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ORIGINAL RESEARCH

A Cloth Facemask Causes No Major Respiratory or Cardiovascular Perturbations During Moderate to Heavy Exercise

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Purpose: Investigate whether a cloth facemask could affect physiological and perceptual responses to exercise at distinct exercise intensities in untrained individuals. ***Methods:*** Healthy participants (n = 35; 17 men, age 30 [4] y, and 18 women, age 28 [5] y) underwent a progressive square wave test at 4 intensities: (1) 80% of ventilatory anaerobic threshold; (2) ventilatory anaerobic threshold; (3) respiratory compensation point; and (4) exercise peak (Peak) to exhaustion, 5-minute stages, with or without a triple-layered cloth facemask (Mask or No-Mask). Several physiological and perceptual measures were analyzed. ***Results:*** Mask reduced inspiratory capacity at all exercise intensities ($P < .0001$). Mask reduced respiratory frequency ($P = .001$) at Peak (–8.3 breaths·min^{-1}; 95% confidence interval [CI], –5.8 to –10.8), respiratory compensation point (–6.9 breaths·min^{-1}; 95% CI, –4.6 to –9.2), and ventilatory anaerobic threshold (–6.5 breaths·min^{-1}; 95% CI, –4.1 to –8.8), but not at Baseline or 80% of ventilatory anaerobic threshold. Mask reduced tidal volume ($P < .0001$) only at respiratory compensation point (–0.5 L; 95% CI, –0.3 to –0.6) and Peak (–0.8 L; 95% CI, –0.6 to –0.9). Shallow breathing index was increased with Mask only at Peak (11.3; 95% CI, 7.5 to 15.1). Mask did not change HR, lactate, ratings of perceived exertion, blood pressure, or oxygen saturation. ***Conclusions:*** A cloth facemask reduced time to exhaustion but had no major impact on cardiorespiratory parameters and had a slight but clinically meaningless impact on respiratory variables at higher intensities. Moderate to heavy activity is safe and tolerable for healthy individuals while wearing a cloth facemask. ClinicalTrials.gov: NCT04887714.

Keywords: mask, COVID-19 pandemic, oxygen saturation, lactate

The use of face masks has been deemed as one of the most effective nonpharmacological strategy to prevent severe acute respiratory syndrome coronavirus 2 infections.[1,2] The recent resurgence of cases and deaths worldwide has led to some decision makers to reissue mask orders to contain the disease, suggesting that this safety tool will remain important as long as the pandemic is not fully mitigated.[3] Furthermore, several cultures employed facemasks as a routine practice to protect against health threats prior to the COVID-19 pandemic[4] and will likely to continue to do so long after it is under control. Wearing a facemask is recommended even during exercise, particularly at indoor fitness facilities and gyms, where COVID-19 outbreaks have been reported.[5] Nevertheless, the physiological impact of facemasks during exercise remains underexplored.

Facemasks and respirators may reduce the ability to breathe comfortably during exercise, which has been confirmed by some[6,7] (using cloth facemask and FFP2/N95 respirators), but not all studies[8] (using cloth or disposable surgical facemasks). It is possible to conjecture that the effects of wearing a mask on cardiorespiratory responses may manifest during exhaustive high-intensity exercise, but not manifest (or manifest less) during low- to moderate-intensity exercise. In fact, Driver et al[6] provide preliminary evidence that the effect of cloth facemasks is dependent on exercise intensity, with differences in oxygen saturation, ratings of perceived exertion (RPE), and dyspnea occurring at different stages of an incremental cardiopulmonary test as exercise intensity increased. However, short-stage maximal incremental tests do not normalize the physiological responses to exercise in relation to the gas exchange or blood acid–base profiles,[9,10] since percentage of maximal oxygen uptake at the ventilatory thresholds largely varies between individuals,[9] hampering accurate determination of exercise intensities and ultimately confounding data interpretation.[10,11] To overcome this limitation, constant load tests based on the dynamic behavior of the pulmonary gas exchange and blood acid–base status have been recommended to accurately determine exercise intensity domains (ie, moderate, heavy, severe, and extreme).[10] This approach allows determination of whether facemasks affect physiological and perceptual parameters at different, well-defined exercise intensities, helping tailor exercise prescription for health that can minimize any negative effects of wearing a mask on cardiorespiratory responses.

Another remaining question is whether women and men respond differently to mask wearing during exercise. Generally, women have smaller lungs and airways, which limits their ability to generate expiratory flow,[12–17] resulting in reduced ventilation during exercise compared with men. Women also have lower oxygen (O_2) carrying capacity, maximum cardiac output, and arteriovenous O_2 difference.[18] Considering the number of

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physiological and morphological sex differences to exercise, one could speculate that any physiological perturbations brought about wearing a mask during exercise could be greater in women, since men have an overall higher cardiorespiratory reserve.

This study aimed to investigate whether wearing a cloth facemask could affect physiological and perceptual responses to exercise at distinct exercise intensities in untrained individuals. A secondary aim was to test whether women and men are affected differently by wearing a mask during exercise.

Methods

Ethics Statement

The protocol was approved by the institutional Ethics Committee for Analysis of Research Projects (approval number 38569420.0.0000.0068). Written informed consent was obtained before participants' enrollment. This study was conducted according to the Declaration of Helsinki.[19]

Study Design and Setting

This was a crossover study (ClinicalTrials.gov: NCT04887714) performed at an intrahospital, exercise physiology laboratory in São Paulo, Brazil. Data collection took place between April and November 2021.

