Physiological Effects of Surgical and N95 Masks During Exercise in the COVID-19 era

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ABSTRACT

Background: During the COVID-19 pandemic, studies of the physiological effects of masking during exercise have been rare.

Methods: Twelve healthcare workers performed a cardiopulmonary exercise test while wearing a surgical mask, an N95 mask, or no mask. Variables were collected at rest, warm-up, anaerobic threshold, and maximal exercise.

Results: From rest to maximal exercise, both the surgical and N95 masks decreased inspiratory flow, minute ventilation, and prolonged inspiratory time compared to the no mask condition. Oxygen uptake (VO_2) and oxygen pulse (VO_2/HR) decreased at rest, warm-up, and maximal exercise in both the surgical and N95 mask conditions (vs. no mask). At the anaerobic threshold, the surgical mask also led to a reduction of oxygen uptake and oxygen pulse compared to no mask. The maximal oxygen uptake (VO_2% predicted) also decreased in both the surgical and N95 mask conditions. In addition, the severity of dyspnea increased, and exercise time decreased for both surgical and N95 masks. Compared to no mask, wearing an N95 mask led to lower breathing frequency and lower ventilation efficacy (assessed by VE/VCO_2 and VE/VO_2) from rest to maximal exercise (all $p < 0.05$ for trend). Wearing an N95 also led to retention of carbon dioxide ($p < 0.05$ for trend).

Conclusions: Wearing a surgical mask leads to a somewhat negative impact on cardiopulmonary function, and this effect is more serious with an N95 mask. Attention should be paid to exercise while wearing surgical or N95 masks.

Key Indexing Terms: Surgical mask; N95; Cardiopulmonary exercise test; Cardiopulmonary function. **[Am J Med Sci 2022;363(5):411–419.]**

BACKGROUND

Coronavirus disease 2019 (COVID-19), caused by the virus SARS-CoV-2, was discovered at the end of 2019.[1,2] On March 11, 2020, the World Health Organization (WHO) declared COVID-19 to be a global pandemic. The main clinical features of COVID-19 are fever, cough, shortness of breath, and radiographic evidence of pneumonia.[3–5] As of March 14, 2021, more than 100 million confirmed cases had been reported, and confirmed deaths had reached 2.6 million.[6] Reducing the rate of newly confirmed cases is a key strategy to reduce mortality.

Person-to-person transmission of SARS-CoV-2 was demonstrated at an early stage of the disease.[7,8] Airborne transmission is the dominant route of transmission.[9,10] Wearing a mask can reduce the flow of respiratory droplets into the air when the wearer coughs, sneezes, or talks and can decrease the inhalation of these droplets by another wearer.[11,12] Evidence shows that wearing a mask is associated with a lower risk for infection.[13,14] Therefore, universal mask wearing in public settings is recommended or mandated in the US, China, Germany, France, Italy, and other countries.[15] However, it have led to widespread debate on the risks present during exercise while wearing a mask.[16,17] Observations of the physiological effects of wearing a mask during exercise are needed to identify such risks. This study explored the physiological effects of wearing a surgical mask (SM) and an N95 mask during exercise.

METHODS

At the end of 2020, 12 non-smoking, healthy volunteers were recruited. All of the volunteers were healthcare workers in our hospital; 6 were male, and 6 were female. Subjects who had chronic respiratory disease, cardiac disease, inflammatory disease, or acute respiratory illness (e.g., pneumonia and upper respiratory tract disease) within the 2 weeks prior to the study were excluded. We also excluded subjects with contraindications for cardiopulmonary exercise testing (CPET). The ethics committee of the First Affiliated Hospital of Chongqing Medical University approved the study protocol (No. 2020−888). Written informed consent was obtained from the participants.

FIG. 1. Wearing a surgical mask and an N95 mask.

