks during controlled physical activity (Mezghani et al., 2023; Keely et al., 2021). This study addresses this evidence gap by evaluating cardiopulmonary responses, including oxygen saturation, heart rate, respiratory rate, and perceived exertion, during moderate-intensity cycling in active adults. By adopting a field-based, outdoor approach, this study seeks to enhance ecological validity and provide evidence relevant to routine scenarios such as occupational tasks, active commuting, and recreational exercise, while also informing the design of future, more controlled trials assessing the tolerability and safety of high-filtration mask use.

2. Material and Methods

2.1 Study Design and Participants

The physiological effects of wearing KN95 versus a standard surgical (non-KN95) mask during moderate-intensity cycling were compared in this study using a randomized parallel group-controlled trial. Participants were recruited using non-probability convenience sampling from community cycling groups in Jakarta. The study was conducted at Lot 8 Sudirman Central Business District (SCBD), Jakarta, between October and November 2022, under standardized supervision by the research team.

A total of 32 healthy adults (20 men and 12 women) were enrolled. Eligible participants were aged 15–64 years, physically active (cycling at least three times per week for ≥30 minutes per session), and reported no history of chronic cardiopulmonary disease. Exclusion criteria included current smoking, acute respiratory illness within the previous two weeks, alcohol or recreational drug use, and any medical contraindication to moderate-intensity physical activity. Baseline characteristics, including age, sex, body weight, height, and body mass index (BMI), were recorded prior to randomization. Participants were then randomly allocated in a 1:1 ratio to either the KN95 mask group (n = 16) or the standard surgical mask group (n = 16) using a computer-generated randomization sequence. Due to the nature of the intervention, blinding of participants and investigators was not feasible.

2.2 Physical Activity Protocol

All participants completed a standardized outdoor cycling protocol using their own bicycles. Each participant was instructed to cycle continuously at a constant speed of 15 km/h over a distance of 8 km, corresponding to approximately 30 minutes of moderate-intensity physical activity. The cycling route was selected to minimize traffic interruptions while maintaining ecological validity representative of urban commuting conditions. Participants were instructed to maintain a steady pace throughout the session while wearing either a KN95 or a standard surgical (non-KN95) mask, according to their randomized group allocation. All masks were new, unused, and worn in accordance with manufacturer instructions to ensure consistency in fit and usage.

Physiological parameters—including heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2)—were assessed once, at 5 minutes following completion of the cycling activity, to evaluate early recovery responses. Measurements during active exercise were not conducted due to logistical and safety considerations in the outdoor setting. We acknowledge that physiological measurements obtained during early recovery may not fully capture the peak cardiopulmonary strain experienced during exercise, which is a limitation of this study. The cycling sessions were conducted in an outdoor urban environment under relatively stable conditions; however, ambient environmental variables, including temperature, relative humidity, and particulate matter (PM2.5), were not objectively monitored during testing. These factors may have influenced physiological responses and are therefore recognized as potential confounders.

2.3 Outcome Measurements

Physiological outcomes were evaluated as early recovery responses, assessed at a single time point, five minutes after completion of the cycling protocol. This time point was selected to ensure participant safety and measurement consistency in an outdoor exercise setting. Heart rate (HR) was measured using a chest strap heart rate monitor and recorded in beats per minute (bpm). Respiratory rate (RR) was assessed through manual counting of thoracic movements over one full minute and verified using a portable respiratory sensor, expressed as breaths per minute. Oxygen saturation (SpO_2) was measured using a validated fingertip pulse oximeter (Masimo Mighty Sat Rx) and recorded as a percentage. All physiological measurements were conducted by trained research personnel under standardized procedures to minimize inter-observer variability.

2.4 Statistical Analysis

Data were analyzed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics were summarized as mean ± standard deviation for continuous variables and frequencies (%) for categorical variables. Independent samples t-tests were used to compare physiological parameters (HR, RR, and SpO_2) between mask conditions, with homogeneity of variances assessed using Levene's test. Analysis of covariance (ANCOVA) was conducted to adjust for potential confounders, including age, sex, and body mass index (BMI). Effect sizes were calculated using Cohen's d for t-tests and partial η^2 for ANCOVA and interpreted according to conventional thresholds (small = 0.01, moderate = 0.06, large = 0.14). Exploratory sex-stratified analyses were performed to examine potential sex-based differences in physiological responses. A two-tailed p-value < 0.05 was considered statistically significant.

2.5 Ethical Consideration

The study protocol was reviewed and approved by the Research Ethics Committee of the Faculty of Medicine, Universitas Trisakti, (Approval No. 139/KER-FK/VII/2022). All study procedures were conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment, and participants were entirely voluntary, with the right to withdraw at any time without consequence. For participants aged under 18 years, written informed consent was obtained from parents or legal guardians, and written assent was obtained from the participants themselves prior to enrollment. Participant safety was ensured throughout the study through appropriate medical supervision and the availability of first-aid support during all study procedures.

3. Results and Discussion

A total of 32 participants (20 men, 12 women) were included in the analysis, with 16 assigned to the KN95 group and 16 to the standard surgical mask group. The mean age was 34.1 ± 1.6 years, and the mean BMI was 22.9 ± 0.1 kg/m². Baseline characteristics (age, sex, and BMI) were comparable between groups, with no significant differences observed (Table 1).

3.1 Cardiopulmonary Responses

Independent samples t-tests showed significant differences across all three physiological parameters (Table 2). Compared with standard surgical masks, KN95 masks were associated with higher heart rate (HR) and respiratory rate (RR) and lower oxygen saturation (SpO_2). Post-physical activity HR was significantly higher in the KN95 group compared to standard surgical mask (+14.4 bpm; p = 0.003), with a large effect size (Cohen's d = 1.15). Respiratory rate was also elevated (+5.1 breaths/min; p = 0.013; d = 0.94), while SpO_2 was significantly reduced (–0.8%; p = 0.019; d = –0.88). Levene's test confirmed homogeneity of variance across analyses. ANCOVA adjusted for age, sex, and BMI confirmed these associations, with moderate-to-large partial η^2 values across outcomes (Table 3). Effect size analysis indicated large effects for all parameters (Cohen's d > 0.8), underscoring the clinical relevance of these findings. These findings demonstrate measurable differences in cardiopulmonary parameters between KN95 and standard surgical mask conditions following moderate-intensity cycling.

