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Original Article

Effects of running with surgical masks on cardiopulmonary function in healthy male university students

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Abstract. [Purpose] In Japan, one measure against the novel coronavirus disease-2019 infection involves the public use of surgical masks. Research indicates that exercising while wearing a mask increases the physical burden, particularly affecting young people during high-intensity exercise. This study examined the effects of wearing masks while running in male university students. [Participants and Methods] The participants were 20 healthy male university students (21.6 ± 1.6 years). The participants underwent cardiopulmonary exercise tests with the masks on and off on different days until exhaustion. The following parameters were measured: exercise duration, Borg Scale rating (respiratory or lower extremities), surface temperature around the mouth, time to sweat onset, metabolic reaction, pulmonary ventilation, and cardiovascular reaction parameters. [Results] The results showed that VO_2 max remained consistent between the mask-on and mask-off conditions. However, minute ventilation, respiratory rate, and heart rate decreased in the mask-on condition, which correlated with a reduction in exercise duration. Furthermore, running with the mask significantly decreased the VE/VO_2, VE/ VO_2, Borg Scale rating of the lower extremities, and the time to sweat onset. [Conclusion] Running with a surgical mask affected respiratory function and decreased exercise duration in healthy male university students. However, it did not induce any changes in VO_2 max.

Key words: Cardiopulmonary exercise test, Maximum oxygen uptake, Exercise endurance

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INTRODUCTION

In Japan, a preventive measure against the novel coronavirus disease 2019 (COVID-19) encompasses using surgical masks (masks) within the public domain. In the spring of 2020, the government declared its first state of emergency in response to the COVID-19 pandemic. After the state of emergency was lifted, a survey was conducted to assess measures taken to prevent the spread of droplets during exercise. The survey revealed that 54.5% of respondents wore masks or neck gaiters while exercising to prevent the spread of the virus[1)]. Given the persistent nature of the COVID-19 pandemic, it is anticipated that individuals will continue to wear masks during physical exertion as a preventive strategy against infection.

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Exercising with a mask may pose challenges to endurance activities, primarily attributed to respiratory muscle fatigue, which can heighten sympathetic vasoconstrictor activity directed towards operational skeletal muscles through respiratory muscle metaboreflexes. This diminishes peripheral limb blood flow and amplifies the magnitude of exercise-induced muscular fatigue[2]. However, the physiological impact of exercising with the masks varies based on the exercise intensity and the level of resistance the mask offers during inhalation. Caretti et al.[3] reported that during exhaustive treadmill exercise at a constant load corresponding to 80% of the maximal aerobic capacity, wearing masks with varying inspiratory resistance led to a proportional reduction in ventilation. Roberge et al.[4] observed increased heart and respiratory rates, along with higher levels of transcutaneous CO_2 when a surgical mask is worn during treadmill exercise at 5.6 km/h, compared to exercising without a mask. Moreover, Driver et al.[5] observed a reduction in exercise duration, maximal oxygen consumption, minute ventilation, maximal heart rate (HR), and an increase in dyspnea during maximal cardiopulmonary exercise tests when wearing a cloth face mask compared to a test conducted without a mask. Conversely, Iwago et al.[6] reported no significant changes in the maximal oxygen uptake, with participants running at 60% or 80% of their maximal oxygen uptake load while wearing a mask. Consequently, a consensus on the repercussions of physiological stress induced by exercise while wearing masks remains elusive.

In this study, we examined the effects of running with surgical masks on the cardiopulmonary function, perioral surface temperature, and exercise performance of male university students.

PARTICIPANTS AND METHODS

The participants comprised 20 healthy male university students (mean age: 21.6 ± 1.6 years) without respiratory or cardiovascular disease and were nonsmokers. Participants underwent cardiopulmonary exercise tests while wearing a mask (Mask-on) and without a mask (Mask-off) on different days until exhaustion. The masks employed were disposable ear-hanging surgical masks designed for adults and commonly used in general circumstances. The cardiopulmonary exercise test (CPET) was performed using an aeromonitor (AE100I) and treadmill (AR-100) from Minato Medical Science Co. (Tokyo, Japan). Assessments were conducted following the TR-4 protocol for the treadmill, involving a 3-minute warm-up followed by a progressive exercise intensity with a gradual increase in oxygen uptake (VO_2) by 4 mL/min/kg per minute. The exercise test can be stopped when the patient's HR exceeds the maximum predicted HR (220 minus the participant's age), when oxygen uptake reaches a plateau, or when the participant reports an inability to continue the exercise. Environmental conditions were set at 20–25°C and 40–60% humidity. The following parameters were measured: exercise duration, Borg Scale (respiratory or lower extremities), surface temperature around the mouth, time to sweat onset, metabolic reaction parameters (VO_2 max, VO_2, Carbon dioxide elimination [VCO_2]), pulmonary ventilation parameters (minute ventilation [VE], respiratory rate (RR), pulse oximeter saturation [SPO_2], VE/VO_2, and VE/VCO_2), and cardiovascular reaction parameters (HR, blood pressure [BP], and VO_2/HR). The perioral surface temperature was assessed before and after CPET using a waterproof digital thermometer (SK-250WPII-I-N; Sato Keiryoki Mfg. Co., Tokyo, Japan) with the skin temperature outside the right corner of the mouth within the area covered by the mask.