When volunteers were enrolled, their height (cm) and weight (kg) were measured, and then their body mass index (BMI) was calculated. Three consecutive symptom-limited incremental exercise tests were performed in each subject in the no mask (NM), disposable SM, and N95 mask (without exhalation valve) conditions. The fitting of the SM and N95 is presented in Fig. 1. The SM and N95 were made in China (Chongqing BaiNa Medical Instrument Co., Chongqing, and Henan Zhongjian Medical Instrument Co., Henan, respectively). All masks were worn under a standard silicone mask (Cosmed, Italy). Leak tightness was confirmed before each test. As this was a randomized crossover study, the order of mask wearing was assigned in a randomized fashion. Mask testing was performed by a technologist at the same time of day at a minimum of 48 h apart and was supervised by a pulmonary physician. The program algorithm and presentation of the measured data were developed according to the specifications of the American Thoracic Society (ATS) and the European Respiratory Society (ERS).[18,19] Prior to data acquisition, the flow and volume calibration of the equipment was performed with a 3 L calibration syringe, and the gas analyzer was calibrated with atmospheric air and a cylinder with a fixed amount of O_2 (16%) and carbon dioxide (CO_2) (5%). Spirometry (Quark spiro COSMED, Italy) was performed without a mask before the CPET according to the standards in the 2005 ATS/ERS spirometry guideline.[20]

CPET was performed using a computer-controlled bicycle ergometer (Ergoline 100/200, Bitz, Germany) with a Quark System (Quark CPET, COSMED, Italy) located in an air-conditioned room with ambient temperature at 20−25°C and low relative humidity (<50%). The mass flow sensor and gas analyzers were calibrated before each test and met current standards for accuracy, reproducibility, and response time.[21] During the CPET, the participants rested quietly on the bicycle for 3 min and conducted a warm-up of unloaded pedaling for 3 min. After this, the workload increased every 1 min by 15 watts for female participants and 20 watts for males using prediction equations that took into account the physical characteristics of the participants until exhaustion.[21] A cycling rate of 55−65 revolutions per minute (rpm) was used. The recovery time for each participant was 3 min. The test was terminated when the participants reported exhaustion or were unable to keep the ergometer at > 50 rpm. Exhaustion was defined as unbearable leg weakening or dyspnea. The severity of dyspnea was assessed by the participants using the Borg dyspnea scale at peak exercise. The data were measured breath-by-breath and averaged over 20-s intervals.

Maximum VO_2 was the highest VO_2 over a 20-s interval obtained at the end of exercise. The maximal power was recorded after exercise testing. Using breath-gas analyses, the following were continuously monitored: tidal volume, minute ventilation (VE), oxygen uptake (VO_2), carbon dioxide production (VCO_2), breathing frequency, inspiratory flow, end-tidal carbon dioxide ($PETCO_2$), heart rate (HR), and hemoglobin saturation (measured by finger oximeter). Blood pressure was measured automatically (Suntech Tango M2) at rest, during warm-up, at 2-min intervals throughout exercise, and at the third minute of recovery. The ventilatory equivalents for carbon dioxide (VE/VCO_2) and for oxygen (VE/VO_2) were calculated. The anaerobic threshold (AT) was determined with the V-slope method using a 10-second interval. This was confirmed by the specific trends of VE/VO_2, VE/VCO_2, and $PETCO_2$.[22,23] The AT was determined by consensus between the two pulmonologists supervising all tests. Total exercise time, defined as the time elapsed from exercise commencement to exhaustion, was recorded. The reduction percentage of VO_2max and VE with SM and N95 was calculated on the base of VO_2max without a mask.

Data were analyzed using statistical software (SPSS 23.0; IBM Corp., Armonk, NY) and were expressed as mean values and standard deviations or frequencies and percentages. Differences between patients with NM, SM, and N95 were analyzed with repeated-measures ANOVA. The least-significant difference for the *post hoc* test was used to analyze the difference between two groups. P values less than 0.05 indicated statistical significance.

RESULTS

The demographic data of the 12 volunteers are presented in Table 1. Their ages ranged from 30 to 41 years and the mean BMI was 21±3 kg/m^2. The respiratory parameters are summarized in Table 2 and Fig. 2. Inspiratory flow gradually increased from rest to maximal exercise regardless of mask condition, whether NM, SM, or N95. Wearing an SM or N95 mask significantly decreased inspiratory flow, decreased VE, and prolonged inspiratory time at rest, warm-up, AT, and maximal exercise (all $p < 0.05$). Breath frequency was also significantly lower for SM and N95 than NM, except at maximal exercise ($p < 0.05$).

