Received: 7 July 2020 | Revised: 10 September 2020 | Accepted: 11 September 2020

DOI: 10.1111/sms.13832

ORIGINAL ARTICLE

WILEY

Return to training in the COVID-19 era: The physiological effects of face masks during exercise

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COVID-19 outbreak has a profound impact on almost every aspect of life. Universal masking is recommended as a means of source control. Routinely exercising in a safe environment is an important strategy for healthy living during this crisis. As sports clubs and public spaces may serve a source of viral transmission, masking may become an integral part of physical activity. This study aimed to assess the physiological effects of wearing surgical masks and N95 respirators during short-term strenuous workout. This was a multiple cross-over trial of healthy volunteers. Using a standard cycle ergometry ramp protocol, each subject performed a maximal exercise test without a mask, with a surgical mask, and with an N95 respirator. Physiological parameters and time to exhaustion were compared. Each subject served his own control. Sixteen male volunteers (mean age and BMI of 34 ± 4 years and 28.72 ± 3.78 kg/m^2, respectively) completed the protocol. Heart rate, respiratory rate, blood pressure, oxygen saturation, and time to exhaustion did not differ significantly. Exercising with N95 mask was associated with a significant increase in end-tidal carbon dioxide ($EtCO_2$) levels. The differences were more prominent as the load increased, reaching 8 mm Hg at exhaustion (none vs N95, $P = .001$). In conclusion, in healthy subjects, short-term moderate-strenuous aerobic physical activity with a mask is feasible, safe, and associated with only minor changes in physiological parameters, particularly a mild increase in $EtCO_2$. Subjects suffering from lung diseases should have a cautious evaluation before attempting physical activity with any mask.

KEYWORDS
Coronavirus disease 2019, face masks, personal distancing, physical activity, sport

1 | INTRODUCTION

On March 11, 2020, the World Health Organization (WHO) has declared the novel coronavirus (COVID-19) outbreak a global pandemic. With no vaccine and minimally effective treatment, most countries have taken a broad approach to decrease the viral spread, "flatten the curve" and avoid overwhelming the healthcare system. The public has been advised to reduce social contacts, avoid traveling, and stay at home in order to reduce human-to-human transmission.[1] The primary route of COVID-19 transmission is likely via small droplets ejected by carriers while speaking, breathing, coughing, or sneezing.[2,3] As a significant portion of carriers, especially young people, are asymptomatic, they serve the

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main source of the disease transmission.[3] Many health authorities recommend, and some even obligate, universal face masks usage by healthy individuals as a means of source control in public places.[4-6] Masks were found to be effective in reducing the spread of influenza and severe acute respiratory syndrome (SARS).[7,8] Surgical masks and N95 respirators were equally effective in preventing influenza among healthcare workers.[9] Recent preliminary reports support the effectiveness of face masks in the COVID-19 pandemic.[4,10]

The mandated restrictions have a major effect on the routine daily activities of billions of people worldwide. These safety measures lead to reduced physical activity and sedentary behaviors which in turn may translate into increased risk for obesity, cardiovascular morbidity, and depression.[11] Professional and recreational athletes, as well as sports club owners, are facing specific challenges during the recent crisis.[12,13] Sports authorities have been urged to develop an "exit strategy" that addresses the athletes' needs while complying with the healthcare recommendations. The new steps which may be necessary to ensure the safety of the trainees include maintaining social distancing of at least 2 meters between the athletes, regular disinfection of the equipment, preventing sick people from visiting sports facilities, and face masks usage by the trainees and the staff.

Although surgical masks and N95 respirators are widely used by healthcare personnel and workers in an atmospherically hostile environment, their usage during strenuous physical activity has never been evaluated and, although speculated in social media, their physiological impact during such activity is unknown.[14] This gap in knowledge might have an impact not only on the healthy population but also on the physical activity recommendations for patients with chronic diseases (ie, congestive heart disease and chronic obstructive pulmonary disease).