Participants

Men and women who were not trained[20] were eligible for this study. Exclusion criteria included any cardiac, pulmonary, and rheumatologic diseases; musculoskeletal limitations; or a body mass index < 18.5 or > 30 kg/m^2. A total of 18 men and 20 women entered the study, although 3 (~8%) dropped out citing personal reasons. Thirty-five individuals (17 men and 18 women) completed all main sessions (age, women: 28 [5] y and men: 30 [4] y; body mass index, women: 22.9 [2.0] kg/m^2 and men: 24.5 [2.6] kg/m^2) and were analyzed (see Supplementary Figure S1 [available online]). Menstrual cycle phase and oral contraceptive use were not recorded. According to the short form of the International Physical Activity Questionnaire instrument,[21] 31 participants were physically active, whereas, 4 were sedentary/inactive (Table 1). All participants reported to be habituated to wear a mask during their daily routines in response to the mask mandates. Specifically, during exercise, participants reported to be habituated to wearing cloth masks (n = 18), surgical masks (n = 11), N95 masks (n = 1), or not wearing any mask (n = 5). Before attending each laboratory session, participants were questioned regarding COVID-19-related symptoms. No participant reported any positive test result for COVID-19 or any symptoms suggestive of this disease throughout the study.

Experimental Design

Participants attended the laboratory on 3 separate occasions, separated by a minimum of 48 hours, at the same time of day to account for circadian variation.[22] The first visit consisted of an incremental cardiopulmonary running test to exhaustion to determine peak oxygen uptake and ventilatory thresholds. The remaining 2 main visits consisted of a running progressive square wave test (PSWT), performed with or without the use of a triple-layered antiviral cloth facemask (fashion masks). The outer layer of the mask was a waterproof polyester fabric, the middle layer was a polypropylene filter, and the inner layer was absorbable cotton. This facemask was chosen because it is widely accessible, recommended to the general public by the CDC, and appropriate for exercise.[23] Participants were required to keep the mask in place over the nose, mouth, and chin during the entire session. Sweating rate was not controlled, but the mask could be changed if participants reported it became wet from

Table 1 Participants' Characteristics and Cardiorespiratory Data From the Incremental Cardiopulmonary Exercise Test From Which Individual Exercise Intensities Were Calculated

	Women (n = 18)	Men (n = 17)
Age, y	28 (5)	30 (4)
Weight, kg	60.9 (9.0)	73.96 (8.1)
Height, m	1.63 (0.07)	1.74 (0.07)
80%VAT		
Heart rate, bpm	115 (12)	109 (20)
Respiratory exchange ratio	0.79 (0.11)	0.83 (0.07)
Minute ventilation, L·min^{-1}	25.4 (5.5)	34.4 (10.7)
VO_2 absolute, L·min^{-1}	1.01 (0.19)	1.43 (0.4)
VO_2 relative, mL·kg^{-1}·min^{-1}	16.2 (3.2)	19.4 (6)
VO_2 %peak, %	42.1 (7.9)	39.8 (10.5)
Speed, km·h^{-1}	5.8 (0.5)	6.2 (1.2)
Inclination, %	1.1 (0.3)	1.2 (0.4)
VAT		
Heart rate, bpm	128 (13)	122 (17)
Respiratory exchange ratio	0.85 (0.09)	0.89 (0.06)
Minute ventilation, L·min^{-1}	32.6 (6.4)	44.7 (10.2)
VO_2 absolute, L·min^{-1}	1.25 (0.21)	1.83 (0.35)
VO_2 relative, mL·kg^{-1}·min^{-1}	20.7 (3.5)	24.9 (5.5)
VO_2 %peak, %	53.6 (7.5)	51.4 (9.8)
Speed, km·h^{-1}	6.6 (0.5)	7.6 (1.7)
Inclination, %	1.5 (0.5)	1.4 (0.5)
RCP		
Heart rate, bpm	168 (9)	161 (10)
Respiratory exchange ratio	1.02 (0.05)	1.04 (0.05)
Minute ventilation, L·min^{-1}	64.3 (10.9)	83.5 (14.8)
VO_2 absolute, L·min^{-1}	2 (0.24)	2.75 (0.35)
VO_2 relative, mL·kg^{-1}·min^{-1}	33.1 (3.6)	37.2 (4.9)
VO_2 %peak, %	86.1 (8.4)	77.0 (8.0)
Speed, km·h^{-1}	9.8 (1.1)	11.3 (1.5)
Inclination, %	1.0 (0.0)	1.2 (0.7)
Peak		
Heart rate, bpm	183 (6)	183 (6)
Respiratory exchange ratio	1.18 (0.06)	1.22 (0.07)
Minute ventilation, L·min^{-1}	95.3 (15.3)	139.4 (25.1)
$\dot{V}E/MVV$	0.73 (0.13)	0.77 (0.16)
VO_2 absolute, L·min^{-1}	2.33 (0.26)	3.59 (0.45)
VO_2 relative, mL·kg^{-1}·min^{-1}	38.7 (4.6)	48.6 (6.3)
Speed, km·h^{-1}	11.8 (0.5)	13.8 (0.5)
Inclination, %	3.3 (2.2)	5.1 (2.5)

Abbreviations: bpm, beats per minute; RCP, respiratory compensation point; VAT, ventilatory anaerobic threshold; $\dot{V}E/MVV$, minute ventilation/maximum voluntary ventilation ratio. Note: Cardiopulmonary exercise test was performed without a cloth facemask. Values are presented as mean (SD).

sweat. However, no participant asked for it to be changed until the exhaustive stage had already been completed. The breath-by-breath facemask was placed over the cloth facemask (see Supplementary Figure S2 [available online]), and participants were required to exhale as forcefully as possible while blocking the inlet/outlet hole, allowing the researchers to adjust the mask to ensure minimal air escaping. The order of sessions was determined by an individual not involved in data collection. Blocks of 2 individuals were allocated to the 2 possible orders (Mask–No Mask; No Mask–Mask) using a random number generator (https://www.randomizer.org/) to ensure the study was counterbalanced. As the investigators could see that the participants were wearing a cloth facemask or not, the session order was provided directly to the research team. Participants were requested to refrain from strenuous exercise, caffeine, and alcohol, and replicated their diet, in the 24 hours prior to each visit. All the research staff wore an N95 mask during the entire test sessions, in accordance with the COVID-19 prevention protocol adopted by the institution.

