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Aerobic Performance Detriments while Wearing a Face Mask Diverge Among Males and Females

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ABSTRACT

International Journal of Exercise Science 15(2): 1105-1116, 2022. The current study examined the impact of wearing a face mask (FM) at rest and while exercising on cardiorespiratory variables and aerobic performance between males and females. Nine males (21.4 ± 0.5 yr) and 9 females (21.8 ± 3.6 yr) performed a pulmonary function test and a graded maximal exercise test (GXT) on a treadmill with an FM and without an FM in random order. During the GXT, cardiorespiratory variables were measured at different exercise intensities (rest, 40%, 55%, 70%, 80%, 100% of VO_2max) and during recovery. Regardless of sex, both males and females significantly (p = .01) reduced their resting pulmonary functions, including forced vital capacity (18.7% and 19.6%, respectively), forced expiratory volume in one second (43.9% and 45.7%, respectively), and peak expiratory flow (85.2% and 87.5%, respectively) with an FM. During the GXT, both VO_2 and ventilation (VE) in males were significantly (p < .01) lower with an FM only at 100% of VO_2max, while females showed a significantly (p < .01) lower VO_2, VE, and tidal volume (V_t) with an FM throughout the entire GXT. The partial pressure of exhaled CO_2 was significantly (p = .02) higher at 100% of VO_2max with an FM only in males. Although wearing an FM reduced resting pulmonary functions and the maximal aerobic performance for both males and females, there was a clear sex-specific response during the GXT, indicating that females were less capable to adapt to the pulmonary obstruction induced by wearing an FM.

KEY WORDS: Oxygen consumption, airway obstruction, aerobic exercise, spirometry, personal protective equipment

INTRODUCTION

With the recent surge of the novel coronavirus 2019 (COVID-19), a disease caused by the SARS-CoV-2 virus, wearing a face mask (FM) indoors and outdoors has been required. COVID-19 can spread from person to person through expelled respiratory droplets that pose the risk of viral transmission when someone talks, coughs, or sneezes. In addition, viral transmission can occur by touching an infected surface, followed by touching the eyes, nose, or mouth (13). As of August 2021, treatment for COVID-19 has dramatically improved, and over 300 million vaccine doses have been distributed to reverse the severity of the pandemic in the United States alone (2). Although it is a matter of time to have a wide amount of people vaccinated, wearing an FM in public areas, including fitness facilities, along with social distancing, hand washing, and disinfecting practices still remain as the standard prevention methods (13).

Engagement in frequent aerobic exercise has been recommended to reduce the modality and mortality of COVID-19 (5, 21). However, caution should be given to exercising with an FM since the extra layers of an FM may obstruct the respiratory airflow. Specifically, aerobic exercise requires oxygen molecules in a bioenergetic pathway to yield energy, thus compromising the capacity to uptake oxygen could reduce the overall energy availability that could lead to an increased cardiovascular strain along with other pathophysiological risks (3). Although there is evidence supporting pulmonary function at rest may be affected by wearing an FM (11), this was only representative of middle-aged males. Furthermore, while there is evidence that exercising with an FM can negatively affect cardiorespiratory variables (7, 11, 15), there is also contradictory evidence indicating that wearing an FM has no detrimental effects on cardiorespiratory variables (19, 20). Thus, caution should be given to interpreting these results, as the differences in findings could perhaps be related to the exercise modality, outcomes measured, study subjects, and the type of FM. For instance, young males and females performing a maximal exercise test on a treadmill while wearing a cloth FM (7) and middle-aged males performing a maximal exercise test on a cycle ergometer while wearing a surgical or N95 FM (11) decreased their aerobic performance (defined by maximal oxygen uptake, VO_2max). However, young males and females wearing a surgical or cloth FM during a cycle ergometer maximal test had no change in aerobic performance (defined by power output) (20). Furthermore, no study has examined the effects of wearing an FM on exercise performance between males and females. A bigger lung volume in males and a higher susceptibility to respiratory muscles fatigue in females (6, 18) are some of the factors to favor males towards a higher aerobic performance, but this may also be impacted by an FM while exercising. Therefore, it is critical to understand how males and females respond differently while exercising with an FM. Therefore, this study aimed to examine the impact of an over-the-counter surgical mask, which is commonly used during the COVID-19 pandemic, on cardiorespiratory variables to broaden the knowledge of how exercising with an FM might hinder aerobic performance, while also analyzing males and females independently to better understand whether the impact of wearing an FM during aerobic exercise differs between males and females. It was hypothesized that both males and females would decrease resting pulmonary functions and aerobic performance with an FM, while females may experience the greater detriment.