Similar effects have been observed in studies of N95 or other high-filtration respirators, which increase breathing resistance and elevate HR and RR compared with surgical masks (Singla et al., 2022; Shui et al., 2022). In contrast, studies focusing on surgical or cloth masks have reported smaller or negligible effects (Shaw et al., 2021; Zheng et al., 2023), likely reflecting lower filtration efficiency and looser mask seals (Lott et al., 2022). A systematic review and meta-analysis by Engeroff et al. (2021) similarly demonstrated that high-filtration masks impair gas exchange and aerobic performance. Consistent with these findings, controlled exercise studies have shown that surgical and FFP2/N95 respirators reduce cardiopulmonary exercise capacity and alter cardiorespiratory responses compared with lower-resistance masks (Fikenzer et al., 2020; do Prado et al., 2022).

Table 1. Baseline demographic and physiological characteristics of study participants (n = 32)

Variable	Mean ± SD or n (%)	95% Confidence Interval for Mean
Sex		–
Male	20 (58.8%)	
Female	12 (35.3%)	
Age (years)	34.09 ± 1.556	30.92 – 37.27
Weight (kg)	80.55 ± 17.536	44.79 – 116.32
Height (cm)	165.88 ± 1.413	162.99 – 168.76
BMI (kg/m²)	22.85 ± 0.129	22.59 – 23.11
Heart Rate (bpm)	128.53 ± 2.534	123.36 – 133.70
Respiratory Rate (x/min)	30.94 ± 1.056	28.78 – 33.09
Oxygen saturation (SpO_2, %)	96.97 ± 0.177	96.61 – 97.33

Field-based evidence from clinical work environments further supports this interpretation. In a prospective cohort study conducted among healthy healthcare workers in an emergency department, Sanri et al. (2022) reported statistically significant changes in cardiopulmonary parameters associated with medical masks and filtering facepiece respirators, while values largely remained within clinically acceptable ranges during routine duties. Together with our findings, this highlights the importance of distinguishing statistical significance from clinical relevance when interpreting physiological responses to respirator use in real-world settings, where environmental exposure and task demands may amplify short-term cardiopulmonary strain. Although KN95 and N95 respirators are regulated under different standards, both achieve ≥95% filtration efficiency and exhibit broadly comparable airflow resistance, supporting the physiological relevance of comparisons with N95-based exercise studies.

Table 2. Unadjusted comparison of physiological parameters between KN95 and standard surgical mask groups after cycling (independent samples t-test with Cohen's d)

Variable	KN95 (n = 16)	standard surgical mask (n = 16)	Mean Difference	t (df)	p-value	95% CI for Difference	Cohen's d
HR (bpm)	135.75 ± 11.63	121.31 ± 13.35	+14.44	3.262 (30)	0.003	5.40 – 23.50	1.15
RR (breaths/min)	33.50 ± 5.60	28.38 ± 5.33	+5.13	2.653 (30)	0.013	1.18 – 9.07	0.94
SpO_2 (%)	96.56 ± 1.03	97.38 ± 0.81	-0.81	-2.484 (30)	0.019	-1.48 – -0.14	-0.88

Notes: Independent samples T-test with Cohen's d, p < 0.05
Values are expressed as mean ± standard deviation (SD). Cohen's d is interpreted as 0.2 = small, 0.5 = medium, and 0.8 = large effect size.

Table 3. Adjusted comparison of physiological parameters between KN95 and standard surgical mask groups after cycling (ANCOVA adjusted for age, sex, and BMI)

Variable	KN95 (Adjusted Mean ± SE)	Standard surgical mask (Adjusted Mean ± SE)	Mean Difference (95% CI)	p-value	Partial η²
HR (bpm)	136.0 ± 3.15	121.0 ± 3.15	+15.0 (5.83 – 24.13)	0.002	0.295
RR (breaths/min)	33.49 ± 1.44	28.39 ± 1.44	+5.1 (0.93 – 9.27)	0.018	0.189
SpO_2 (%)	96.56 ± 0.21	97.38 ± 0.21	–0.82 (–1.44 – –0.21)	0.011	0.218

Notes: Adjusted means were estimated using ANCOVA. The acronym SE stands for standard errors. Partial η² is interpreted as 0.01 = small, 0.06 = medium, and 0.14 = large effect size.