Oxygen pulse (VO_2/HR) gradually increased from rest to maximal exercise in all conditions (Table 2 and Fig. 3). The SM and N95 conditions showed lower oxygen pulse at rest, warm-up, and maximal exercise (all $p < 0.05$). Oxygen uptake (VO_2) also decreased at rest, warm-up, and maximal exercise both in SM and N95 (vs. NM, all $p < 0.05$). At the anaerobic threshold, SM led to a reduction in oxygen uptake and oxygen pulse ($p < 0.05$). In addition, N95 showed higher carbon dioxide ($PETCO_2$), lower breathing frequency, and lower ventilation efficacy (VE/VCO_2 and VE/VO_2; Fig. 4, all $p < 0.05$ for trend).

The reasons for failure to maintain the ergometer at >50 rpm are presented in Table 3. However, one volunteer prematurely terminated CPET due to blood pressure beyond 200 mmHg. The main reason for termination was unbearable leg weakening. No volunteers reported unbearable dyspnea while not wearing a mask. Two volunteers reported unbearable dyspnea with an SM and five did so with an N95 mask. At maximal exercise in the NM condition, the 12 volunteers reached 79±12% of predicted maximal oxygen uptake. However, those wearing an SM or N95 only reached 63±9% and 66±10% of predicted maximal oxygen uptake, much lower than the

Table 1. Demographics.

Volunteer Number	Age, years	Sex	BMI kg/m^2	FEV_1, L (% pred)	FVC, L (% pred)	FEV_1/FVC (%)	IC, L (% pred)	MVV, L (% pred)
1	30	F	17.9	2.32 (81%)	2.96 (90%)	78.3%	1.68 (83%)	95 (89%)
2	30	F	23.8	2.64 (94%)	3.08 (95%)	85.9%	2.22 (112%)	139 (131%)
3	32	M	25.9	3.6 (101%)	4.13 (99%)	87.0%	2.36 (82%)	165 (128%)
4	34	M	18.9	4.0 (99%)	4.91 (101%)	81.5%	2.69 (75%)	159 (112%)
5	34	F	21.4	3.02 (97%)	3.62 (101%)	83.6%	2.26 (94%)	121 (108%)
6	32	M	24.8	2.81 (78%)	3.93 (93%)	71.5%	2.41 (82%)	125 (96%)
7	37	F	18	2.53 (93%)	2.72 (86%)	92.9%	1.67 (81%)	106 (103%)
8	41	F	20.2	2.47 (105%)	3.02 (110%)	81.8%	2.1 (120%)	98 (104%)
9	30	M	21.7	3.73 (91%)	4.45 (92%)	83.8%	2.92 (83%)	149 (104%)
10	30	M	21.6	4.22 (101%)	5.14 (104%)	82.2%	2.91 (80%)	216 (148%)
11	37	M	24.4	3.09 (84%)	3.85 (88%)	80.2%	2.55 (80%)	138 (105%)
12	37	F	18.8	2.41 (89%)	2.87 (91%)	84.1%	1.68 (81%)	124 (121%)
Mean ± SD	34±4	–	21±3	3.07±0.66 (93±8%)	3.72±0.82 (96±7%)	82.8±5.1%	2.29±0.45 (88±14%)	134±34 (112±17%)

BMI = body mass index, FEV_1 = forced expiratory volume in one second, FVC = forced vital capacity, IC = inspiratory capacity, MVV = maximal voluntary ventilation, F = female, M = male, SD = standard deviation.

Table 2. Comparisons between subjects with NM, SM, and N95 from rest to maximal exercise.