The primary objectives of this feasibility study were (a) to assess the ability of healthy subjects to perform maximal stress test while wearing a face mask and (b) to determine the physiological effects of wearing surgical masks and N95 respirators during short-term moderate-strenuous exertion tasks performed by healthy volunteers.

2 | MATERIALS AND METHODS

2.1 | Study design and subjects

The ethical committee of the Rambam Health Care Campus for the use of human subjects in research provided ethical approval of the study. The experiments were performed in accordance with the Helsinki declaration. Signed informed consent was obtained from all participants.

The study population consisted of healthy, non-smoking young adult male volunteers (age >18 years) who participate in regular recreational aerobic activity- jogging, running, or cycling for at least 75 minutes (vigorous-intensity activity) or 150 minutes (moderate-intensity activity) a week. Subjects were excluded if they were soldiers, inmates or had any known medical condition that may be exacerbated by strenuous physical activity, including diabetes mellitus, any chronic respiratory or cardiovascular disease, or acute respiratory illness (ie, pneumonia or upper respiratory tract disease) within 2 weeks before the study. Preparticipation physical examination was performed on all subjects to exclude any occult cardiac or respiratory illness.

Demographic data were collected by a questionnaire. Height (cm) and weight (kg) were measured for each subject and body mass index (BMI) was calculated. All the exercise tests were performed in a standardized manner on the same electrically braked bicycle ergometer (Ergoselect 100, Ergoline GmbH) located in an air-conditioned room with ambient temperature at 20-25°C and low relative humidity (≤50%). The participants performed dynamic stretching and a warm-up in concordance with personal preferences for 5-10 minutes. A standard cycle ergometry ramp protocol was used commencing at 25 watts. The load was then increased every 3 minutes by 25 watts until exhaustion.[15] A cycling rate of 55-65 revolutions per minute (rpm) was used. Immediately before and during the test, heart rate (HR), oxygen saturation (SO_2), respiratory rate (RR), and end-tidal carbon dioxide ($EtCO_2$) were continuously monitored by ePM 12M patient monitor (Mindray medical). Blood pressure (BP) was measured immediately before the test and at exhaustion. RR and $EtCO_2$ were measured through the Smart CapnoLine™ Plus (Medtronic) non-invasive nasal prongs. During the test, each subject was asked to rate the level of perceived exertion (RPE) on a scale from 1 to 10, every 3 minutes.[16] Total exercise time, defined as the time elapsed from exercise commencing to exhaustion, was recorded. As the exhaustion load varied between the subjects, the results were compared according to the percentage of the maximum load at each stage of the protocol.

This was a multiple cross-over, self-control trial. Each subject served as his own control and performed the test three times: (a) without a face mask (control); (b) wearing a surgical mask (Kimberly-Clark); and (c) wearing an N95 respirator (Duckbill style fluid shield 2 N95 particulate filter respirator, Halyard). To avoid bias, each subject's sequence of interventions was randomly assigned. The minimal time interval between the tests was 24 hours. Strenuous physical activity was prohibited during the 24 hours preceding the test, and a night sleep of at least 6 hours was mandated.

2.2 | Statistical analysis

As there is very little information to create baseline assumptions, we did not perform a formal sample size estimation.

Participants' characteristics were summarized with descriptive statistics. Mean (±standard deviation) and median (interquartile range) were used for the description of normally and non-normally distributed quantitative variables, respectively. Distribution normality was determined using histograms. To determine if there was a change in parameters following masking, a repeated measures analysis of variance (ANOVA) was conducted. Effect sizes for all outcomes were calculated as partial eta-squared (ηp^2) and interpreted as small (0.01), medium (0.06), or large (0.14).[17] Data analysis was conducted with the Statistical Package for the Social Sciences, version 23.0 (IBM SPSS Statistics for Windows, vVersion 23.0: IBM Corp) and Microsoft Excel version 14.0 (Microsoft Corporation).