Cardiorespiratory Exercise Test

Immediately prior to the cardiorespiratory exercise test, participants performed a pulmonary function test according to recommendations.[24] The cardiorespiratory exercise test was performed on a motorized treadmill (Centurion 300, Micromed) using a stepwise increase in workload each minute. For men, the test started at 5 $km{\cdot}h^{-1}$ and increased speed (1 $km{\cdot}h^{-1}{\cdot}min^{-1}$) up to a maximum velocity of 14 $km{\cdot}h^{-1}$. For women, the test started at 4 $km{\cdot}h^{-1}$ and increased speed (1 $km{\cdot}h^{-1}{\cdot}min^{-1}$) up to 13 $km{\cdot}h^{-1}$. For those participants who reached these maximal speeds, there was a subsequent increase in inclination ($2\%{\cdot}min^{-1}$) until exhaustion. Ventilatory and gas exchange measurements were recorded continuously throughout the test using a breath-by-breath system (MetaLyzer 3B, Cortex), as was heart rate (HR; ergo PC elite, Micromed). Maximal effort was determined according to published criteria[25] and individual peak oxygen uptake was determined as the $\dot{V}O_2$ averaged over the final 30 seconds. The cardiorespiratory test was performed without a cloth facemask.

The ventilatory anaerobic threshold (VAT) was determined to occur at the breakpoint between the increase in the carbon dioxide output and $\dot{V}O_2$ (V-Slope), or at the point at which the minute ventilation/carbon dioxide production ($\dot{V}E/\dot{V}O_2$) reached a minimum value and began to rise without a concomitant rise in the ventilatory equivalent for carbon dioxide ($\dot{V}E/\dot{V}CO_2$).[26] The respiratory compensation point (RCP) was determined to be the point at which the $\dot{V}E/\dot{V}CO_2$ reached a minimum value and began to rise and the carbon dioxide partial pressure ($PetCO_2$) reached its highest value before its progressive fall.

Progressive Square Wave Test

Data from the cardiorespiratory exercise test were used to determine exercise workload for the square wave treadmill test according to the VAT and the RCP. The PSWT protocol was performed on a motorized treadmill (Centurion, model 200, Micromed) and consisted of three 5-minute stages at workloads equivalent to (1) 80%VAT, (2) VAT, and (3) RCP. These stages represented moderate, heavy, and severe domains[10] and corresponded to 41% (9%), 53% (9%), and 81% (8%) of peak oxygen uptake of the volunteers. Participants then completed a final stage to exhaustion at a running speed equivalent to the maximum achieved during the cardiorespiratory exercise test (Peak). Ventilatory and gas exchange measurements were recorded continuously throughout using a breath-by-breath system (MetaLyzer 3B, Cortex), with the spirometer mask placed over the cloth facemask.

To determine the effect of the mask on pattern of change in operating lung volumes, we evaluated end-expiratory lung volume to functional vital capacity (FVC) ratio. Inspiratory capacity was determined at rest and at the end of each exercise stage during the PSWT. Ventilatory constraint was evaluated as the difference between inspiratory capacity at rest and at each exercise workload.[27] Ventilatory efficiency was determined using the $\dot{V}E/\dot{V}CO_2$ and end-tidal $PetCO_2$ during each stage. Breathing pattern was evaluated during each stage using the breathing frequency to tidal volume ratio ratio.[28]

The RPE were assessed at the end of each stage with participants pointing to a chart using the 6- to 20-point Borg scale.[29] How to use the scale was fully explained to each participant by a member of the research team. HR was monitored continuously throughout (ergo PC elite, Micromed). A fingertip blood sample (20 μL) was collected at baseline, at the end of each stage, and 4-minute postexhaustion for the subsequent analysis of lactate. Blood was homogenized in the same volume of 2% NaF; centrifuged at 2000 g for 5 minutes before plasma was removed, and stored at −20 °C until analysis. Plasma lactate was determined spectrophotometrically using an enzymatic–colorimetric method (Katal, Interteck). The temperature and relative humidity in the laboratory were kept at ~22 °C and ~65% during the exercise sessions.

Subjective Perception of Discomfort Questionnaire

Participants completed a questionnaire[30] following the completion of the PSWT to rate their perception of ten sensations of discomfort (ie, humidity, heat, breathing resistance, itchiness, tightness, saltiness, feeling unfit, odor, and fatigue) related to the spirometry mask versus spirometry mask plus cloth mask. They were also required to rate their overall feeling of discomfort on a scale from 0 to 10, with 0 to 3 representing "Comfortable," >3 to 7 representing "Uncomfortable," and >7 representing "Extremely uncomfortable."