	Rest	Warm-up	AT	Maximum
Inspiratory flow, L/s				
NM	0.47±0.10	0.69±0.15	1.30±0.28	2.44±0.33
SM	0.31±0.07	0.47±0.10	0.84±0.16	1.70±0.40
N95	0.31±0.7	0.47±0.09	0.90±0.18	1.58±0.30
p	<0.01	<0.01	<0.01	<0.01
Inspiratory time, s				
NM	1.29±0.23	1.12±0.23	1.06±0.26	0.76±0.08
SM	1.62±0.47	1.35±0.40	1.36±0.40	0.94±0.25
N95	1.75±0.45	1.45±0.36	1.40±0.46	1.07±0.29
p	<0.01	<0.01	<0.01	<0.01
Tidal volume, L				
NM	0.59±0.13	0.80±0.19	1.34±0.42	1.81±0.43
SM	0.47±0.11	0.64±0.14	1.11±0.33	1.54±0.42
N95	0.52±0.12	0.70±0.18	1.29±0.61	1.61±0.47
p	<0.01	<0.01	0.19	0.04
Minute ventilation, L				
NM	11.13±2.32	17.66±3.60	33.83±8.63	66.75±11.61
SM	7.54±1.68	12.44±2.39	24.10±4.89	52.25±11.48
N95	7.92±1.64	12.88±2.30	26.43±6.26	48.58±7.46
p	<0.01	<0.01	<0.01	<0.01
$PETCO_2$, mmHg				
NM	31.2±3.4	34.9±4.8	41.4±4.8	45.9±3.7
SM	32.8±2.3	37.0±2.9	43.8±3.7	46.8±3.8
N95	35.2±3.6	38.7±3.6	45.8±4.3	49.7±4.1
p	0.01	0.06	0.03	0.03
Breathing frequency, bpm				
NM	19.3±2.9	19.3±2.9	26.0±5.9	38.4±6.0
SM	16.7±4.0	16.7±4.0	22.9±5.9	37.0±6.5
N95	16.0±4.0	16.0±4.0	22.5±5.3	34.6±7.9
p	<0.01	<0.01	0.02	0.28
Heart rate, bpm				
NM	83±15	97±17	136±18	176±12
SM	80±15	97±17	131±17	168±16
N95	80±10	97±12	135±17	172±13
p	0.66	0.98	0.44	0.08
VO_2, mL/min				
NM	336±69	532±88	1129±281	1653±401
SM	251±70	406±72	891±223	1345±325
N95	269±48	467±90	1030±277	1417±363
p	<0.01	<0.01	<0.01	<0.01
VO_2/HR, mL/min*bpm				
NM	4.2±1.4	5.6±1.4	8.4±2.1	9.6±2.3
SM	3.1±0.9	4.4±1.1	6.9±2.2	8.1±2.2
N95	3.4±0.9	4.9±1.2	7.7±2.1	8.3±2.4
p	<0.01	<0.01	<0.01	<0.01
FiO_2-FeO_2, %				
NM	3.7±0.6	3.8±0.7	4.2±0.6	3.2±0.4
SM	3.9±0.6	4.1±0.6	4.5±0.6	3.3±0.5
N95	4.1±0.6	4.5±0.5	4.8±0.4	3.6±0.5
p	0.07	<0.01	0.02	0.10

p for difference between participants in the NM, SM, and N95 conditions.
NM = no mask, SM = surgical mask, AT = anaerobic threshold, $PETCO_2$ = partial pressure end-tidal carbon dioxide, HR = heart rate, VO_2 = oxygen uptake, FiO_2 = fraction of inspiratory oxygen, FeO_2 = fraction of expiratory oxygen.