METHODS

Participants

A total of 18 physically healthy adults, 9 males (21.4 ± 0.5 yr) and 9 females (21.8 ± 3.6 yr) were recruited (Table 1). An a-priori power analysis was conducted with G*Power 3.1.9.7 (Universität Kiel, Germany) (10) to determine the required amount of participants for the study. The effect size was calculated from published studies with a similar research protocol (7, 8, 11). The a-priori power analysis indicated that at least 16 participants were required with an effect size of 0.58, an alpha level of 0.05, and a power of 0.82. The inclusion criteria were: 1) not pregnant, 2) able to perform a graded maximal exercise test (GXT), and 3) having no contraindication to exercise as outlined by the American College of Sports Medicine (16). Lastly, participants gave their informed consent to participate in the study that was approved by the Institutional Revision Board at Baylor University, and all data collection was conducted per the principles embodied in the "Declaration of Helsinki" and in accordance to the ethical standards of the International Journal of Exercise Science (17).

Table 1. Demographic data of participants.

Sex	Age	Body Mass Index	Body Fat Percentage	Fat-Free Mass (kg)	Fat Mass (kg)	Total Bone Mineral Density (gram/cm^2)
Males	21.4 ± 0.5	24.7 ± 2.3	15.8 ± 4.0*	67.3 ± 4.2*	12.7 ± 3.5	1.15 ± 0.1
Females	21.8 ± 3.6	24.2 ± 3.9	25.6 ± 5.1	49.7 ± 6.6	17.6 ± 6.8	1.13 ± 0.1

Data are presented as mean ± standard deviation.
*$p < .05$ males vs females.

Protocol

Participants completed a resting pulmonary function test and a GXT on two separate trials, without an FM (WOFM) and with an FM (WFM), in random order. There was a 48-hour break between each trial. An FDA-approved BFE ≥ 95% over-the-counter 3-layer disposable surgical mask (Excellent Artisan, Zhongshan, China) was used for the WFM trial. Height (cm) and weight (kg) were assessed on a standard dual-beam balance scale with a height measuring rod (Detecto 439; Detecto, Webb City, MO, USA). Body composition (fat-free mass, fat mass, body fat percentage, and total bone mineral density) were assessed via dual-energy x-ray absorptiometry (DXA, only during their first visit) (Horizon; Hologic, Marlborough, MA, USA). Heart rate (HR) was measured using a heart rate monitor (T31; Polar, Kempele, Finland), and blood pressure (BP) was measured manually with a standard aneroid blood pressure cuff. Resting HR and BP were measured after 5 minutes of seated rest. During the GXT, HR and BP were measured at the last 30 seconds of each exercise stage.

Resting Pulmonary Function Test: A spirometer (Breeze Suite 8.5.0.65; MGCDiagnostics, St. Paul, MN, USA) was used to assess forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and peak expiratory flow (PEF) at rest. Participants performed 2 practice attempts, followed by 3 testing attempts with 2 minutes of rest in-between. Out of the 3 testing attempts, the highest value was recorded and utilized to compare the differences between trials. Figure 1A illustrates the pneumotach placement during the WOFM and WFM trials.

Figure 1. Illustration of the pneumotach (A) placement and metabolic mask fitting (B) during the without a face mask (on the left) and with a face mask (on the right) trials.