Statistical Analyses

Repeated-measures mixed model analyses of variance were performed with condition (Mask and No-Mask), sex (female and male), and exercise intensity (Baseline [except RPE], 80%VAT, VAT, RCP, and Peak) as fixed factors and participants as random factors; the order of conditions was used as a covariate. Exceptions were spirometry, time to exhaustion (TTE), and questionnaire-related outcomes, which were not repeated measures and, therefore, intensity was not included as a fixed factor. For TTE, the model was corrected by treatment order, since participants were not familiarized to the protocol. Lactate data were log10 transformed before mixed model analysis, turning the model into an exponential data mixed model, and transformed back through exponentiation for the final reporting of data. Whenever outlying data points were considered improbable (eg, a value of 50 mm Hg for systolic blood pressure), they were considered measurement or transcription error and were excluded. When a significant main effect or interaction was detected, post hoc pairwise comparisons were performed with Tukey adjustment. Cohen *d* effect sizes were calculated for pairwise comparisons with the estimated means derived from the mixed models and their variances (sigma), along with the number of degrees of freedom for each pairwise comparison. All analyses were performed with the RStudio software (Rstudio 1.4.11003, PBC) using the "lmer" function of the lmerTest package, "emmeans" and "eff size" functions of the emmeans package. SEs were transformed into 95% confidence intervals (CIs). Values are expressed as estimated differences and 95% CIs, and data in figures are represented as mean ± 1SD. The significance threshold was set as $P < .05$.

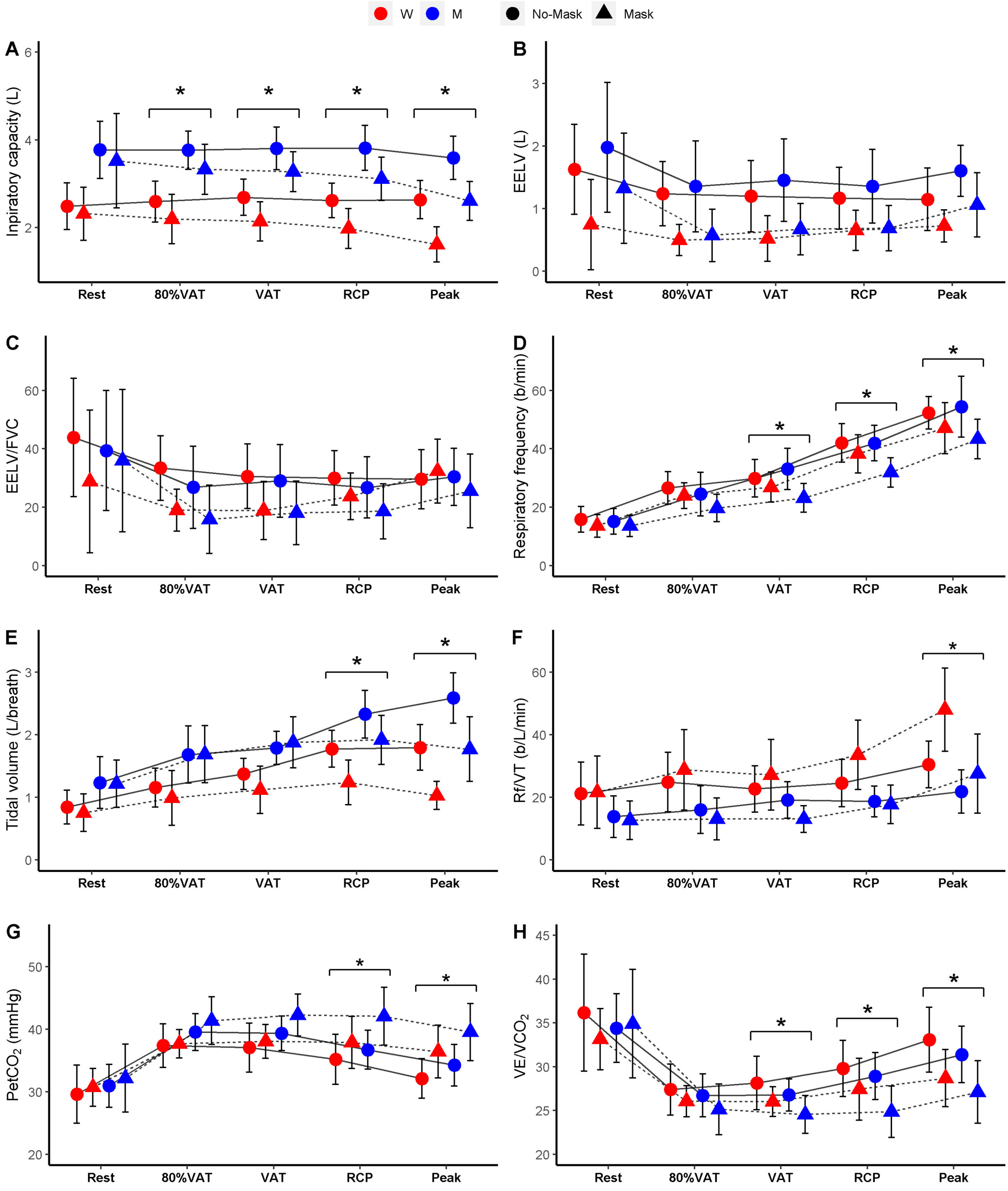

Figure 1 — Inspiratory capacity, EELV, EELV by FVC ratio (EELV/FVC), respiratory frequency, tidal volume, respiratory frequency by tidal volume, $PetCO_2$, and $\dot{V}E/\dot{V}CO_2$ data expressed as mean ± 1 SD. Continuous and dashed lines connect performance data between No-Mask and Mask conditions. *Significant interaction detected by the mixed model between condition and intensity (Mask and No-mask) irrespective of sex (condition × intensity). EELV indicates end-expiratory lung volume; FVC, forced vital capacity; M, men; $PetCO_2$, CO_2 partial pressure; RCP, respiratory compensation point; VAT, ventilatory anaerobic threshold; $\dot{V}E/\dot{V}CO_2$, ventilatory equivalent for carbon dioxide; W, women.

Results

Lactate data from 2 individuals (1 male and 1 female) who did not complete the third stage were excluded from the RCP and peak analyses. Furthermore, 1 male and 1 female reported "discomfort" (difficulty to breath) while wearing the mask and stopped exercising before volitional exhaustion; as they did not complete Peak, their dataset relative to this stage had to be excluded, but submaximal data were maintained in the analyses. Therefore, there were no TTE data for those 4 subjects who did not complete the entire exercise protocol.