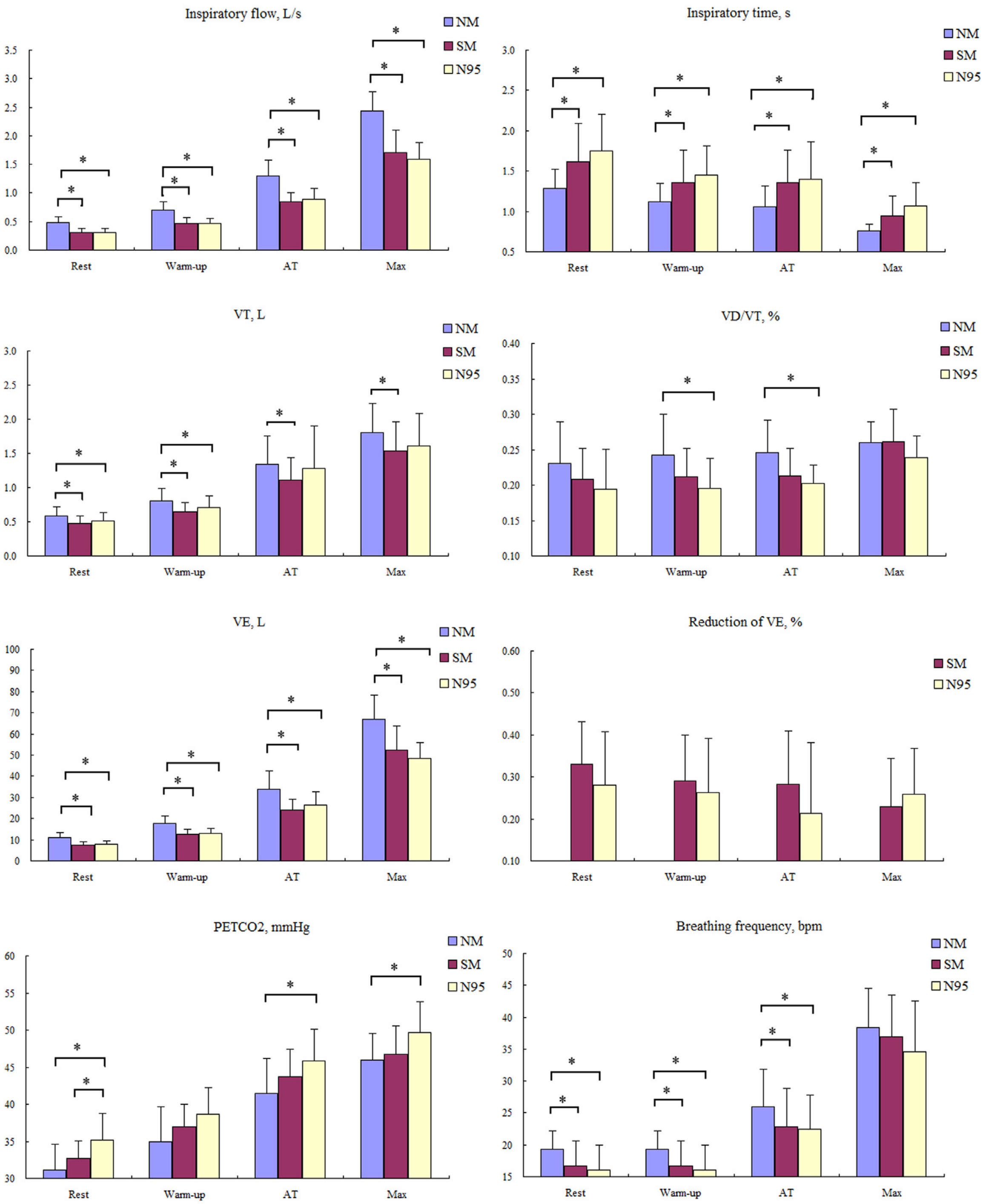

FIG. 2. Respiratory parameters from rest to maximal exercise. **p* < 0.05 between two groups. *Abbreviations*: NM, no mask, SM, surgical mask, VT, tidal volume, VE, minute ventilation, VD, dead space, $PETCO_2$, partial pressure end-tidal carbon dioxide

NM condition (Fig. 5; all $p < 0.05$). Furthermore, exercise time decreased, and the Borg scale increased in volunteers with SM and N95 compared to those without a mask (all $p < 0.05$). The maximal power was also lower in volunteers with an N95 than those without a mask ($p < 0.05$).

DISCUSSION

In our study, wearing a mask was associated with perceived shortness of breath and decreased exercise time. Wearing an N95 seems to be associated with more negative impact on exercise. The reasons for this may be rooted in a reduction of inspiratory flow, minute