A paired t-test was used to compare each parameter between the Mask-on and Mask-off conditions. Data processing was done using statistical software (SPSS 25.0; IBM Corp., Armonk, NY, USA), and the significance level was set at $p<0.05$. Approval was obtained from the Ethical Review Committee of the International University of Health and Welfare (22-Ifh-011). Prior to participation, participants were provided with both oral and written explanations of the study, and their consent was obtained.

RESULTS

Table 1 shows the basic characteristics of the participants. Table 2 shows the outcomes of comparing parameters derived from CPET conducted under both Mask-on and Mask-off conditions. The results showed that running with the mask led to reduced exercise duration (9.0 ± 1.2 vs. 9.6 ± 1.3 min) and time to sweat onset (5.3 ± 2.7 vs. 7.0 ± 1.2 min), along with a significantly reduced Borg Scale rating for the lower extremities (6.0 ± 2.1 vs. 6.9 ± 1.7) ($p<0.05$). Furthermore, VE (67.0 ± 17.0 vs. 85.6 ± 12.7 L/min), RR (33.1 ± 8.0 vs. 40.6 ± 7.1 times/min), VE/VO_2 (27.8 ± 4.9 vs. 35.7 ± 7.0), VE/VCO_2 (24.7 ± 3.3 vs. 30.0 ± 5.6), and HR (175.3 ± 12.4 vs. 186.5 ± 4.9 beats/min) also exhibited statistically significant reductions ($p<0.05$).

DISCUSSION

In this study, we examined the physiological effects of wearing a surgical mask during CPET with maximum exercise in healthy male university students. The results showed that running with a mask reduced VE, RR, and HR, thereby reducing exercise duration but not affecting VO_2 max. These findings contrast with those of Driver and Zhang et al[5, 7].

The use of masks increased respiratory resistance and dead space volume, leading to reductions in VE and RR. A deepening of respiratory efforts becomes imperative for maintaining the inspired oxygen concentration in the presence of heightened respiratory resistance, thereby augmenting diaphragmatic contraction and intensifying the engagement of auxiliary respiratory muscles, such as the intercostal and sternocleidomastoid muscles[8].

The increased dead space induced by the mask and facial skin requires a greater air volume during inhalation, prolonging the inspiratory duration and attenuating the respiratory rate[9)]. The respiratory pattern observed during CPET in healthy individuals encompasses an increase in minute ventilation up to the anaerobic threshold, followed by a rise in the respiratory rate concomitant with escalating ventilation. In this study, the participants exercised until exhaustion, necessitating an elevation

Table 1. Baseline characteristics

Male university students (n=20)	
Age (years)	21.6 ± 1.6
Height (cm)	172.0 ± 5.5
Body weight (kg)	66.3 ± 8.1
BMI (kg/m^2)	22.5 ± 3.1
Body fat percentage (%)	19.7 ± 8.8
SMI	7.7 ± 0.6
SBP (mmHg)	122.4 ± 13.0
DBP (mmHg)	80.3 ± 9.6
HR (beats/min)	77.0 ± 12.1
SPO_2 (%)	97.4 ± 1.1
Exercise habit, n (%)	5 (25)

Mean ± standard deviation. BMI: body mass index; SMI: skeletal muscle mass index; SBP: systolic blood pressure; DBP: diastolic blood pressure; HR: heart rate; SPO_2: pulse oximeter saturation.

Table 2. Comparison of mask-on and mask-off during high-intensity exercise

	Mask-off	Mask-on
Cardiopulmonary exercise stress tests performance		
Exercise duration (min)	9.6 ± 1.3	9.0 ± 1.2*
Borg Scale: respiratory	6.9 ± 2.0	6.8 ± 2.1
Borg Scale: lower extremities	6.9 ± 1.7	6.0 ± 2.1*
Tface (°C)		
Rest	33.5 ± 1.1	33.7 ± 1.0
Peak	34.3 ± 1.2	34.1 ± 1.0
Time to Sweat onset (min)	7.0 ± 1.2	5.3 ± 2.7*
Metabolic reaction parameters		
VO_2 max (mL/min/kg)	37.2 ± 6.1	36.3 ± 6.1
VO_2 (mL/min)	2,441.4 ± 378.5	2,389.3 ± 400.4
VCO_2 (mL/min)	2,897.2 ± 432.1	2,706.0 ± 613.9
Pulmonary ventilation parameters		
VE (L/min)	85.6 ± 12.7	67.0 ± 17.0*
RR (b/min)	40.6 ± 7.1	33.1 ± 8.0*
TV (L)	2.3 ± 0.3	2.1 ± 0.4*
SPO_2 (%)	96.1 ± 1.1	96.1 ± 1.1
VE/VO_2	35.7 ± 7.0	27.8 ± 4.9*
VE/VCO_2	30.0 ± 5.6	24.7 ± 3.3*
Cardiovascular reaction parameters		
HR (beats/min)	186.5 ± 4.9	175.3 ± 12.4*
SBP (mmHg)	172.6 ± 27.5	162.6 ± 23.9
DBP (mmHg)	89.9 ± 18.6	96.1 ± 20.9
Peak VO_2/HR (mL/beat)	12.7 ± 1.5	13.6 ± 1.5