Cardiorespiratory Exercise Test

Participants' characteristics and respiratory data at the ventilatory thresholds and calculated stages are presented in Table 1.

Progressive Square Wave Test

Inspiratory Capacity. Mask reduced inspiratory capacity at all exercise intensities (interaction effect condition × intensity: $F_{4,283} = 8.6$, $P < .0001$; Figure 1A) compared with No-Mask irrespective of sex (80%VAT: −0.4 L; 95% CI, −0.2 to −0.6; VAT: −0.5 L; 95% CI, −0.4 to −0.7; RCP: −0.7 L; 95% CI, −0.5 to −0.9; Peak: −1.0 L; 95% CI, −0.8 to −1.2) except at Baseline (−0.2 L; 95% CI, 0.0 to −0.4).

End-Expiratory Lung Volume and End-Expiratory Lung Volume/FVC. Mask did not influence EELV or end-expiratory lung volume/FVC, irrespective of exercise intensities and sex (all $P \geq .1$; Figure 1B and 1C).

Respiratory Frequency. Mask reduced respiratory frequency (Rf) versus No-Mask (interaction effect of condition × intensity: $F_{4,288} = 4.6$, $P = .001$; Figure 1D) at Peak (−8.3 breaths·min^{-1}; 95% CI, −5.8 to −10.8), RCP (−6.9 breaths·min^{-1}; 95% CI, −4.6 to −9.2), and VAT (−6.5 breaths·min^{-1}; 95% CI, −4.1 to −8.8), but not at Baseline or at 80%VAT (both $P \geq .06$). Rf was reduced similarly in men (−7.5 breaths·min^{-1}; 95% CI, −6.0 to −9.0) and women (−3.4 breaths·min^{-1}; 95% CI, −1.9 to −4.9) with Mask (Figure 1D).

Tidal Volume. Mask reduced tidal volume (VT) (interaction effect of condition × intensity, $F_{4,287} = 18.3$, $P < .0001$; Figure 1E) at both RCP (−0.5 L; 95% CI, −0.3 to −0.6) and Peak (−0.8 L; 95% CI, −0.6 to −0.9), but not at Baseline, 80%VAT, or VAT (all $P \geq .97$). Sex had no influence on the effects of Mask on VT ($P = .053$).

Tobin Index (Rf/VT or Shallow Breathing Index). Mask increased the Tobin index at Peak compared with No-Mask (+11.3; 95% CI, 7.5 to 15.1), but not at any other intensity (all $P \geq .4$, interaction effect of condition × intensity: $F_{4,286} = 7.3$, $P < .0001$). Rf/VT in men was not affected by Mask whereas, it was increased in Mask versus No-Mask for women (interaction effect of condition × sex: $F_{1,286} = 25.1$, $P < .0001$; men: +1.1; 95% CI, −1.1 to 3.3; women: +6.9; 95% CI, 4.7 to 9.1; Figure 1F).

Carbondioxide Partial Pressure. Mask increased $PetCO_2$ at both RCP (+4.0 mm Hg; 95% CI, 2.8 to 5.3; Figure 1G) and Peak (+4.9 mm Hg; 95% CI, 3.5 to 6.3) compared with No-Mask (interaction effect condition × intensity: $F_{4,288} = 6.8$, $P < .0001$), but had no effect at Baseline, 80%VAT, or VAT (all $P \geq .09$). The effect of Mask on $PetCO_2$ increases was comparable in men (+3.4 mm Hg; 95% CI, 2.5 to 4.2) and women (+1.9 mm Hg; 95% CI, 1.1 to 2.7).

Ventilatory Equivalent for Carbon Dioxide. Mask reduced $\dot{V}E/\dot{V}CO_2$ at the 3 highest intensities compared with No-Mask (interaction effect of condition × intensity, $F_{4,288} = 3.7$, $P = .006$): VAT (−VE2.2; 95% CI, −0.9 to −3.5), RCP (−3.2; 95% CI, −1.9 to −4.5), and Peak (−4.4; 95% CI, −3.0 to −5.8) (Figure 1H), irrespective of sex.

HR During Exercise. No effects of Mask at any exercise intensity were seen for HR. Despite an interaction effect of condition × sex for HR ($F_{1,286} = 4.6$, $P = .03$), post hoc comparisons did not show any significant differences (all $P \geq .4$; Figure 2A).

Lactate. Mask did not affect lactate measures at any exercise intensities, irrespective of sex (Figure 2B).

Ratings of Perceived Exertion. Mask did not influence RPE at any exercise intensity. However, Mask increased RPE for men, but not women (interaction effect of condition × sex, $F_{1,221} = 6.2$, $P = .01$, men: +1.4; 95% CI, 0.9 to 2.0; women: +0.4; 95% CI, −0.1 to 1.0; Figure 2C).

Blood Pressure. Mask did not affect both systolic and diastolic blood pressure at any exercise intensity (Figure 2D and 2E), regardless of sex.

Oxygen Saturation. Mask did not affect oxygen saturation at any exercise intensity (Figure 2F), regardless of sex.

Time to Exhaustion. Mask reduced TTE compared with No-Mask (−34.5 s; 95% CI, −17.0 to −52.1; main effect of condition: $F_{1,27} = 14.9$, $P = .0007$; Figure 3), with no condition × sex interaction (women, No-Mask: 157.6 [59.6]; women, Mask: 124.9 [42.1]; men, No-Mask: 174.9 [35.2]; men, Mask: 143.3 [39.1]). There was no effect of visit order ($P = .20$).