3 | RESULTS

Sixteen male volunteers, that met the eligibility criteria, successfully completed the full study protocol (all the three training sessions). The mean age of the participants was 34 ± 4 years. The mean height, weight, and BMI were 179 ± 7 cm, 76.3 ± 11.8 kg, and 28.72 ± 3.78 kg/m^2, respectively. Four tests (8.33%) were performed after a minimally required rest of 24 hours, the mean time between the tests was 79.5 ± 40.8 hours. Six tests were performed after a maximal rest time of 144 hours.

Times to exhaustion were 18.9 ± 3.7 minutes without a mask, 18.3 ± 3.7 minutes with a surgical mask, and 18.5 ± 3.6 minutes with an N95 respirator. The differences were not statistically significant, $F(1.88,26.26) = 1.27$, $P = .3$. Systolic blood pressure at exhaustion also did not vary significantly between the study groups (143 ± 14 mm Hg without a mask, 143 ± 16 mm Hg with a surgical mask and 147 ± 16 mm Hg with N95), $F(2,22) = 0.05$, $P = .96$. The changes in the other physiological parameters (HR, RR, SO_2) and RPE during the exercise test are presented in Figure 1. The differences in HR, RR, SO_2, and RPE did not reach statistical significance at any stage of the protocol. The differences in $EtCO_2$ at different stages of the test are presented in Table 1 and Figure 2. No significant differences were noted in the $EtCO_2$ level in subjects exercising with surgical masks vs no masks but in the last stage of the workout. On the other hand, wearing N95 respirator was associated with higher $EtCO_2$ values at most phases of the exercise, compared to exercise performed without a mask. The ηp^2 statistic indicated a large effect size ($\eta p^2 > 0.22$) between the groups.

4 | DISCUSSION

Our findings demonstrate that strenuous aerobic exercise, as measured during a standardized maximal bicycle stress testing, can be safely performed by healthy young volunteers