Graded Maximal Exercise Protocol**:** Figure 1B illustrates the metabolic mask fitting during the WOFM and WFM trials. Before participants began the GXT, an air leakage test was conducted by asking participants to forcefully exhale air while the air escape valve of the metabolic mask was covered. The leakage test ensured correct fitting by identifying whistling noise or mask movement that would have indicated air escaping from somewhere else than the mouthpiece, and herein, led to incorrect gas sampling by the metabolic cart. The GXT was performed during both WOFM and WFM trials on a treadmill. HR, BP, Borg's rating of perceived exertion (RPE), oxygen saturation, and respiratory gases were measured at different exercise intensities (rest, 40%, 55%, 70%, 80%, 100% of VO_2max) as well as during a walking recovery and seated recovery. A traditional metabolic mask (Hans Rudolph 7450; Cosmed, Shawnee, KS, USA) as shown in Figure 1B and a metabolic cart (TrueOne 2400; Parvo Medics, Salt Lake City, UT, USA) were used to measure respiratory gases. The GXT began after 3 minutes of seated rest with an initial 2-minute warm-up stage at 1.7 mph with 0% incline. Thereafter, stage 1 had a speed of 2.5 mph and a 5% incline. Stage 2 increased the incline to 8%, and stage 3 increased the incline to 10%, which remained constant for the remaining of the protocol. Speed increased by 1 mph from stage 1 to stage 5 and by 2 mph after stage 5 until VO_2max was reached. Each exercise stage lasted 3 minutes. Upon terminating the GXT, a walking (active) recovery stage was performed at 1.7 mph and 0% incline, followed by a seated (static) recovery stage for 3 minutes each. A pulse oximeter (NPB-40; Nellcor, Pleasanton, CA, USA) was used to assess the oxygen saturation and perfusion index during the GXT. The pulse oximeter was placed on the index finger of the participant's dominant hand for 1 minute before recording both values during each stage of the protocol.

Statistical Analysis

All data are reported as mean ± standard deviation (SD), with the statistical significance set at $p < 0.05$. Pulmonary function and cardiorespiratory variables between the WOFM and the WFM trials for each sex were compared using a two-way repeated-measures ANOVA. Statistical analyses were conducted using IBM SPSS (Version 27.0; IBM Corp., Armonk, NY, USA).

RESULTS

Regardless of sex, the resting pulmonary functions were significantly reduced with an FM in both males and females (Table 2). For example, males had a significantly lower FVC (18.7%), FEV_1 (43.9%), and PEF (85.2%) during the WFM trial than the WOFM trial. Furthermore, females had a 19.6% lower FVC, 45.7% lower FEV_1, and 87.5% lower PEF with an FM.

Table 2. Pulmonary Functions for Males and Females at Rest

Variables	Trial	Males	*F*-value	*p*-value	*Females*	*F*-value	*p*-value
FVC (L)	WOFM	5.7 ± 0.5	37.403	< .01	3.9 ± 0.6	140.858	< .01
	WFM	4.8 ± 0.5			3.3 ± 0.6		
FEV_1 (L)	WOFM	4.2 ± 0.7	36.421	< .01	2.7 ± 0.8	9.604	< .01
	WFM	2.9 ± 0.6			1.9 ± 0.6		
PEF (L/min)	WOFM	341.3 ± 57.5	40.469	< .01	246.7 ± 131.4	10.168	< .01
	WFM	191.7 ± 37.9			139.6 ± 62.9		

Data are presented as mean ± standard deviation.
FVC = Forced Vital Capacity, FEV_1 = Forced Expiratory Volume in 1 second, PEF = Peak Expiratory Flow, and WOFM/WFM = without/with a face mask.
Significance denotes a difference between the WOFM vs WFM trials ($p < 0.01$).

In males, VO_2 (Figure 2A) was significantly lower with an FM only during the 100% VO_2max ($F(1, 8) = 25.118$, $p < .01$), walking recovery ($F(1, 8) = 28.666$, $p < .01$), and seated recovery ($F(1, 8) = 10.015$, $p < .01$) intensities. Similarly, ventilation (VE, Figure 2B) was significantly lower during the same intensities with an FM ($F(1, 8)$ = 46.060, 236.671, and 17.571, $p < .01$, respectively). In contrast, females had a significantly lower VO_2 (Figure 2A) during the rest ($F(1, 8) = 13.298$, $p < .01$), 40% ($F(1, 8) = 8.766$, $p < .01$), 55% ($F(1, 8) = 10.045$, $p < .01$), 70% ($F(1, 8) = 15.155$, $p < .01$), 80% ($F(1, 8) = 6.696$, $p < .01$) and 100% VO_2max ($F(1, 8) = 29.425$, $p < .01$) intensities. Similarly, VE (Figure 2B) was significantly lower with an FM during the same intensities ($F(1, 8)$ = 8.351, 23.627, 32.863, 18.260, 12.663, and 22.071, $p < .01$, respectively), and during the seated recovery ($F(1, 8) = 12.924$, $p < .01$) intensity. Lastly, tidal volume (V_t, Table 3 and Table 4) was significantly lower with an FM only during the walking recovery ($F(1, 8) = 22.099$, $p < .01$) intensity for males, whereas for females it was significantly lower throughout ($F(1, 8)$ = 15.512, 8.255, 10.117, 9.436, 14.087, and 15.449, $p < .01$, respectively) the entire GXT alike VO_2.