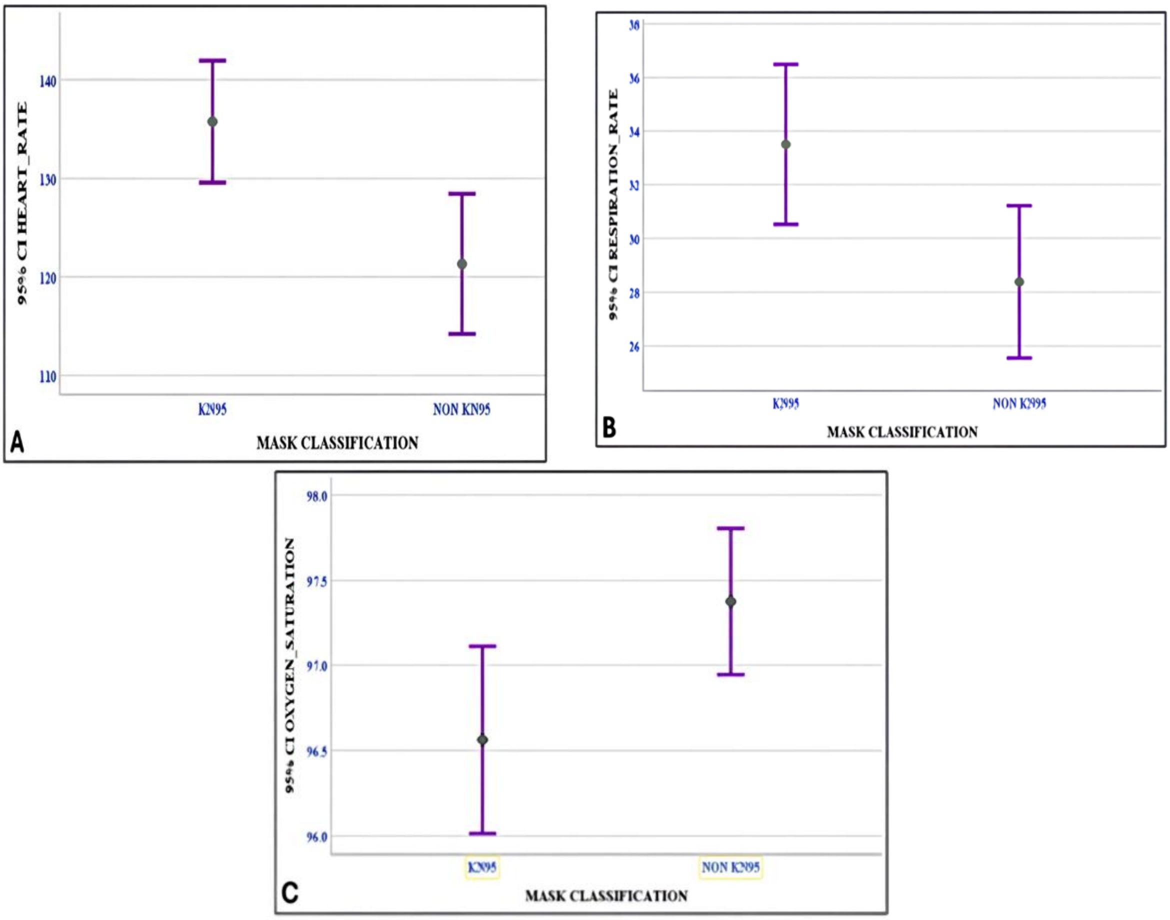

Fig. 1. Estimated marginal means (± SE) of heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2) in the KN95 and standard surgical mask (referred to as "non-KN95" in the figure labels) groups after cycling. Error bars represent standard errors

From a physiological standpoint, the elevated HR may reflects the increased cardiovascular workload mediated by sympathetic activation secondary to enhanced respiratory effort (Grassi & Drager, 2024). The higher RR represents compensatory hyperventilation to maintain alveolar ventilation against greater inspiratory resistance (Braga et al., 2023). The modest but significant decline in SpO_2 suggests impaired oxygen diffusion or delivery, possibly exacerbated by partial CO_2 rebreathing within the mask dead space. These mechanisms are consistent with prior reports that respirators may shift the ventilatory threshold, making the balance between oxygen supply and demand more fragile during physical activity (Han et al., 2023; Sukul et al., 2022). Although oxygenation remained within clinically acceptable ranges, the findings underscore that even moderate activity can elicit detectable strain when performed with KN95 masks (O'Driscoll Bret al., 2024; Han et al., 2023).

Clinically, these findings are particularly relevant for individuals with a reduced cardiopulmonary reserve. Patients with chronic respiratory diseases (e.g., asthma, COPD) or cardiovascular conditions may be less able to compensate for the additional ventilatory resistance imposed by KN95 masks, which may contribute to physical activity intolerance, dyspnea, or oxygen desaturation during physical activity (Rogliani et al., 2019; Jiang et al., 2025). Athletes and highly active individuals may also experience premature fatigue or performance impairment when training with high-filtration masks, especially at higher intensities where oxygen demand is greater (Hostrup & Bangsbo, 2017; Behrens et al., 2022). Beyond infection control, respirator-type masks are also advocated in polluted environments, where the trade-off between protection and physical activity capacity becomes important (Xu et al., 2020). Tailored recommendations—such as limiting strenuous outdoor physical activity with KN95 masks, promoting mask-free activity in low-risk or well-ventilated environments, or using alternative protective strategies—may help balance safety with physiological well-being across different populations (Greenhalgh et al., 2024).

Table 4. Subgroup analysis of physiological parameters by gender (estimated marginal means ± SE from ANCOVA)

Outcome	Gender	Mask	Mean ± SD	Mean Difference (95% CI)	p-value	Partial Eta Squared
HR (bpm)	Male	KN95	135.1 ± 11.2	+12.0 (0.45–23.55)	0.043	0.209 (moderate)
		standard surgical mask	123.1 ± 13.3			
	Female	KN95	136.8 ± 13.3	+18.5 (0.84 – 36.16)	0.042	0.353 (large)
		standard surgical mask	118.3 ± 14.2			
RR (breath/mim)	Male	KN95	33.4 ± 5.6	+5.1 (1.12 – 9.13) *	0.014	0.203 (moderate)
		standard surgical mask	28.3 ± 5.3			
	Female	KN95	33.6 ± 5.7	+5.2 (1.20 – 9.25) *	0.015	0.196 (moderate)
		standard surgical mask	28.4 ± 5.4			
SpO_2 **(%)**	Male	KN95	96.8 ± 0.9	-0.6 (-1.2 – -0.1) *	0.031	0.142 (moderate)
		standard surgical mask	97.4 ± 0.8			
	Female	KN95	96.3 ± 1.0	-1.0 (-1.6 – -0.4) *	0.004	0.278 (large)
		standard surgical mask	97.3 ± 0.8			

**Values expressed as mean ± standard deviation (SD). Between-group differences were tested using ANCOVA adjusted for covariates. *p < 0.05. Partial η² interpretation: 0.01 = small, 0.06 = moderate, 0.14 = large.*

3.2 Subgroup Analysis by Gender

Gender-stratified analyses reveal consistent patterns across groups (Table 4, Figure 2). Both men and women exhibited higher HR and RR with KN95 use compared with standard surgical mask, along with reduced SpO_2. The magnitude of change was more pronounced in women: HR increased by +18.5 bpm ($p = 0.042$, $\eta^2 = 0.353$, large effect) compared with +12.0 bpm in men ($p = 0.043$, $\eta^2 = 0.209$, moderate effect). Similarly, reductions in SpO_2 were also slightly greater in women (–1.0%; $p = 0.004$) than in men (–0.6%; $p = 0.031$). RR differences were similar across sexes (approximately +5 breaths/min).

Our gender-stratified analysis, although exploratory given the modest sample size, suggests that women may experience more pronounced physiological strain when exercising with KN95 masks, particularly in HR and SpO_2 responses. These trends may reflect underlying physiological differences. Women generally have smaller lung volumes, lower hemoglobin concentrations, and reduced cardiopulmonary reserve compared with men, which could amplify the impact of increased respiratory resistance imposed by KN95 masks and disproportionately challenge women's ventilatory and oxygen transport capacity (Molgat-Seon et al., 2018; Santisteban et al., 2022; Harms et al., 2008). Such physiological differences may amplify the impact of increased inspiratory resistance, disproportionately challenging ventilatory efficiency and oxygen transport in women. While we did not detect a statistically significant mask × gender interaction, the consistent patterns observed warrant attention, as they imply that women may experience relatively greater physiological burden under the tested conditions, although these observations should be interpreted cautiously given the exploratory nature of the analysis.