Mean ± standard deviation, *$p<0.05$.
VO^2: oxygen uptake; VCO_2: carbon dioxide elimination; VE: minute ventilation; RR: respiratory rate; TV: tidal volume; SPO_2: pulse oximeter saturation; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure.

in the respiratory rate to maintain ventilation. However, the constraint in increasing the respiratory rate, as observed in the absence of a mask, resulted in a decline in the ventilation rate when wearing a mask. The reduction in peak VE indicated that inspiratory volume did not align with the increase in oxygen consumption, potentially contributing to a marginal decrease in exercise duration (−0.6 min) when wearing the mask. Consequently, it was inferred that the Borg scale rating for the lower extremities also declined when wearing a mask.

Furthermore, the preservation of VO_2 max, a metric indicative of exercise tolerance, may be attributed to the absence of prolonged high-intensity exercise in the protocol and the adoption of a mask with minimal respiratory resistance. Consequently, the likelihood of respiratory muscle fatigue, as documented in prior studies[2, 10, 11], is low, and a decrease in arterial–venous oxygen difference is not anticipated. The lack of changes in respiratory distress and blood pressure during exercise with a mask implies a minimal impact of muscle sympathetic nerve activity associated with respiratory muscle fatigue. Consequently, blood flow and oxygen supply to the lower extremities were unlikely to be compromised. Nevertheless, to preserve VO_2 max, HR should ideally be increased to levels comparable to those observed in the Mask-off condition. Contrary to this expectation, a reduction in HR was evident in this study. Under typical circumstances, cardiac output should be elevated during a progressive exercise test as the sympathetic nervous system is activated, increasing HR and heightened myocardial contractility in response to escalating exercise intensity.

Zhang et al. suggested that the reduction in HR during high-intensity exercise while wearing a mask may be directly related to shortened exercise duration[7]; however, further investigation is warranted. In our study, the duration of continuous exercise shortened when participants wore the mask, suggesting a plausible influence on exercise duration. Conversely, the increased respiratory resistance induced by the mask increases the negative pressure in the thoracic cavity during inspiration, which promotes an increase in venous return and cardiac preload[12]. As a result, stroke volume increased, suggesting that VO_2 max may not have decreased. The participants were healthy male university students whose VO_2 max during exercise without a mask exceeded the standard value of 2,395 mL/min (actual value of 2,441.4 mL/min) for a 20-year-old Japanese man weighing 65 kg. These results suggest that cardiac work efficiency and oxygen utilization did not decrease due to the contraction of inactive muscles and visceral blood vessels attributed to increased sympathetic nerve activity[13].

Finally, despite the higher density of thermoreceptors on the face[14], we expected an increase in the surface temperature around the mouth due to mask wear. However, no discernible difference was observed when compared with the Mask-off condition. This lack of difference is likely because sweating rather than respiration primarily influences evaporative heat loss during exercise, and wearing a surgical mask does not significantly impact thermoregulatory responses[15]. Wearing a mask during exercise has been suggested as a factor that could increase blood CO_2 levels because of the rebreathing of residual exhaled air within the mask, potentially exacerbating dyspnea[16]. In addition, it can increase the temperature and humidity around the face, leading to moisture accumulation, mask distortion, and subsequent increase in respiratory resistance. However, based on the results of this study, no increase in CO_2 was observed during mask use, and respiratory muscle fatigue was unlikely to occur, thereby reducing the incidence of respiratory distress.

The findings of this study revealed that performing CPET on a treadmill while wearing a mask resulted in reductions in VE, RR, HR, and exercise duration, while VO_2 max remained unchanged. However, given that the participants were healthy male university students and the respiratory resistance to the mask was low, it can be inferred that the increase in respiratory muscle workload was relatively modest, allowing the participants to maintain their exercise capacity even while wearing the mask. Acknowledging that the burden of wearing masks may be disproportionately higher for older adults or those with reduced physical fitness due to respiratory or circulatory diseases, it is critical to understand that the ability to exercise while wearing a mask depends on the individual's ability to compensate.

This study focused solely on healthy male university students, limiting generalizability to broader populations. Additionally, this study did not examine the changes in mask breathing resistance or exercise intensity. Subsequent studies should investigate the physiological stress imposed on individuals with cardiopulmonary diseases undergoing exercise therapy while wearing masks.

Conference presentation

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Conflict of interest

The authors declare no conflict of interest.

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