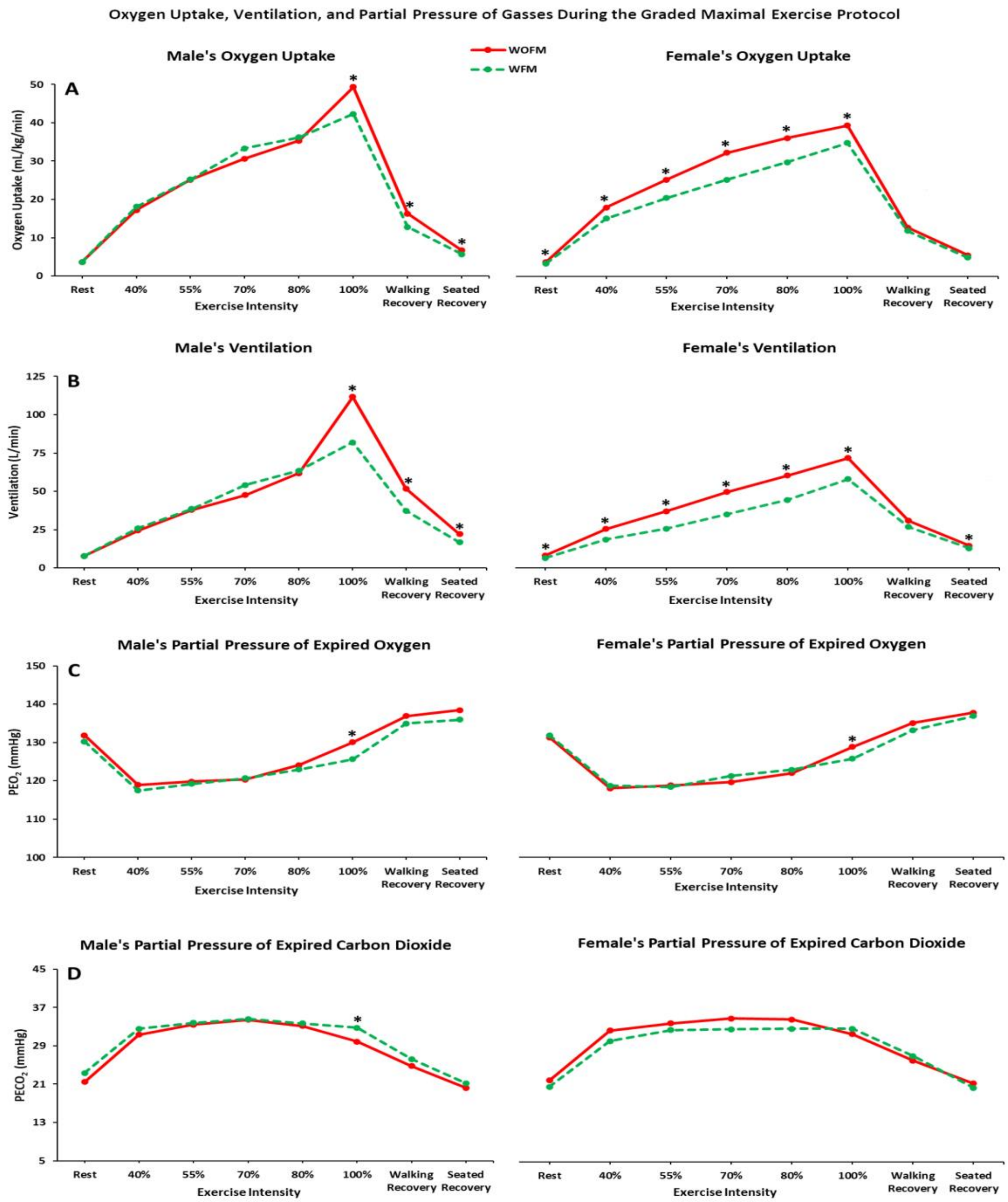

Figure 2. WOFM/WFM = without/with a face mask. * Significance denotes a difference between the WOFM vs WFM trials at the given exercise intensity ($p < 0.05$).