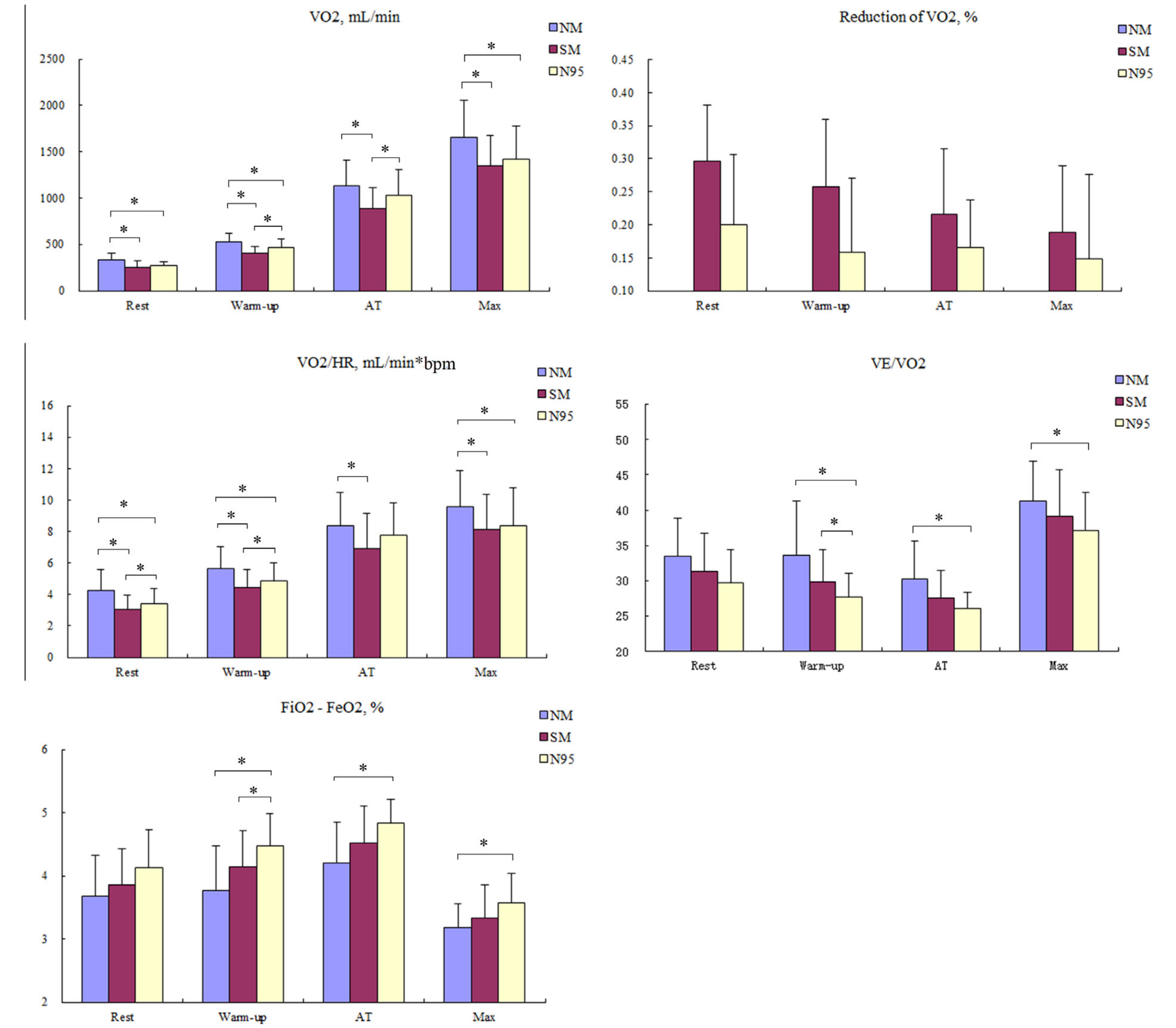

FIG. 3. Oxygenation consumption from rest to maximal exercise. *$p < 0.05$ between two groups. *Abbreviations*: NM, no mask, SM, surgical mask, VO_2, oxygen uptake, VE, minute ventilation, HR, heart rate, FiO_2, fraction of inspiratory oxygen, FeO_2, fraction of expiratory oxygen

ventilation, oxygen uptake, and oxygen pulse from rest to maximal exercise.

Wearing a mask is associated with decreased risk for infection, but it causes resistance to inhalation and exhalation. Previous studies have reported that wearing an SM or N95 is associated with reductions in FEV_1, FVC, and PEF at rest.[24,25] Another study reported that wearing an N95 leads to an increment of inspiratory and expiratory flow resistance.[26] In our study, we did not perform a pulmonary function test when the SM and N95 were used. However, we found that inspiratory flow was decreased and inspiratory time was prolonged at rest while wearing an SM or an N95. This indicates that inspiratory resistance increased while wearing an SM or an N95, which supports previous studies. Importantly, increased inspiratory resistance while wearing an SM or an N95 can increase inspiratory force, which is the main cause of dyspnea and decreased exercise tolerance.