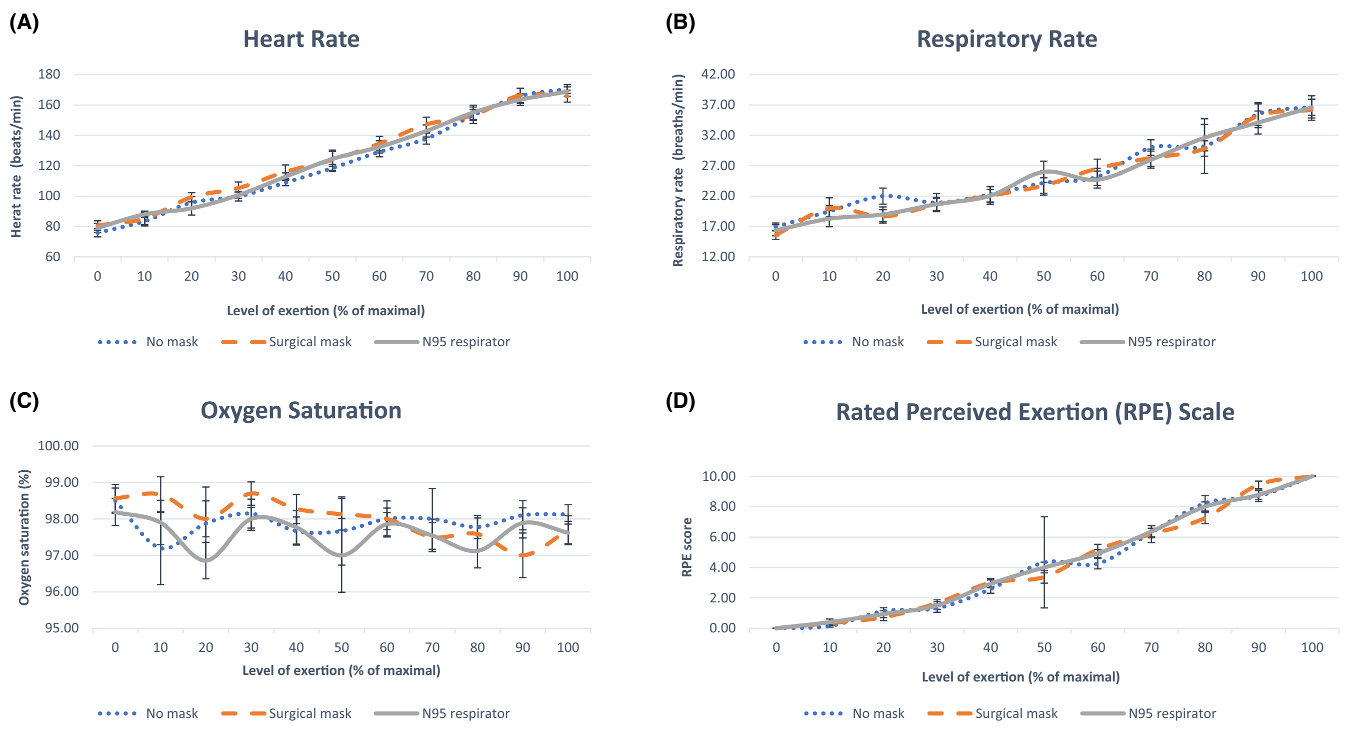

FIGURE 1 Mean changes in physiological parameters throughout the exercise test performed by 16 subjects without a mask, with a surgical mask, and with N95 respirator. A, Heart rate (beats/min). B, Respiratory rate (breaths/min). C, Oxygen saturation (%). D, Rated Perceived Exertion (RPE) Scale (score). Error bars represent 95% confidence interval

TABLE 1 Comparison of mean end-tidal carbon dioxide level (mm Hg) at different exercise levels without mask, with surgical mask, and with N95 respirator

	Mean $EtCO_2$, mm Hg (SD)				Pairwise comparisons (*P*-value)		
Level of workout (% until exhaustion)	None	Surgical mask	N95 respirator	Within-subjects effect (F, P-value, ηp^2)	None vs Surgical mask	None vs N95 respirator	Surgical mask vs N95 respirator
0% (Rest)	39 (2)	39 (4)	41 (3)	$F(2,30) = 4.31$, $\boldsymbol{P = .02}$, $\eta p^2 = 0.22$	1	***0.03***	0.1
10%	42 (4)	44 (5)	45 (4)	$F(1.94, 9.72) = 5.68$, $\boldsymbol{P = .02}$, $\eta p^2 = 0.53$	1	***0.01***	0.23
30%	43 (3)	46 (5)	48 (4)	$F\ (2,20) = 5.5$, $\boldsymbol{P = .01}$, $\eta p^2 = 0.35$	0.77	***0.03***	0.19
60%	43 (7)	46 (5)	49 (3)	$F(2,12) = 2.86$, $P = .1$, $\eta p^2 = 0.32$	--	--	--
90%	39 (5)	40 (4)	44 (4)	$F(2,8) = 5.08$, $\boldsymbol{P = .04}$, $\eta p^2 = 0.56$	0.89	0.2	0.16
100% (exhaustion)	35 (6)	40 (4)	43 (4)	$F(2,30) = 13.42$, $\boldsymbol{P < .001}$, $\eta p^2 = 0.47$	***0.04***	***0.001***	***0.04***

Abbreviations: $EtCO_2$, end-tidal carbon dioxide; SD, standard deviation; ηp^2, partial eta-squared.
Statistically significant differences are highlighted by bold italic font.