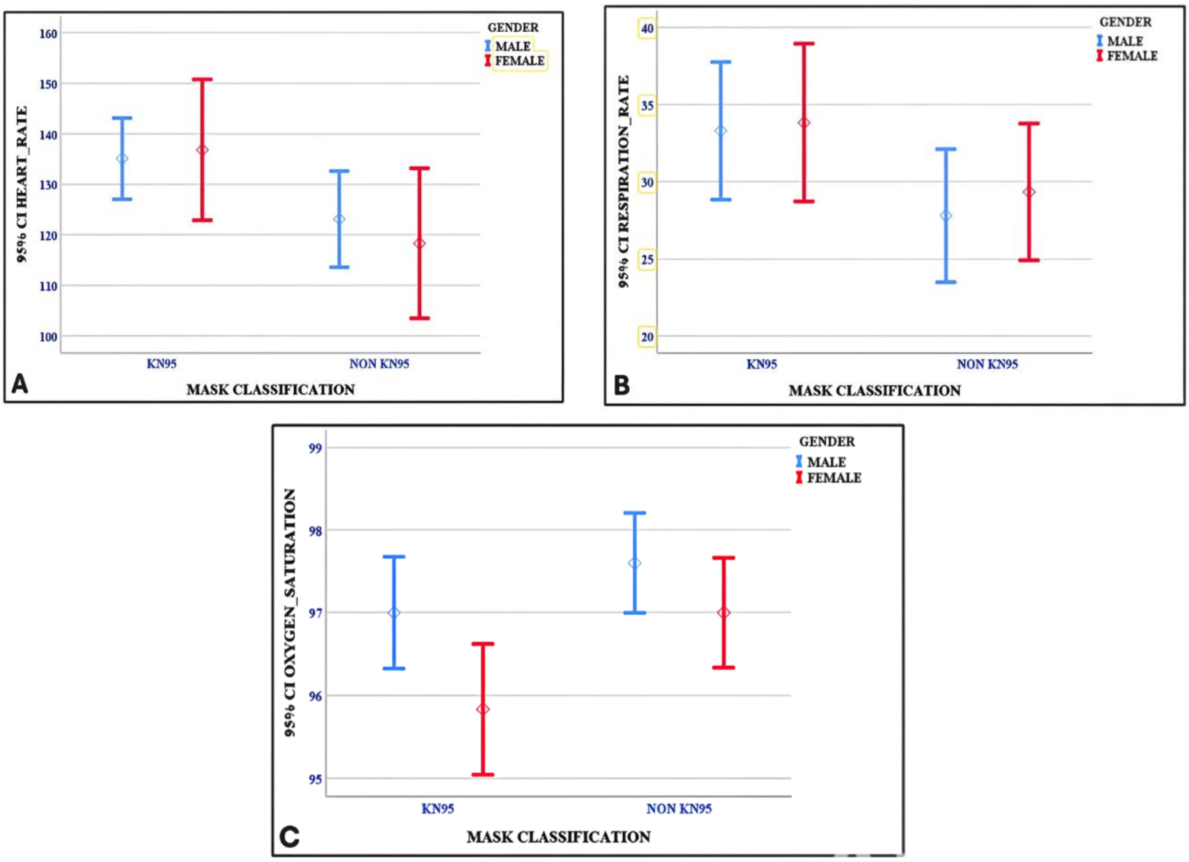

Fig. 2. Gender-stratified estimated marginal means (± SE) of heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2) in KN95 and standard surgical mask (referred to as "non-KN95" in the figure labels) groups

These findings add to the limited literature exploring sex-specific responses to mask use during physical activity. Most previous studies have not stratified by gender, focusing instead on overall averages (Engeroff et al., 2021; Mezghani et al., 2023). A recent systematic review by Asín-Izquierdo et al. (2022) emphasized that sex-based differences in ventilatory physiology may alter tolerance to mask use during exercise, but empirical field data remain limited. By demonstrating differential trends, our inquiry emphasizes the value of considering sex differences in both research and guideline development. In practical terms, women engaging in regular physical activity with KN95 masks—particularly in urban areas with high air pollution or during pandemics—may face relatively higher risks of discomfort or physiological burden (Zheng et al., 2023; Das et al., 2023). This has implications not only for athletic performance but also for occupational and community settings where women may engage in prolonged activity while masked. Tailoring mask recommendations to account for biological differences may therefore enhance both safety and adherence.

3.3 Public Health Implications

These findings carry practical implications for public health guidelines. KN95 masks provide superior protection against airborne pathogens and environmental pollutants, but their use during physical activity imposes measurable cardiopulmonary strain (O'Kelly et al., 2021). For healthy and active adults, this additional load is modest and unlikely to pose adverse outcomes during short-duration physical activity. However, for individuals with limited cardiopulmonary reserves, such as older adults, patients with chronic respiratory or cardiovascular disease, or those engaging in prolonged or high-intensity activity, the burden may become clinically relevant (Tesfaldet & Ndeh, 2022; MacIntyre et al., 2025).

Public health recommendations may need to balance infection control benefits with potential physiological burdens, particularly in contexts where physical activity is encouraged for health promotion. From an *urban health* perspective, this is especially relevant in Jakarta, where levels of fine particulate matter (PM2.5) often exceed WHO thresholds, making high-filtration masks advisable for protection against air pollution. Yet, the same masks may reduce exercise capacity and adherence to active commuting practices, such as cycling (Liu et al., 2020). These findings may inform discussions around adaptive recommendations—for example, encouraging lighter masks or mask-free exercise in low-risk, well-ventilated outdoor environments, while reserving KN95 use for periods of extreme pollution or elevated infection risk (Engeroff et al., 2021; Zheng et al., 2023).

Furthermore, gender-specific trends observed in this study suggest that women may experience greater physiological strain, underscoring the potential for tailored advice in occupational or community physical activity programs. Ultimately, incorporating physiological evidence into mask-related public health guidance will help optimize both safety and adherence. Clear communication of risks and benefits will empower individuals to make informed decisions about mask use during exercise, thereby supporting broader health promotion goals without compromising cardiopulmonary well-being (Farah et al., 2025; Wismans et al., 2022; Howard et al., 2021).

These implications should be interpreted considering the study's strengths and limitations. Strengths include randomized allocation, controlled physical activity intensity, and comprehensive adjustment for potential confounders, supported by both unadjusted and adjusted analyses. However, the modest sample size, which was determined based on feasibility and participant availability rather than an a priori power calculation, limits the statistical power to detect interaction effects, particularly in subgroup analyses such as sex-specific comparisons. Furthermore, the inclusion of only healthy adults restricts the generalizability of the findings to older populations or individuals with cardiopulmonary comorbidities. Physiological parameters were assessed only once during the early recovery phase, at five minutes of post-physical activity, which may have underestimated transient or peak cardiopulmonary strain experienced during exercise. Continuous physiological monitoring during activity would provide more precise estimates of physiological burden and should be considered in future studies. Finally, the study was limited to moderate-intensity cycling with a fixed duration, which may not reflect physiological responses during higher-intensity exercise, longer durations, or alternative physical activity modalities.