In males, respiratory rate (RR) was significantly lower with an FM during the 100% (F (1, 8) = 27.289, p < .01) and walking recovery (F (1, 8) = 10.644, p < .01) intensities. The respiratory exchange ratio (RER) and partial pressure of expired oxygen (PEO_2) were significantly lower with an FM at the 100% VO_2max intensity in both males ((F (1, 8) = 10.926), p = .01, and (F (1, 8) = 12.756), p < .01, respectively) and females ((F (1, 8) = 6.747), p = .032, and (F (1, 8) = 7.016), p = .02, respectively). However, only males had a significantly lower PEO_2 with an FM during the seated recovery (F (1, 8) = 8.474, p = .02) intensity, along with the partial pressure of expired carbon dioxide ($PECO_2$) being significantly higher with an FM at the 100% VO_2max (F (1, 8) = 8.314, p = .02) intensity. Data on these respiratory variables for both males and females are presented in Figure 2, Table 3, and Table 4.

Table 3. Cardiorespiratory variables for males during the graded maximal exercise protocol.

Variable	Trial	Males							
		Rest	40%	55%	70%	80%	Max	WR	SR
Oxygen Uptake (mL/kg/min)	WOFM	3.65 ± 0.82	17.25 ± 3.88	25.11 ± 4.43	30.65 ± 6.39	35.35 ± 7.33	49.33 ± 4.75*	16.29 ± 1.14*	6.68 ± 0.58*
	WFM	3.66 ± 0.91	18.07 ± 2.22	25.17 ± 4.38	33.29 ± 3.38	36.22 ± 4.60	42.29 ± 5.33	12.79 ± 2.09	5.69 ± 0.57
Ventilation (L/min)	WOFM	7.86 ± 1.94	24.44 ± 6.18	37.86 ± 10.35	47.60 ± 14.85	61.83 ± 18.09	111.71 ± 14.32*	51.75 ± 7.71*	22.06 ± 3.59*
	WFM	7.89 ± 1.91	25.98 ± 2.66	38.47 ± 4.71	54.21 ± 7.73	63.48 ± 9.41	82.04 ± 14.32	37.32 ± 7.51	16.66 ± 3.05
Tidal Volume (L)	WOFM	0.48 ± 0.08	1.19 ± 0.35	1.51 ± 0.43	1.85 ± 0.29	1.83 ± 0.35	2.24 ± 0.23	1.54 ± 0.22*	1.07 ± 0.30
	WFM	0.56 ± 0.12	1.42 ± 0.45	1.63 ± 0.56	1.84 ± 0.39	1.97 ± 0.44	2.07 ± 0.32	1.25 ± 0.24	0.86 ± 01.12
Respiratory Exchange Ratio	WOFM	0.80 ± 0.05	0.77 ± 0.06	0.87 ± 0.08	0.91 ± 0.55	0.99 ± 0.04	1.13 ± 0.03*	1.29 ± 0.07	1.10 ± 0.11
	WFM	0.84 ± 0.05	0.79 ± 0.05	0.87 ± 0.06	0.94 ± 0.45	0.99 ± 0.04	1.06 ± 0.06	1.28 ± 0.15	1.02 ± 0.11
PEO_2 (mmHg)	WOFM	131.89 ± 2.09	118.94 ± 3.03	119.82 ± 3.34	120.34 ± 2.69	124.09 ± 2.37	130.06 ± 2.89*	136.91 ± 3.21	138.42 ± 2.88*
	WFM	130.24 ± 2.16	117.44 ± 3.75	119.22 ± 4.73	120.64 ± 3.15	122.94 ± 2.94	125.62 ± 2.91	134.98 ± 3.24	135.98 ± 3.88
$PECO_2$ (mmHg)	WOFM	21.46 ± 1.75	31.32 ± 2.85	33.41 ± 2.72	34.44 ± 2.45	33.14 ± 3.29	29.87 ± 2.56*	24.77 ± 3.19	20.22 ± 2.51
	WFM	23.34 ± 2.10	32.58 ± 2.16	33.82 ± 2.24	34.61 ± 1.88	33.71 ± 1.99	32.77 ± 2.56	26.25 ± 2.09	21.16 ± 2.49
Respiratory Rate (bpm)	WOFM	17 ± 4	21 ± 4	25 ± 5	30 ± 5	34 ± 7	50 ± 6*	34 ± 6*	22 ± 5
	WFM	15 ± 4	19 ±4	25 ± 5	30 ± 4	33 ± 7	40 ± 5	30 ± 6	20 ± 5

WOFM/WFM= without/with a face mask.
WR/SR = walking/seated recovery.
PEO_2/CO_2 = partial pressure of exhaled oxygen and carbon dioxide.
*p < .05 WOFM vs WFM.