Wearing an N95 was associated with higher $PETCO_2$ than in the NM condition. This supports the finding of a previous study.[27] In addition, we found a trend of lower VE/VO_2 and lower VE/VCO_2 in N95 than in NM. Thus, N95 had a negative impact on exercise. A previous study showed that wearing an N95 resulted in a reduction of air-exchange volume by 37%.[26] Another study showed that $PETCO_2$ was significantly higher after a 6-min walk with a mask than a walk without a mask in patients with

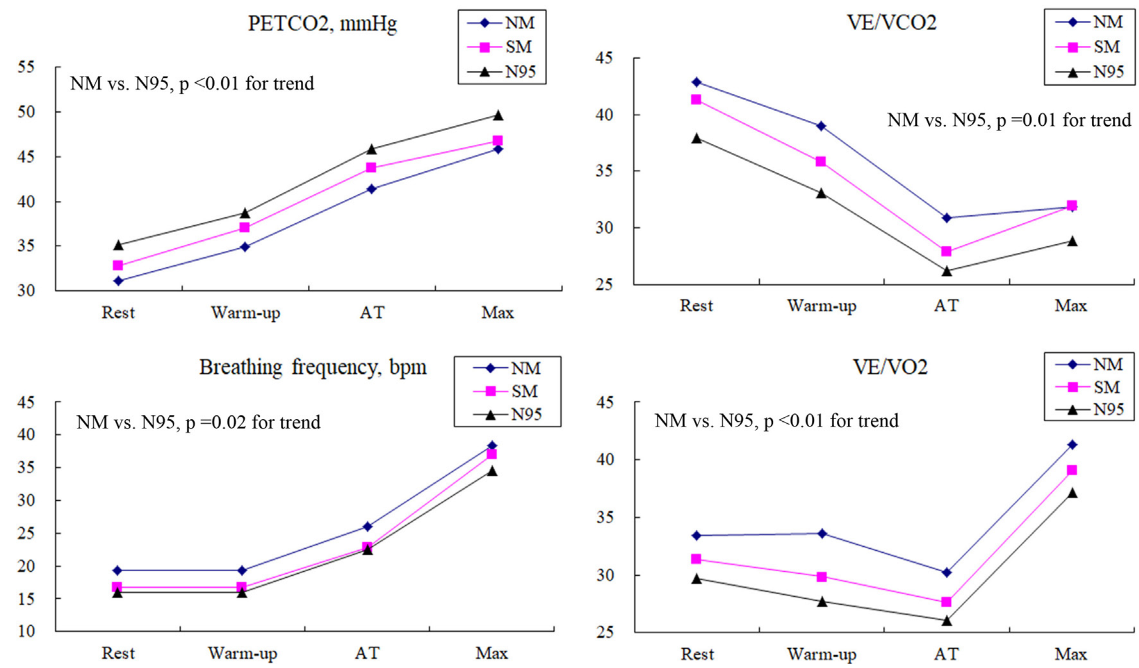

FIG. 4. Variation trend from rest to maximal exercise. *Abbreviations*: NM, no mask, SM, surgical mask, $PETCO_2$, partial pressure end-tidal carbon dioxide, VE, minute ventilation, VO_2, oxygen uptake, VCO_2, production of carbon dioxide

chronic obstructive pulmonary disease.[28] All of these results indicate that wearing an N95 could lead to an enlargement of dead cavities and repeated inhalation of CO_2 during exercise. This shows that exercise with a mask, particularly with an N95, produced the risk for CO_2 retention. In addition, ventilation efficacy (assessed by VE/VCO_2 and VE/VO_2) also decreased while wearing an N95 in our study. This could explain the severe impact of N95 on dyspnea and exercise tolerance. Thus, N95 masks should be worn during exercise only with caution, particularly during high-intensity exercise and in those with chronic pulmonary disease.

Fikenzer et al.[24] found no differences in tidal volume and VE at rest while wearing SM or N95 compared to NM. Mapelli et al.[25] found that the tidal volume was not different, but VE was reduced at rest, while wearing an SM or an N95, and only VO_2 was reduced while wearing an N95 compared to NM. However, we found that tidal volume, VE, VO_2, and VO_2/HR were decreased both at rest and warm-up, regardless of whether an SM or an N95 was worn. This indicates that wearing an SM or an N95 somewhat influences the cardiopulmonary function of routine low-intensity work.

VO_2/HR was higher at rest, warm-up, and maximal exercise while wearing an SM or an N95 in our study. Because no differences were seen in heart rate between the NM, SM, and N95 conditions, the reduction in VO_2/HR can be attributed to a reduction of VO_2. Wearing an SM or an N95 significantly increased respiratory resistance, which can lead to a reduction in VE.[26] This can explain why the oxygen uptake was reduced.