Further studies should explore long-term effects of mask use during physical activity, include more diverse populations such as older adults and individuals with chronic cardiopulmonary conditions, and assess subjective outcomes such as perceived exertion, comfort, and adherence. Additionally, continuous monitoring of cardiopulmonary parameters could clarify the temporal dynamics of cardiopulmonary adaptation to mask use.

4. Conclusion

KN95 mask use during moderate-intensity outdoor cycling was associated with higher heart rate and respiratory rate and modestly reduces oxygen saturation compared with standard surgical masks, with trends toward greater physiological impact in women. Although changes remained within clinically acceptable limits for healthy adults, they may be more relevant for individuals with limited cardiopulmonary reserve or during prolonged or higher-intensity activity. These findings highlight the need for public health recommendations that balance infection-control benefits with physiological safety, particularly in settings requiring both respiratory protection and physical activity.

Consent

As per international standards or university standards, Participants' written consent has been collected and preserved by the author(s).

Ethical Approval

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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Physiological Responses to KN95 Masks During Moderate-Intensity Activity: Public Health Implications

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ABSTRACT

Aims: To evaluate the cardiopulmonary effects of wearing KN95 respirators compared with non-KN95 surgical masks during moderate-intensity outdoor cycling, and to explore potential sex-based differences in physiological responses.
Study design: This was a randomized parallel-group controlled trial conducted in an outdoor field environment at the Sudirman Central Business District (SCBD), Jakarta, Indonesia, from October to November 2022.
Methodology: Thirty-two healthy, physically active adults were randomly assigned (1:1) to wear either a KN95 mask (n = 16) or a non-KN95 surgical mask (n = 16) while cycling 8 km at a constant speed of 15 km/h (~30 minutes). Heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2) were measured five minutes post-exercise. Independent t-tests compared groups, and ANCOVA adjusted for age, sex, and body mass index (BMI). Effect sizes were calculated using Cohen's d and partial η^2. Gender-stratified analyses were conducted exploratorily.
Results: Compared with non-KN95 masks, KN95 use significantly increased HR (+14.4 bpm; p = 0.003; d = 1.15) and RR (+5.1 breaths/min; p = 0.013; d = 0.94), and reduced SpO_2 (–0.8%; p = 0.019; d = 0.88). Adjusted analyses confirmed these associations (partial η^2 range: 0.189–0.295). All effect sizes were large. Oxygen saturation remained within clinically acceptable ranges in both groups. Gender-stratified analyses suggested more pronounced HR elevation and SpO_2 reduction in women, although interaction effects were not statistically significant.
Conclusion: KN95 respirators impose measurable cardiopulmonary strain during moderate-intensity cycling compared with surgical masks, with potentially greater effects in women. While physiologically tolerable for healthy adults during short-duration activity, these findings have implications for individuals with limited cardiopulmonary reserves and for public health guidance in settings requiring both infection control and physical activity promotion.

Keywords: KN95 mask; physical activity physiology; cardiopulmonary response; cycling; oxygen saturation; public health

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1. INTRODUCTION

Global public health policies were reshaped by the COVID-19 pandemic, including widespread recommendations for mask usage in both community and physical activity settings (Vito et al., 2022). Despite their effectiveness in preventing the spread of viruses, face masks have aroused controversy when worn during physical activity due to possible effects on breathing, oxygen exchange, and performance during physical activity (Boulos et al., 2023; Howard et al., 2021). Cycling and other aerobic physical activities require a high ventilatory capacity, raising concern about the possibility that airflow resistance from masks may change cardiopulmonary physiological responses (Han et al., 2023).

Previous research on mask usage during physical activity has yielded contradictory results. Some report increased dyspnea, elevated heart rate, and lower oxygen saturation following moderate-intensity physical activity, whereas others imply negligible physiological effects (Lott et al., 2022; Zheng et al., 2023; Asín-Izquierdo et al., 2022). However, most of these investigations have focused on surgical or cloth masks. Evidence regarding respirator-type masks, particularly KN95 masks with higher filtration efficiency and tighter fit, remains scarce. This creates a critical knowledge gap, as KN95 masks may impose greater breathing resistance compared to non-KN95 masks, potentially influencing physical activity tolerance in active individuals. Understanding these effects is essential not only for infection prevention during pandemics, but also for broader contexts such as air pollution exposure and protection of vulnerable populations (Lai et al., 2024; Duncan et al., 2021). Public health recommendations must balance protective efficacy with physiological safety and user comfort, particularly in active adults who may regularly engage in physical activity while wearing masks.

To our knowledge, few studies have directly compared the physiological impact of KN95 versus non-KN95 masks in controlled physical activity conditions (Mezghani et al., 2023; Keely et al., 2021). This study therefore addresses an important evidence gap by evaluating cardiopulmonary responses—including oxygen saturation, heart rate, respiratory rate, and perceived exertion—during moderate cycling in active adults. The findings are expected to provide evidence-based public health guidance on mask use during physical activity, ensuring both safety and practicality.

2. MATERIAL AND METHODS

2.1. Study Design and Participants

The physiological effects of wearing KN95 versus non-KN95 masks during moderate-intensity cycling were compared in this study using a randomized parallel group-controlled trial. In this investigation, non-random sampling strategies were utilized to pick samples that had previously satisfied the inclusion and exclusion criteria. The study was conducted at Lot 8 Sudirman Central Business District (SCBD), Jakarta, from October to November 2022, under supervision controlled by the research team.

A total of 32 healthy adult (20 men and 12 women) were recruited through community cycling groups in Jakarta. Eligible participants were aged 15–64 years, reported being physically active (cycling at least three times per week for ≥30 minutes per session), and absence history of chronic cardiopulmonary disease. Exclusion criteria included current smoking, acute respiratory illness within the past two weeks, use of alcohol or recreational drugs, and any contraindication to physical activity. Baseline characteristics, including age, sex, weight, height, and body mass index (BMI), were recorded before randomization.

Eligible participants who met the inclusion and exclusion criteria were randomly assigned in a 1:1 ratio to wear either a KN95 mask (n = 16) or a non-KN95 surgical mask (n = 16) during the cycling protocol.

2.2. Physical Activity Protocol

All participants performed a standardized outdoor cycling test using their bicycles under controlled environmental conditions. Each participant was instructed to cycle continuously at a constant speed of 15 km/h for a target distance of 8 km, corresponding to approximately 30 minutes of moderate-intensity physical activity. The route was selected to minimize traffic interruptions while reflecting real-world urban commuting conditions. Participants were instructed to maintain a steady pace throughout the session while wearing either a KN95 or a non-KN95 surgical mask according to their randomized allocation. Physiological outcomes—including heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2)—were measured once, at 5 minutes post-physical activity, to capture immediate recovery responses. Two mask types were tested: [1] a KN95 mask, providing ≥95% filtration efficiency with a tight fit; [2] a non-KN95 mask, a standard 3-ply surgical mask commonly used for daily activities. All masks were new, unused, and fitted according to the manufacturer's instructions to ensure consistency.