Table 4. Cardiorespiratory variables for females during the graded maximal exercise protocol.

Variable	Trial	Females							
		Rest	40%	55%	70%	80%	Max	WR	SR
Oxygen Uptake (mL/kg/min)	WOFM	3.74 ± 0.72*	17.89 ± 2.21*	25.13 ± 4.33*	32.16 ± 3.83*	36.26 ± 4.62*	39.26 ± 6.17*	12.67 ± 1.63	5.45 ± 0.74
	WFM	3.35 ± 0.67	14.60 ± 2.72	20.42 ± 3.06	25.17 ± 4.92	29.72 ± 5.52	34.72 ± 6.22	11.85 ± 1.60	4.89 ± 0.88
Ventilation (L/min)	WOFM	8.19 ± 2.08*	25.39 ± 3.89*	37.05 ± 7.41*	49.62 ± 0.85*	60.32 ± 3.44*	71.75 ± 2.80*	30.75 ± 6.12	14.54 ± 2.39*
	WFM	6.51 ± 1.19	18.17 ± 1.21	25.54 ± 3.97	35.04 ± 6.41	44.38 ± 9.12	57.90 ± 12.37	26.79 ± 4.16	12.81 ± 2.60
Tidal Volume (L)	WOFM	0.57 ± 0.19*	1.29 ± 0.29*	1.49 ± 0.43*	1.81 ± 0.45*	1.97 ± 0.41*	1.61 ± 0.19*	1.10 ± 0.14	0.72 ± 0.19
	WFM	0.38 ± 0.09	0.89 ± 0.26	1.05 ± 0.22	1.28 ± 0.29	1.37 ± 0.25	1.44 ± 0.21	1.07 ± 0.27	0.67 ± 0.17
Respiratory Exchange Ratio	WOFM	0.83 ± 0.08	0.80 ± 0.04	0.87 ± 0.05	0.92 ± 0.03	0.99 ± 0.03	1.16 ± 0.08*	1.26 ± 0.11	1.14 ± 0.09
	WFM	0.81 ± 0.06	0.76 ± 0.05	0.82 ± 0.06	0.92 ± 0.09	0.98 ± 0.08	1.09 ± 0.09	1.24 ± 0.12	1.07 ± 0.10
PEO_2 (mmHg)	WOFM	131.31 ± 1.84	118.02 ± 2.12	118.76 ± 4.03	119.67 ± 2.67	122.02 ± 3.12	128.81 ± 3.38*	135.07 ± 3.73	137.78 ± 1.93
	WFM	131.84 ± 4.42	119.06 ± 4.67	118.38 ± 3.01	121.26 ± 5.30	122.90 ± 5.88	125.74 ± 4.19	133.21 ± 3.61	136.88 ± 3.75
$PECO_2$ (mmHg)	WOFM	21.98 ± 2.31	32.42 ± 1.45	33.91 ± 1.92	34.89 ± 1.89	34.71 ± 2.45	31.65 ± 3.93	26.14 ± 3.13	21.33 ± 2.07
	WFM	20.64 ± 2.79	29.98 ± 3.26	32.52 ± 3.44	32.66 ± 3.80	32.76 ± 4.89	32.78 ± 3.79	27.08 ± 3.33	20.43 ± 2.411
Respiratory Rate (bpm)	WOFM	15 ± 5	20 ± 4	25 ± 4	28 ± 5	31 ± 6	45 ± 11*	28 ± 6	21 ± 4
	WFM	18 ± 5	22 ± 6	25 ± 4	28 ± 8	33 ± 9	40 ± 8	26 ± 5	20 ± 4

WOFM/WFM= without/with a face mask.
WR/SR = walking/seated recovery.
PEO_2/CO_2 = partial pressure of exhaled oxygen and carbon dioxide.
*$p < .05$ WOFM vs WFM.