This study had several limitations. First, only 12 participants were enrolled. This small sample size was not able to identify sex-based differences. Second, one volunteer terminated the CPET due to hypertension. Thus, the cardiopulmonary effects of mask wearing on exercise may not be fully reflected. Third, the subjects in our study were young and had no chronic cardiopulmonary disease, inflammatory disease, or acute respiratory illness. Thus, these results cannot be directly extrapolated to other populations but can be used, with caution, as a reference.

Table 3. Reasons for failure to keep the ergometer at >50 rpm.

	NM	SM	N95	*p*
Unbearable leg weakening	11	11	8	
Unbearable dyspnea	0	2	5	0.21
Hypertension	1	1	1	

p for difference between participants in the NM, SM, and N95 conditions.
Some volunteers reported more than one reasons for failure to keep the ergometer >50 rpm.
One volunteer prematurely terminated CPET due to blood pressure beyond 200 mmHg.
NM = no mask, SM = surgical mask.

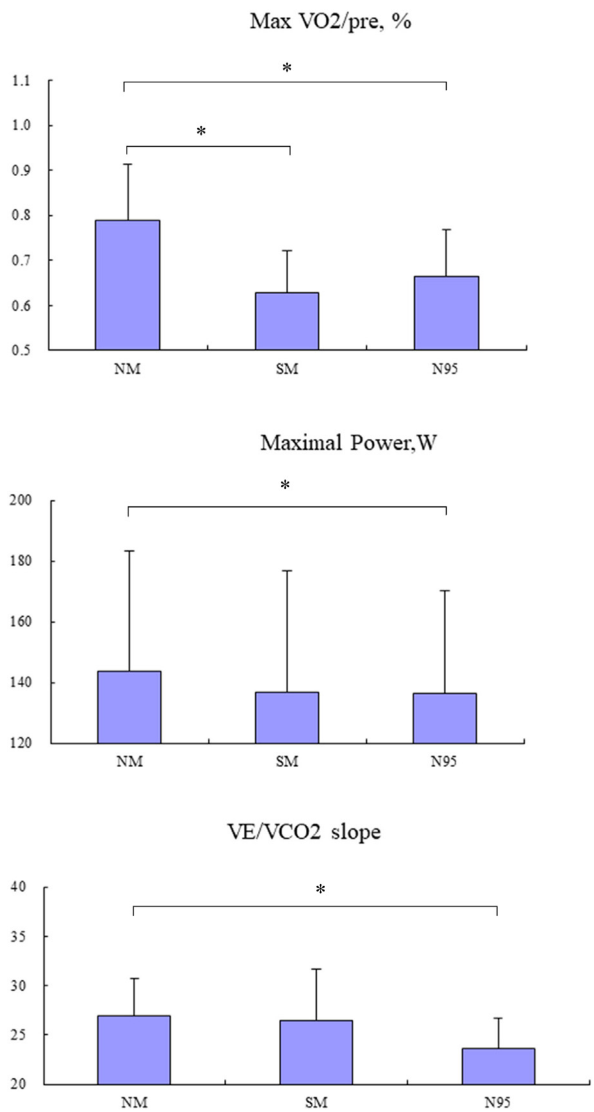

FIG. 5. Outcomes between NM, SM and N95. *Abbreviations*: NM, no mask, SM, surgical mask, VE, minute ventilation, VO_2, oxygen uptake, VCO_2, production of carbon dioxide

CONCLUSIONS

In healthy subjects, wearing an SM led to a somewhat negative impact on cardiopulmonary function, and this effect was greater for wearing an N95 mask. Attention should be paid to exercise while wearing an SM or an N95 mask.

AUTHORS' CONTRIBUTIONS

Lili Shui and Jun Duan conceived this study, performed the study design, data analysis and data interpretation, and drafted the manuscript. Lili Shui, Binbin Yang, Hong Tang, Yan Luo, Shuang Hu and Xiaoqing Zhong performed the CPET and joined in data collection. All of the authors read and revised the final version of the manuscript. Jun Duan took responsibility for the integrity of the work as a whole.

FUNDING

None.

CONFLICT OF INTEREST

We declare that there is no conflict of interest in this study.

ACKNOWLEDGEMENTS

We are grateful to the 12 healthcare workers in our hospital as volunteers to join in this study.

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Submitted June 8, 2021; accepted February 23, 2022.

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