2.3. Outcome Measurements

Physiological outcomes were assessed at a single time point, five minutes after the completion of cycling. Heart rate (HR) was measured using a chest strap heart rate monitor, expressed in beats per minute (bpm). Respiratory rate (RR) was determined by manual observation of thoracic movements for one full minute, verified by a portable respiratory sensor, and expressed in breaths per minute. Oxygen saturation (SpO_2) was measured using a validated fingertip pulse oximeter (Masimo MightySat Rx) and expressed as a percentage of arterial oxygen saturation. All measurements were performed by trained research staff under standardized conditions to minimize inter-observer variability.

2.4. Statistical Analysis

Data were analyzed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics were reported as mean ± standard deviation for continuous variables and frequencies (%) for categorical variables. Independent samples t-tests were used to compare physiological parameters (HR, RR, and SpO_2) between mask conditions. Homogeneity of variances was verified using Levene's test. Analysis of covariance (ANCOVA) was performed to adjust for potential confounders including age, sex, and body mass index (BMI). Effect sizes were calculated using Cohen's d for t-tests and partial η^2 for ANCOVA, interpreted according to conventional thresholds (small = 0.01, moderate = 0.06, large = 0.14). Gender-stratified analyses were performed to explore potential sex-based differences. A two-tailed p-value < 0.05 was considered statistically significant.

2.5. Ethical consideration

The study protocol was reviewed and approved by the Research Ethics Committee of the Faculty of Medicine, Universitas Trisakti, under approval number No. 139/KER-FK/VII/2022. All procedures were conducted in accordance with the Declaration of Helsinki. Participants provided written informed consent prior to participation and were free to withdraw at any time without consequence. Safety protocols, including medical supervision and first-aid availability, were implemented throughout the study.

3. RESULTS AND DISCUSSION

A total of 32 participants (20 men, 12 women) were included in the analysis, with 16 assigned to the KN95 group and 16 to the non-KN95 group. The mean age was 34.1 ± 1.6

years, and the mean BMI was 22.9 ± 0.1 kg/m². Baseline characteristics (age, sex, and BMI) were comparable between groups, with no significant differences observed (Table 1).

Table 1. Baseline demographic and physiological characteristics of study participants (n = 32).

Variable	**Mean ± SD or n (%)**	**95% Confidence Interval for Mean**
Sex		
Male	20 (58.8%)	–
Female	12 (35.3%)	
Age (years)	34.09 ± 1.556	30.92 – 37.27
Weight (kg)	80.55 ± 17.536	44.79 – 116.32
Height (cm)	165.88 ± 1.413	162.99 – 168.76
BMI (kg/m²)	22.85 ± 0.129	22.59 – 23.11
Heart Rate (bpm)	128.53 ± 2.534	123.36 – 133.70
Respiratory Rate (x/min)	30.94 ± 1.056	28.78 – 33.09
Oxygen saturation (SpO_2, %)	96.97 ± 0.177	96.61 – 97.33

3.1. Cardiopulmonary Responses

Independent samples t-tests showed significant differences across all three physiological parameters (Table 2). Compared with non-KN95 masks, KN95 masks were associated with higher heart rate (HR) and respiratory rate (RR) and lower oxygen saturation (SpO_2). Post-physical activity HR was significantly higher in the KN95 group compared to non-KN95 (+14.4 bpm; $p = 0.003$), with a large effect size (Cohen's $d = 1.15$). Respiratory rate was also elevated (+5.1 breaths/min; $p = 0.013$; $d = 0.94$), while SpO_2 was significantly reduced (–0.8%; $p = 0.019$; $d = –0.88$). Levene's test confirmed homogeneity of variance across analyses. ANCOVA adjusted for age, sex, and BMI confirmed these associations, with moderate-to-large partial η^2 values across outcomes (Table 3). Effect size analysis indicated large effects for all parameters (Cohen's $d > 0.8$), underscoring the clinical relevance of these findings. These findings indicate that KN95 masks impose a measurable cardiopulmonary burden during moderate intensity cycling.

Similar effects have been observed in studies of N95 or high-filtration respirators, which increase breathing resistance and elevate HR and RR compared with surgical masks (Singla et al., 2022; Shui et al., 2022). In contrast, studies focusing on surgical or cloth masks have reported smaller or negligible effects (Shaw et al., 2021; Zheng et al., 2023). This likely reflects the tighter seal and higher airflow resistance of KN95 respirators, which impose greater ventilatory load. In contrast, studies that reported negligible physiological effects often involved mask types with lower filtration efficiency and looser seal (Lott et al., 2022). A systematic review and meta-analysis by Engeroff et al. (2021) similarly demonstrated that high-filtration masks impair gas exchange and aerobic performance, but the magnitude of change in our study was greater. This may be due to our field-based setting, which exposed participants to additional stressors such as outdoor temperature, humidity, and air pollution, thereby amplifying cardiopulmonary strain.

Table 2. Unadjusted comparison of physiological parameters between KN95 and non-KN95 groups after cycling (independent samples t-test with Cohen's d).

Variable	KN95 (n = 16)	Non-KN95 (n = 16)	Mean Difference	t (df)	p-value	95% CI for Difference	Cohen's d
HR (bpm)	135.75 ± 11.63	121.31 ± 13.35	+14.44	3.262 (30)	0.003	5.40 – 23.50	1.15
RR (breaths/min)	33.50 ± 5.60	28.38 ± 5.33	+5.13	2.653 (30)	0.013	1.18 – 9.07	0.94
SpO_2 (%)	96.56 ± 1.03	97.38 ± 0.81	-0.81	-2.484 (30)	0.019	-1.48 – -0.14	-0.88

Notes:
Independent samples T-test with Cohen's d, $p < 0.05$
Values are expressed as mean ± standard deviation (SD). Cohen's d is interpreted as 0.2 = small, 0.5 = medium, and 0.8 = large effect size.