Only females had a significantly lower HR with an FM during the walking (F (1, 8) = 9.444), p = .01) and seated recovery (F (1, 8) = 5.838), p = .04) intensities, along with a lower pulse index percentage (PI%) at rest (F (1, 8) = 5.991, p = .04). Furthermore, neither males nor females had a significant difference in oxygen saturation (O_2%) between trials, while males had a significantly higher RPE (F (1, 8) = 8.258), p = .02) and diastolic BP (F (1, 7) = 19.296, $p < .01$) with an FM during the seated recovery. Data on these variables are presented in Table 5. Lastly, the GXT duration for both males (F (1, 8) = 8.115), p = .02) and females (F (1, 8) = 9.863, p = .01) were significantly shorter with an FM. Specifically, males ran for a total of 12.9 ± 1.1 minutes during the WFM trial and 14.6 ± 2.0 minutes during the WOFM trial, and females ran for a total of 9.7 ± 2.1 minutes (WFM) and 10.2 ± 2.1 minutes (WOFM), respectively.

Table 5. Physiological exertion variables for males and females during the graded maximal exercise protocol.

Variable	Trial	Males				Females			
		Rest	Max	WR	SR	Rest	Max	WR	SR
Heart Rate (bpm)	WOFM	73 ± 10	195 ± 7	146 ± 16	113 ± 12	80 ± 12	196 ± 6	158 ± 13*	117 ± 13*
	WFM	75 ± 8	192 ± 8	146 ± 17	109 ± 13	78 ± 15	192 ± 11	148 ± 18	111 ± 11
Systolic Blood Pressure (mmHg)	WOFM	124 ± 4	175 ± 7	148 ± 21	126 ± 10	118 ± 7	159 ± 10	140 ± 13	122 ± 9
	WFM	124 ± 8	180 ± 6	154 ± 10	132 ± 16	117 ± 6	161 ± 10	144 ± 11	119 ± 5
Diastolic Blood Pressure (mmHg)	WOFM	82 ± 4	84 ± 10	67 ± 8	74 ± 5*	76 ± 4	79 ± 11	73 ± 11	71 ± 11
	WFM	77 ± 7	76 ± 14	75 ± 12	80 ± 5	78 ± 2	79 ± 11	76 ± 9	77 ± 8
Perfusion Index (%)	WOFM	3.0 ± 1.7	5.3 ± 2.9	6.2 ± 2.2	10.8 ± 4.4	1.9 ± 1.4*	1.9 ± 1.7	2.8 ± 1.5	6.5 ± 2.9
	WFM	2.9 ± 2.3	3.9 ± 3.0	5.7 ± 1.4	8.2 ± 1.3	1.0 ± 0.9	1.7 ± 1.2	3.2 ± 1.1	6.6 ± 2.9
Oxygen Saturation (%)	WOFM	97.8 ± 0.7	93.3 ± 3.5	96.3 ± 1.0	95.7 ± 0.9	98.0 ± 0.9	90.7 ± 9.4	95.7 ± 3.2	96.0 ± 1.4
	WFM	98.3 ± 0.7	91.9 ± 4.5	97.2 ± 0.9	96.3 ± 0.9	96.9 ± 4.9	89.0 ± 9.3	96.8 ± 1.6	96.4 ± 0.9
Rating of Perceived Exertion	WOFM	6 ± 0	17 ± 2	12 ± 2	8 ± 2*	6 ± 0	16 ± 3	11 ± 3	8 ± 2
	WFM	6 ± 0	19 ± 2	13 ± 2	9 ± 1	6 ± 0	16 ± 2	11 ± 2	8 ± 2

WOFM/WFM= without/with a face mask.
WR/SR = walking/seated recovery.
*$p < .05$ WOFM vs WFM.

DISCUSSION

The current study examined the impact of wearing an FM at rest and while exercising on cardiorespiratory variables and aerobic performance in males and females. This study portrays how wearing an FM negatively impacted resting pulmonary functions, cardiorespiratory variables, and aerobic performance during exercise in both males and females. However, it must be denoted that females experienced greater detriments to their cardiorespiratory variables and aerobic performance than males. In addition, as seen in middle-aged individuals who significantly decreased their resting pulmonary functions with an FM (11), the current study showed the same result in young males and females. This result suggests that an FM-induced reduction in resting pulmonary functions may be caused by the extra layers/filters of an FM, which obstruct the flow of air (12). As such, anybody wearing an FM may experience a respiratory obstruction, regardless of their age.