P values, means, standard deviations, and Cohen's *d* effect sizes for all respiratory and exercise outcomes by exercise intensity, overall, and separated by sex are presented in Supplementary Table S1 (available online).

Spirometry

FVC at Rest. Mask reduced FVC compared with No-Mask (−1.8 L; 95% CI, −1.1 to −1.5; condition: $F_{1,31} = 117.7$, $P < .0001$), with no condition × sex interaction (Table 2).

FEV1 at Rest. Mask reduced forced expiratory volume in 1 second (FEV1) compared with No-Mask (−1.2; 95% CI, −1.0 to −1.4; main effect of condition: $F_{1,31} = 156.2$, $P < .0001$), with no condition × sex interaction (Table 2).

FVC/FEV1 at Rest (FVC by FEV1 ratio). Mask did not influence the FVC/FEV1 ratio, irrespective of sex (Table 2).

Peak Expiratory Flow at Rest. Mask reduced peak expiratory flow compared with No-Mask (−3.4; 95% CI, −2.8 to −4.0, main effect of condition: $F_{1,32} = 122.1$, $P < .0001$), independently of sex (Table 2).

Subjective Perception Questionnaire. Mask increased the subjective feelings of heat, misfitting, discomfort, fatigue, resistance, saltiness, and humidity (all $P \leq .01$), but did not affect feelings of saltiness, tightness, or itchiness (all $P \geq .1$). No interaction between condition and sex was detected (Table 2).

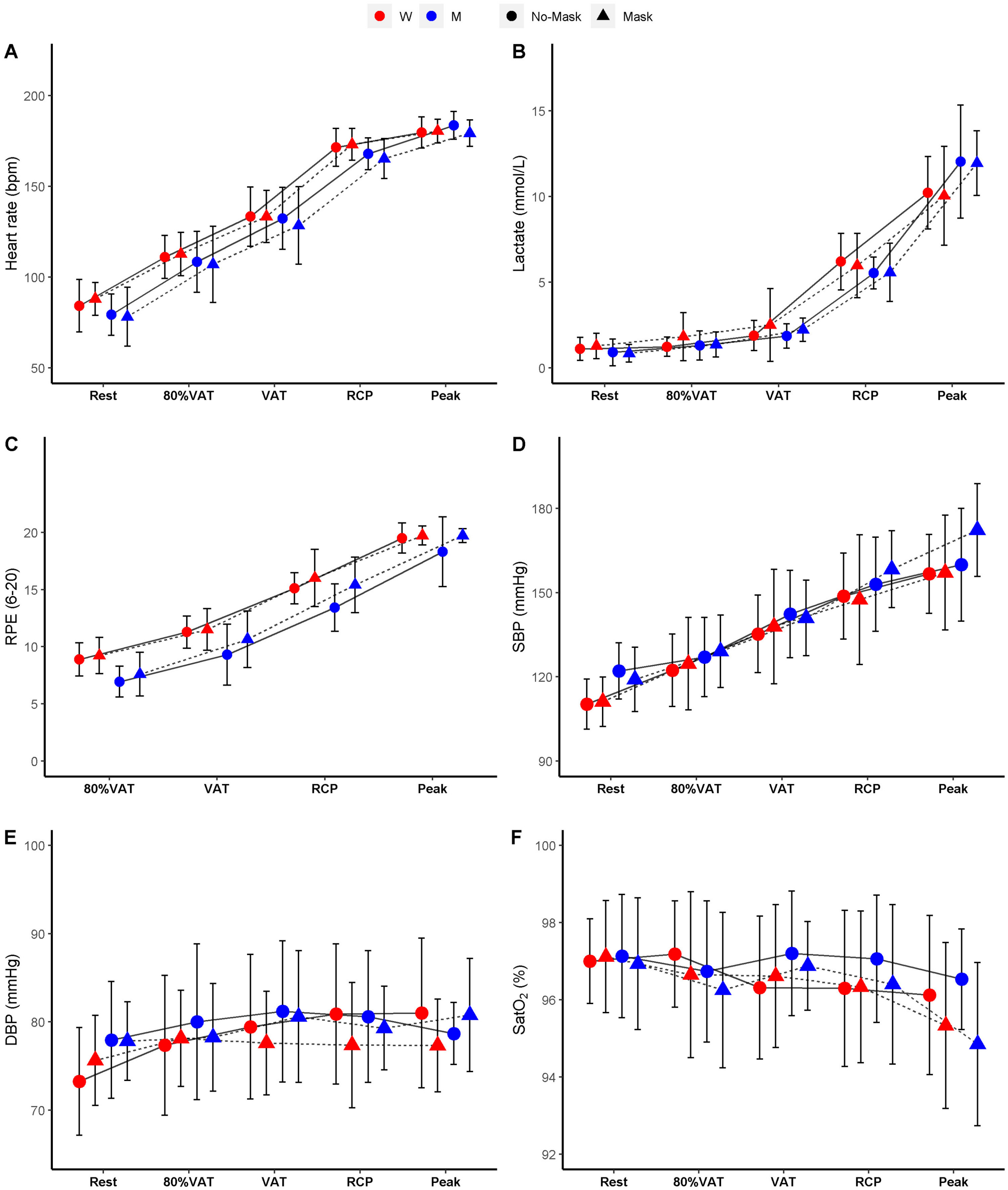

Figure 2 — Heart rate, lactate, RPE, SBP and DBP, and $SatO_2$ expressed as mean ± 1 SD. Continuous and dashed lines connect performance data between No-Mask and Mask conditions. No significant interactions were detected by the statistical test. bpm indicates beats per minute; DBP, diastolic blood pressure; M, men; RCP, respiratory compensation point; RPE, rating of perceived exertion; $SatO_2$, oxygen saturation; SBP, systolic blood pressure; VAT, ventilatory anaerobic threshold; W, women.