From a physiological standpoint, the elevated HR reflects the increased cardiovascular workload mediated by sympathetic activation secondary to enhanced respiratory effort (Grassi & Drager, 2024). The higher RR represents compensatory hyperventilation to maintain alveolar ventilation against greater inspiratory resistance (Braga et al., 2023). The modest but significant decline in SpO_2 suggests impaired oxygen diffusion or delivery, possibly exacerbated by partial CO_2 rebreathing within the mask dead space. These mechanisms are consistent with prior reports that respirators may shift the ventilatory threshold, making the balance between oxygen supply and demand more fragile during physical activity (Han et al., 2023; Sukul et al., 2022). Although oxygenation remained within clinically acceptable ranges, the findings underscore that even moderate activity can elicit detectable strain when performed with KN95 masks (O'Driscoll Bret al., 2024; Han et al., 2023).

Table 3. Adjusted comparison of physiological parameters between KN95 and non-KN95 groups after cycling (ANCOVA adjusted for age, sex, and BMI).

Variable	KN95 (Adjusted Mean ± SE)	Non-KN95 (Adjusted Mean ± SE)	Mean Difference (95% CI)	p-value	Partial η^2
HR (bpm)	136.0 ± 3.15	121.0 ± 3.15	+15.0 (5.83 – 24.13)	0.002	0.295
RR (breaths/min)	33.49 ± 1.44	28.39 ± 1.44	+5.1 (0.93 – 9.27)	0.018	0.189
SpO_2 (%)	96.56 ± 0.21	97.38 ± 0.21	–0.82 (–1.44 – –0.21)	0.011	0.218

Notes:
Adjusted means were estimated using ANCOVA. The acronym SE stands for standard errors. Partial η^2 is interpreted as 0.01 = small, 0.06 = medium, and 0.14 = large effect size.

Clinically, these findings are particularly relevant for individuals with a reduced cardiopulmonary reserve. Patients with chronic respiratory diseases (e.g., asthma, COPD) or cardiovascular conditions may be less able to compensate for the additional ventilatory resistance imposed by KN95 masks, increasing the risk of physical activity intolerance, dyspnea, or oxygen desaturation during physical activity (Rogliani et al., 2019; Jiang et al., 2025). Athletes and highly active individuals may also experience premature fatigue or performance impairment when training with high-filtration masks, especially at higher intensities where oxygen demand is greater (Hostrup & Bangsbo, 2017; Behrens et al., 2022). Beyond infection control, respirator-type masks are also advocated in polluted environments, where the trade-off between protection and physical activity capacity becomes important (Xu et al., 2020). Tailored recommendations—such as limiting strenuous outdoor physical activity with KN95 masks, promoting mask-free activity in low-risk or well-ventilated environments, or using alternative protective strategies—may help balance safety with physiological well-being across different populations (Greenhalgh et al., 2024).

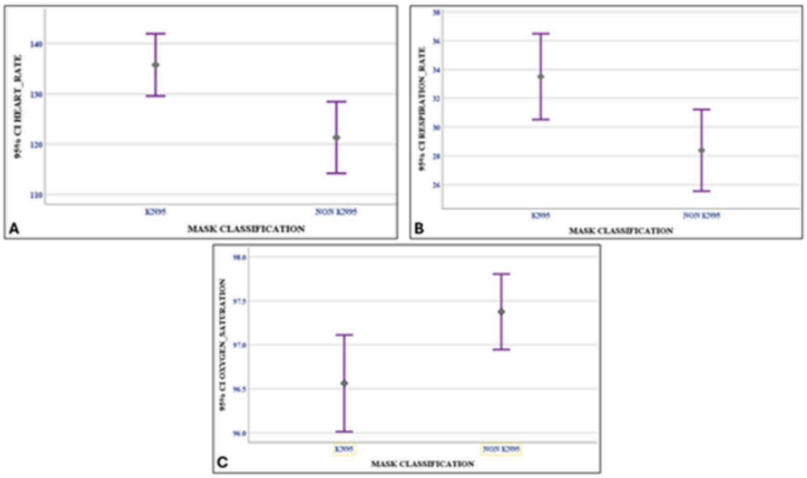

Fig. 1. Estimated marginal means (± SE) of heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2) in the KN95 and non-KN95 groups after cycling. Error bars represent standard errors.

3.2. Subgroup Analysis by Gender

Gender-stratified analyses reveal consistent patterns across groups (Table 4, Figure 2). Both men and women exhibited higher HR and RR with KN95 use compared with non-KN95 masks, along with reduced SpO_2. The magnitude of change was more pronounced in women: HR increased by +18.5 bpm ($p = 0.042$, $\eta^2 = 0.353$, large effect) compared with +12.0 bpm in men ($p = 0.043$, $\eta^2 = 0.209$, moderate effect). Similarly, reductions in SpO_2 were also slightly greater in women (–1.0%; $p = 0.004$) than in men (–0.6%; $p = 0.031$). RR differences were similar across sexes (approximately +5 breaths/min).

Our gender-stratified analysis, although exploratory given the modest sample size, suggest that women may experience more pronounced physiological strain when exercising with KN95 masks, particularly in HR and SpO_2 responses. These trends may reflect underlying physiological differences. Women generally have smaller lung volumes, lower hemoglobin concentrations, and reduced cardiopulmonary reserve compared with men, which could amplify the impact of increased respiratory resistance imposed by KN95 masks and disproportionately challenge women's ventilatory and oxygen transport capacity (Molgat-Seon et al., 2018; Santisteban et al., 2022; Harms et al., 2008). Such physiological differences may amplify the impact of increased inspiratory resistance, disproportionately challenging ventilatory efficiency and oxygen transport in women. While we did not detect a statistically significant mask × gender interaction, the consistent patterns observed warrant attention, as they imply that women could be more vulnerable to mask-induced desaturation and cardiovascular strain during physical activity.

These findings add to the limited literature exploring sex-specific responses to mask use during physical activity. Most previous studies have not stratified by gender, focusing instead on overall averages (Engeroff et al., 2021; Mezghani et al., 2023). A recent systematic review by Asín-Izquierdo et al. (2022) emphasized that sex-based differences in ventilatory physiology may alter tolerance to mask use during exercise, but empirical field data remain limited. By demonstrating differential trends, our inquiry emphasizes the value of considering sex differences in both research and guideline development. In practical terms, women engaging in regular physical activity with KN95 masks—particularly in urban areas with high air pollution or during pandemics—may face relatively higher risks of discomfort or physiological burden (Zheng et al., 2023; Das et al., 2023). This has implications not only for athletic performance but also for occupational and community settings where women may engage in prolonged activity while masked. Tailoring mask recommendations to account for biological differences may therefore enhance both safety and adherence.

Table 4. Subgroup analysis of physiological parameters by gender (estimated marginal means ± SE from ANCOVA).