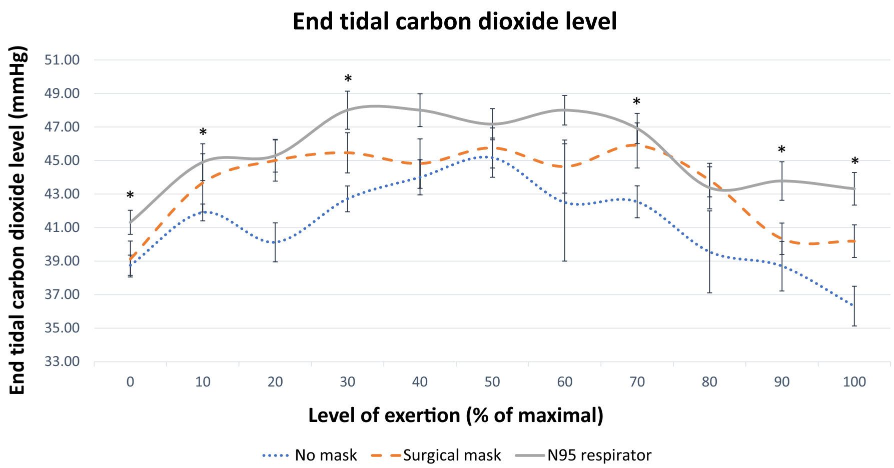

FIGURE 2 Mean changes in end-tidal carbon dioxide throughout the exercise test performed by 16 subjects without a mask, with a surgical mask, and with N95 respirator. Error bars represent 95% confidence interval. *indicate significant differences ($P < .05$)

with either a surgical mask or an N95 respirator. Nonetheless, physical activity with a face mask is associated with a mild but significant rise in carbon dioxide (CO_2) partial pressure which is more prominent as the level of the workout is increased and with N95 respirator.

Participation in some form of physical activity is a core component of maintaining a healthy lifestyle, and routinely exercising in a safe environment is an important strategy for healthy living, especially during the coronavirus crisis. Mass masking for source control is a useful and low-cost adjunct to social distancing and hand hygiene during the COVID-19 pandemic.[5] The US Centers for Disease Control and Prevention recommends wearing a mask or cloth face-covering in public, especially in places where maintaining social distancing is difficult.[18] Several countries and some parts of the US have made this practice mandatory.[6] As sports clubs, gyms, and public spaces may serve an important source of viral transmission, masking may become an integral part of physical activity.[19] This measure might be even more important during aerobic activity, such as running or biking, as some preliminary studies show that small droplets can spread as far as 5 meters while walking at a pace of 4 km/h and 10 meters when running at 14.4 km/h.[20]

Our knowledge regarding the safety and physiological effects of masking during physical activity is scant and based primarily on studies performed during the routine work of health care personnel. Nonetheless, it is concordant with our findings. Previous studies found that the primary effect of masking during physical activity is a mild increase in $EtCO_2$ concentration occurring during mild to moderate workout. Roberge et al assessed the effect of wearing an N95 mask during 1-hour treadmill walking sessions, at 1.7 miles/h, and at 2.5 miles/h, among healthy healthcare workers. The researchers found no significant differences between the mask and the control group in physiological variables, exertion scores, or comfort scores. However in the N95 group, the dead-space CO_2 and oxygen levels were significantly above and below, respectively, the ambient workplace standards and the researchers noted that an elevated partial pressure of CO_2 is possible.[21] The effect of wearing a mask during short walking (5-6 minutes) was evaluated by Person et al and Chen et al Both found that wearing either a surgical mask or N95 was associated with increased respiratory muscle effort but no differences were found in other parameters.[22,23] Our results stretch these findings to demonstrate that the same holds true in healthy volunteers performing strenuous exercise. It must be noted, however, that subjects with pulmonary comorbidity may be much more affected by masking. For example, in patients with chronic obstructive pulmonary disease (COPD) usage of N95 mask was associated with increased HR, RR, and $EtCO_2$ during rest and 6-minute walk test. SpO2 levels were significantly lower during walking with N95.[24]