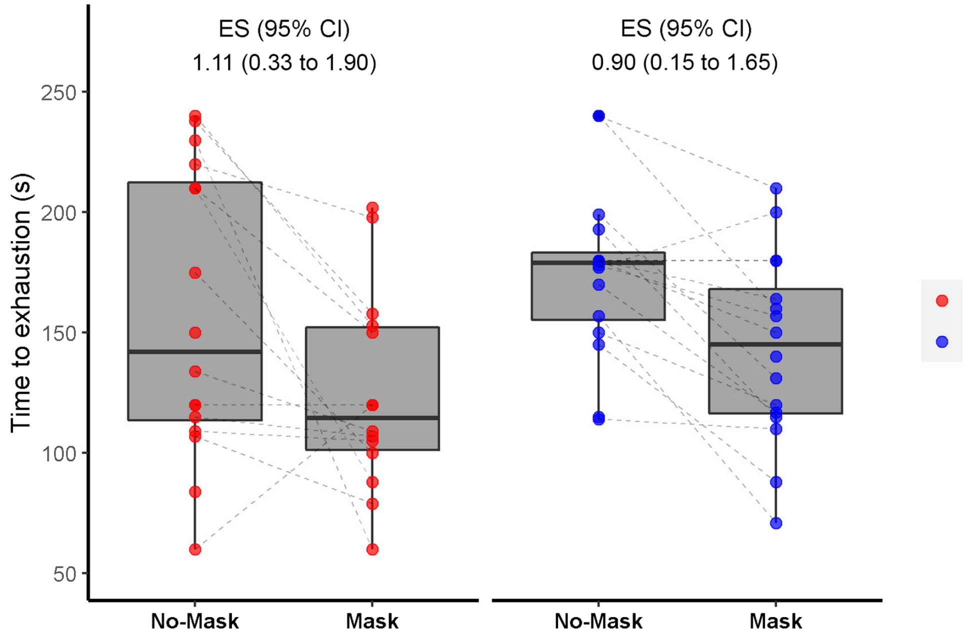

Figure 3 — Time to exhaustion during the final stage (Peak). Dashed lines connect individual performance data between No-Mask and Mask conditions. CI indicates confidence intervals; ES, Cohen *d* effect sizes; M, men; W, women.

Table 2 Spirometry at Rest and Subjective Questionnaire Outcomes

	P	Women			Men		
		No-Mask	Mask		No-Mask	Mask	
	(Condition × sex)	Mean (SD)	Mean (SD)	ES (95% CI)	Mean (SD)	Mean (SD)	ES (95% CI)
Spirometry							
FEV1, L[a,b]	.20	3.4 (0.4)	2.3 (0.5)	−2.7 (−1.9 to −3.6)	4.5 (0.5)	3.2 (0.6)	−3.4 (−2.4 to −4.3)
FVC, L[a,b]	.61	3.8 (0.6)	2.6 (0.6)	−2.5 (−1.7 to −3.3)	5 (0.7)	3.7 (0.7)	−2.8 (−1.9 to −3.6)
FVC/FEV1, %	.06	90.7 (7.7)	90.5 (7.2)	0.0 (0.7 to −0.6)	90.8 (6.7)	87.3 (8.4)	−0.9 (−0.2 to −1.6)
PEF, L·s^{-1} [a,b]	.60	7.7 (1.8)	4.4 (1.1)	−2.6 (−1.7 to −3.4)	9.2 (1.9)	5.7 (1.6)	−2.8 (−2.0 to −3.7)
Questionnaire							
Tightness	.93	3.4 (2.4)	4.2 (3.4)	0.3 (−0.3 to 1.0)	2.5 (2.2)	3.4 (2.5)	0.4 (−0.3 to 1.1)
Heat[a]	.90	3.6 (2.1)	6.2 (2.5)	1.4 (0.7 to 2.2)	3.3 (2.2)	5.9 (2.3)	1.4 (0.6 to 2.1)
Itchiness	.42	0.8 (1.1)	1.1 (2.2)	0.2 (−0.5 to 0.9)	1.6 (2.7)	2.8 (3.1)	0.6 (−0.1 to 1.3)
Misfitting[a]	.08	1.8 (2.3)	2.6 (2.5)	0.5 (−0.2 to 1.2)	1.6 (2.1)	4.1 (2.7)	1.4 (0.6 to 2.1)
Discomfort[a]	.40	4.5 (1.4)	7.9 (2.3)	2.1 (1.4 to 3.0)	4.2 (2.9)	7.1 (2.6)	1.7 (1.0 to 2.5)
Fatigue[a]	.67	5.2 (3.1)	8.2 (1.8)	1.3 (0.6 to 2.0)	5.0 (2.6)	8.6 (2.4)	1.5 (0.8 to 2.2)
Odor	.24	1.2 (2.4)	0.9 (1.8)	−0.1 (−0.8 to 0.6)	0.9 (1.3)	1.7 (2.4)	0.5 (−0.2 to 1.2)
Resistance[a]	.42	3.4 (2.3)	8.6 (1.2)	2.6 (1.8 to 3.5)	4.0 (2.8)	8.4 (1.3)	2.3 (1.5 to 3.0)
Saltiness[a,b]	.11	0.3 (0.5)	0.7 (1.6)	0.2 (−0.5 to 0.9)	1.0 (1.8)	2.7 (3.5)	1.0 (0.3 to 1.8)
Humidity[a]	.35	3.7 (2.6)	5.3 (2.3)	0.9 (0.2 to 1.6)	4.1 (1.9)	6.6 (2.4)	1.4 (0.6 to 2.1)

Abbreviations: CI, confidence interval; ES, Cohen *d* effect size; FEV1, forced expiratory volume in 1 second; FVC, forced vital capacity; FVC/FEV1, FVC by FEV1 ratio; PEF, peak expiratory flow.
[a]Main effect of condition. [b]Main effect of sex.