Outcome	Gender	Mask	Mean ± SD	Mean Difference (95% CI)	p-value	Partial Eta Squared
HR (bpm)	Male	KN95	135.1 ± 11.2	+12.0 (0.45–23.55)	0.043	0.209 (moderate)
		Non-KN95	123.1 ± 13.3			
	Female	KN95	136.8 ± 13.3	+18.5 (0.84 – 36.16)	0.042	0.353 (large)
		Non-KN95	118.3 ± 14.2			
RR (breath/mim)	Male	KN95	33.4 ± 5.6	+5.1 (1.12 – 9.13) *	0.014	0.203 (moderate)
		Non-KN95	28.3 ± 5.3			
	Female	KN95	33.6 ± 5.7	+5.2 (1.20 – 9.25) *	0.015	0.196 (moderate)
		Non-KN95	28.4 ± 5.4			
SpO_2 **(%)**	Male	KN95	96.8 ± 0.9	-0.6 (-1.2 – -0.1) *	0.031	0.142 (moderate)
		Non-KN95	97.4 ± 0.8			
	Female	KN95	96.3 ± 1.0	-1.0 (-1.6 – -0.4) *	0.004	0.278 (large)
		Non-KN95	97.3 ± 0.8			

**Values expressed as mean ± standard deviation (SD). Between-group differences were tested using ANCOVA adjusted for covariates. *p < 0.05. Partial η² interpretation: 0.01 = small, 0.06 = moderate, 0.14 = large.*

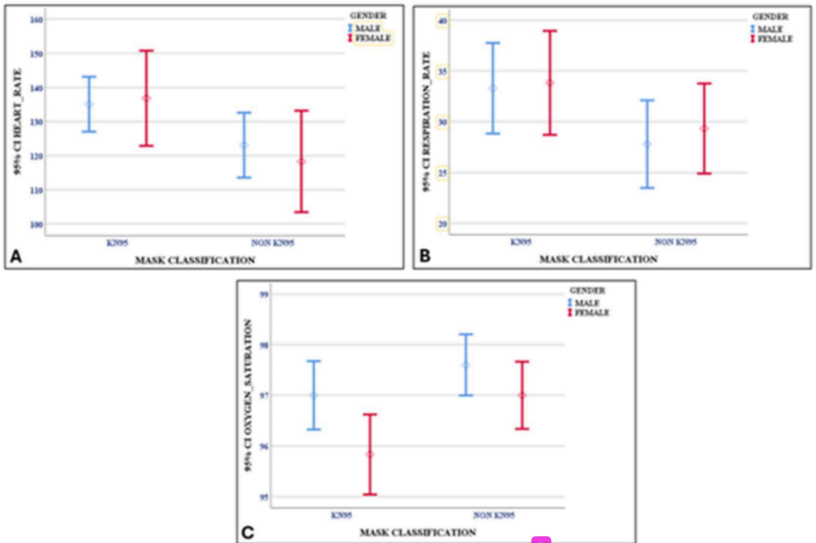

Fig. 2. Gender-stratified estimated marginal means (± SE) of heart rate (HR), respiratory rate (RR), and oxygen saturation (SpO_2) in KN95 and non-KN95 groups.

3.3. Public Health Implications

These findings carry practical implications for public health guidelines. KN95 masks provide superior protection against airborne pathogens and environmental pollutants, but their use during physical activity imposes measurable cardiopulmonary strain (O'Kelly et al., 2021). For healthy and active adults, this additional load is modest and unlikely to pose adverse outcomes during short-duration physical activity. However, for individuals with limited cardiopulmonary reserves, such as older adults, patients with chronic respiratory or cardiovascular disease, or those engaging in prolonged or high-intensity activity, the burden may become clinically relevant (Tesfaldet & Ndeh, 2022; MacIntyre et al., 2025).

Public health recommendations should therefore balance infection control benefits with potential physiological burdens, particularly in contexts where physical activity is encouraged for health promotion. From an *urban health* perspective, this is especially relevant in Jakarta, where levels of fine particulate matter (PM2.5) often exceed WHO thresholds, making high-filtration masks advisable for protection against air pollution. Yet, the same masks may reduce exercise capacity and adherence to active commuting practices, such as cycling (Liu et al., 2020). Policymakers could consider adaptive recommendations—for example, encouraging lighter masks or mask-free exercise in low-risk, well-ventilated outdoor environments, while reserving KN95 use for periods of extreme pollution or elevated infection risk (Engeroff et al., 2021; Zheng et al., 2023).

Furthermore, gender-specific trends observed in this study suggest that women may experience greater physiological strain, underscoring the potential for tailored advice in occupational or community physical activity programs. Ultimately, incorporating physiological evidence into mask-related public health guidance will help optimize both safety and adherence. Clear communication of risks and benefits will empower individuals to make informed decisions about mask use during exercise, thereby supporting broader health promotion goals without compromising cardiopulmonary well-being (Farah et al., 2025; Wismans et al., 2022; Howard et al., 2021).

These implications should be interpreted considering the study's strengths and limitations. Strengths include randomized allocation, controlled physical activity intensity, and comprehensive adjustment for confounders, supported by both unadjusted and adjusted analyses that provide robust evidence for the physiological effects of KN95 masks. However, modest sample size limits statistical power to detect interaction effects, particularly for subgroup analyses such as gender-specific comparisons. The inclusion of only healthy adults restricts the generalizability of our findings to older adults or individuals with cardiopulmonary comorbidities. In addition, physiological parameters were assessed only once, at five minutes of post-physical activity, which may have underestimated transient or peak physiological responses. Finally, the study was limited to moderate-intensity cycling with a fixed duration, which may not reflect physiological responses during higher-intensity physical activity, longer durations, or different physical activity modalities.

Further studies should explore long-term effects of mask use during physical activity, include more diverse populations such as older adults and individuals with chronic cardiopulmonary conditions, and assess subjective outcomes such as perceived exertion, comfort, and adherence. Additionally, continuous monitoring of cardiopulmonary parameters could clarify the temporal dynamics of cardiopulmonary adaptation to mask use.

4. CONCLUSION

Wearing KN95 masks during moderate-intensity outdoor cycling significantly increases heart rate and respiratory rate and modestly reduces oxygen saturation compared with surgical masks, with trends toward greater physiological impact in women. Although changes remained within clinically acceptable limits for healthy adults, they may be more relevant for individuals with limited cardiopulmonary reserve or during prolonged or higher-intensity activity. These findings highlight the need for public health recommendations that balance infection-control benefits with physiological safety, particularly in settings requiring both respiratory protection and physical activity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved of the final manuscript.

CONSENT

Not applicable. No identifiable individual participant data are presented.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

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