Our findings demonstrate that using a mask during aerobic training has only minimal and statistically inconsistent effects on major physiological parameters such as HR, RR, BP, and SO_2. However, as shown in previous studies, wearing N95 respirator during aerobic activity is associated with increased $EtCO_2$ at rest and any level of exertion. The effect of the surgical mask on $EtCO_2$ is milder and seems to be significant only during a heavy workout. The increase in $EtCO_2$ may be explained by the fact that re-breathing of the expired air which remains within the mask practically increases the dead space and may contribute to a mild hypercapnia. Breathing through a face mask is also associated with increased resistance. Previous studies found that the use of N95 respirators leads to a mean increment of 126% and 122% in inspiratory and expiratory flow resistances, respectively.[25]

Acute respiratory acidosis can cause headache, confusion, anxiety, decreased exercise tolerance, and at extreme levels, dim vision, vomiting, disorientation, hemodynamic instability, drowsiness, and stupor (CO_2 narcosis).[26] Prolonged exposure to mildly increased levels of CO_2 is commonly referred to as “sick building syndrome” and may cause headache, fatigue, difficulty concentrating, and increase in HR and BP.[27] The effect of mild and short-term elevation of the partial pressure of CO_2 on physical and cognitive performances is unknown. Intermittent exposure to mildly increased CO_2 during training with an elevation training mask can contribute to improved respiratory adaptation, decreasing the rate of fatigue of the respiratory muscles.[28] In rats, transcutaneous CO_2 exposure during aerobic training was beneficial for performance and muscle development during endurance exercise. The authors speculated that it may enhance recovery from fatigue.[29] Although a mild increase observed in our study is unlikely to produce acute symptoms in healthy trainees, it may cause a slight shortness of breath. The effect of prolonged training with a mask on physical and cognitive performances was beyond the scope of this study and should be evaluated prospectively.

Another important aspect that was not addressed in our study is the effect of masks on thermoregulation. The use of protective facemasks may negatively impact respiratory and dermal mechanisms of human thermoregulation through impairment of convection, evaporation, and radiation processes. However, Roberge et al found that wearing surgical masks and N95 respirators during usual work activities for 30 minutes was associated with insignificant increases in tympanic temperature of 0.07 and 0.03°C, respectively.[30] The effect of masking during more strenuous and prolonged activity was not studied.

Interpretation and generalization of our results should be cautious at this point as we tested the physiological effect of applying a mask during exercise only on healthy non-smoking volunteers. The small but significant increase in $EtCO_2$ may be much more pronounced in subjects with obstructive lung disease and the increased respiratory muscle effort may be much more crucial in subjects with heart disease and reduced cardiac output. The safety of face masks should be evaluated in specifically designed studies before considering physical activity with a respirator in these unique populations.

Our study has some additional limitations. First, the effect of surgical masks and N95 respirators was not tested in a large number of subjects and the effect of factors such as fitness, gender (only males were included in this trial), age, and BMI should be additionally addressed. Second, different mask models and designs may have different effects on different physiological parameters. Third, the physiological effect of masking may vary with different physical activities in different settings. Forth, the effect of masking on thermoregulation during prolonged strenuous exercise was not addressed in our study and should be evaluated separately. Fifth, the resting time between the tests was not standardized and some trainees performed a test after a short recovery period of 24 hours.

5 | PERSPECTIVE

In healthy subjects, aerobic exercise with either a surgical mask or N95 respirator is safe and feasible. Although it may be associated with some discomfort, masking has only minor effects on physiological parameters during exercise. Subjects with obstructive lung diseases such as asthma or COPD and heart diseases should undergo meticulous evaluation before attempting physical activity with a mask.

CONFLICT OF INTEREST

AR is a consultant and received research support from Medtronic (not related to this study). All the other authors declare that they have no conflicts of interest.

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How to cite this article: Epstein D, Korytny A, Isenberg Y, et al. Return to training in the COVID-19 era: The physiological effects of face masks during exercise. *Scand. J. Med. Sci. Sports*. 2021;31:70–75. https://doi.org/10.1111/sms.13832