Discussion

This study showed that breathing difficulty with a cloth facemask is dependent upon the exercise intensity, with lower distress at less severe intensities. Mask wearing did affect a few respiratory variables, which suggests an increased difficulty breathing, though it did not substantially modify physiological or metabolic variables during exercise, regardless of sex and intensity. From a practical perspective, these data suggest that use of a cloth facemask for protecting individuals from severe acute respiratory syndrome coronavirus 2 infections should not be a barrier to the engagement in moderate to vigorous physical activity.

The main novelty of the current study is that we assessed the influence of wearing a mask on respiratory and cardiovascular variables across several exercise intensities, spanning moderate to severe domains.[10] Only at high exercise intensity did the cloth mask have a slight but clinically meaningless impact on these variables. For instance, inspiratory capacity was reduced at 80% VAT with the facemask, which is possibly reflective of a fatigue-related decrease in contractile power of the inspiratory muscles (which was not measured in this study). This inspiratory distress may place a greater strain on the respiratory muscles to maintain breathing requirements during exercise, possibly since inspiratory flow may cause greater mask adherence to the skin, increasing the strain on the respiratory muscles to draw air into the lungs. This distress was not seen in the moderate to heavy domains but was manifested as an inability to maintain the physiological increases in Rf and tidal volume at the higher intensities. For example, during VAT, although Rf was reduced, this was likely compensated by increases in tidal volume as evidenced by no differences between conditions, suggesting that the cloth facemask did not inhibit the ability of the respiratory system to work at moderate exercise intensity. At higher intensities, however, both Rf and tidal volume were reduced with a mask, which may have affected subsequent performance. Although there was no evidence of hypoventilation (given that $PetCO_2$ was at or below 40 mm Hg), a reduced $\dot{V}E/\dot{V}CO_2$ with a mask was evident from VAT. These mechanisms combined could explain the reduced TTE at Peak. Our data are in agreement with previous studies showing a reduced exercise capacity with different facemasks,[6,30] though other studies have shown no negative impact.[8,31] It is possible that different types of facemasks and respirators (eg, FFP2/N95, surgical, cloth facemasks) and participants' fitness level may have contributed to these conflicting findings.

Despite changes in respiratory variables, no cardiovascular measure was affected by wearing a cloth facemask. Even during the higher exercise intensity domains, there were no changes in HR, systolic, or diastolic blood pressure when wearing a facemask. In addition, despite an overall slight reduction in blood oxygen saturation, there were no differences at individual exercise intensities while absolute differences were not clinically meaningful; thus, it is unlikely that this reduction could lead to harmful events, at least in healthy individuals. Our results complement previous studies showing no effect of wearing a facemask on oxygen saturation during exercises of varying intensities.[32,33] In particular, the current study employed a 3-layer cloth facemask (as per World Health Organization recommendations) that is inexpensive and widely available to the general population, which makes the current data of great applicability. Also, the findings can be used to counteract the misinformation during the ongoing COVID-19 pandemic,[34,35] particularly relating to the use of masks during exercise and its supposed negative effects on cardiac overload, acid–base balance, and oxygen saturation.[36]

We had speculated that any potential physiological effects associated with wearing a mask during exercise could be greater in women, who have an overall lower higher cardiorespiratory reserve than men, owing to classically described morphological and physiological sex differences (eg, smaller lungs, lower O_2 carrying capacity, and maximum cardiac output, etc). This hypothesis was not confirmed, as the effects of the cloth facemask on physiological measures were mostly similar between women and men irrespective of exercise intensities. Exercise capacity was reduced by 23.9% in women and 17.8% in men when using a cloth facemask, with no differences between sexes. It is possible to conjecture that the stress imposed by wearing a mask does not constitute a greater physiological or metabolic burden to women versus men, despite the well-known sex differences during exercise.[12–17]

There are several strengths and limitations with the current study. Although the measurement of respiratory variables during the PSWT provides novel information regarding the respiratory response during different intensities, participants were required to wear a facemask for breath-by-breath measures over the cloth facemask. This may have increased the discomfort felt by the participants and may also have led to some inaccuracies in measurements due to air escaping. We ensured that the masks were fitted as comfortably and tightly as possible to avoid these issues as best as possible, but it cannot be ruled out that this contributed somewhat to the current results. The current data cannot be directly extrapolated to highly trained individuals; however, we felt it important to investigate this matter among nonathletes, as there has been intense debate on the physiological repercussions and potential adverse effects of face masks in untrained individuals. Since sufficient levels of physical activity prevent morbidities and mortality[37–39] and improve vaccine immunogenicity,[40] it is important that mask mandates do not lead to a reduction in physical activity. In this regard, the present data provide relevant information that wearing a cloth facemask will not have a negative impact during exercise at moderate-to-heavy intensities, which are associated with a plethora of health-related benefits.[41,42] Whether the negative perpetual feelings related to the use of masks may result in less adherence to exercise remains to be examined. We did not monitor or control for menstrual cycle phase, which might affect perceptual and physiological responses to masks during exercise. Nonetheless, meta-analytical data suggest that performance effects due to different menstrual cycle phases are likely to be trivial.[43] Furthermore, the influence of mask wearing during exercise in patients with cardiorespiratory comorbidities warrants investigation.

Conclusion

Wearing a cloth facemask during exercise performed at moderate to heavy exercise intensities may increase breathing difficulty, but is unlikely to incur significant respiratory or cardiovascular perturbations in untrained healthy individuals. These data have important practical implications as they can debunk unfounded allegations of harmful effects of cloth facemasks during exercise.

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