Accounting that cardiorespiratory variables were significantly reduced with a FM, in alignment with our hypothesis, both males and females also reduced their aerobic performance while exercising with an FM. However, since females' aerobic performance was hindered more than in males, analyzing the individual sex response is essential to understand what could have led to such different responses. As previously reported in males of an age range of 30 – 44 years (9,11), wearing a surgical or N95 FM during a maximal exercise protocol reduced aerobic performance by primarily lowering VO_2, VE, V_t, and RR. Another recent study whose mean participant age was 23.2 ± 3.1 years that included both males and females demonstrated detriments in aerobic performance by affecting those same variables while exercising with a cloth FM (7). In the current study, we also found the same results with a BFE ≥ 95% over-the-counter 3-layer surgical mask, which may suggest that regardless of the type of masks, exercising with an FM will inevitably reduce maximal aerobic performance. However, our study adds the connotation evidencing there were clear sex-based differences in the pattern of an FM-induced reduction in aerobic performance, as portrayed by males experiencing a reduced aerobic performance at maximal effort only, while females were affected throughout the entire GXT.

In hindsight, these sex-based differences may be explained by the inability of female participants to compensate for the respiratory obstruction induced by the FM. One of the major factors limiting females' aerobic performance as compared with males is their lower lung volume (4,14). In addition, even though having smaller lungs might help females to expand their lungs more, this might only be possible if there is mechanical efficiency of the respiratory muscles (1). However, when compared to males, females require an extra amount of the total inhaled oxygen during exercise to supply their respiratory muscles that otherwise would fatigue faster (6). Therefore, it is plausible that during the GXT, females naturally compensated for the respiratory obstruction of the FM (a factor that likely reduced their respiratory mechanical efficiency), as evidenced by their reduced V_t with an FM. Although males had a significantly different V_t only during recovery, females' V_t was significantly different throughout the entire GXT. However, males had a higher average V_t during the WFM trial, while females had a significantly lower V_t in comparison to their respective WOFM trial. Furthermore, at maximal effort, only males had a higher $PECO_2$. This might signify that although males still had a reduced aerobic performance at maximal effort, their overall respiratory mechanical efficiency was not hindered by a barrier (the FM) while exercising. This may also suggest that males were still able to exhale accumulated CO_2, which was attributed to the FM's filtering ability that trapped particles between the FM and the metabolic mask. In contrast, it may be possible that females were not able to compensate for the CO_2 buildup as indicated by their inability to exhale more CO_2 at maximal effort. In part, this could be the reason why their V_t with an FM was lower than in their WOFM trial, and the FM created major stress to their respiratory system that hindered their ability to move air.

Our study had some limitations that must be mentioned. First, we were not able to control for years of previous endurance training nor familiarity with exercising while wearing an FM. Similarly, under normal testing conditions, it is unnatural to wear an FM under a metabolic mask, which could have created extra distress to participants. These two factors could have impacted the response that participants had during the WFM and WOFM trials. Nevertheless, this study reported significant differences in cardiorespiratory variables and aerobic performance between males and females, portraying how males and females respond differently to a GXT while wearing a surgical FM. Awareness of this different adaptation between males and females can help health practitioners and coaches to better understand the adaptation during aerobic exercise while wearing an FM. Especially, understanding that females will experience a greater detriment in cardiorespiratory variables attributed to greater stress on their respiratory system could help to develop training programs that account for the wear of an FM. In this context, we recommend that future studies examine different exercise modalities combined with different types of FMs to determine if these would affect females differently as it did in our study.

In conclusion, although there is contradictory evidence as to whether exercising with an FM will impact restring pulmonary function and aerobic performance, the current study demonstrated that wearing an FM lowered pulmonary function at rest for both males and females. However, the aerobic performance in males while wearing an FM was significantly reduced only at maximal intensity, whereas females experienced a reduced aerobic performance throughout the entire progression of a GXT.

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REFERENCES

1. Bellemare F, Jeanneret A, Couture J. Sex differences in thoracic dimensions and configuration. Am J Respir Crit Care Med 168(3): 305–12, 2003.

2. Centers for Disease Control and Prevention. COVID data tracker. (November 14): 7–11, 2020.

3. Chandrasekaran B, Fernandes S. "Exercise with facemask; Are we handling a devil's sword?" – A physiological hypothesis. Med Hypotheses 144(2020): 1–4, 2020.

4. Cureton K, Bishop P, Hutchinson P, Newland H, Vickery S, Zwiren L. Sex difference in maximal oxygen uptake - Effect of equating haemoglobin concentration. Eur J Appl Physiol Occup Physiol 54(6): 656–60, 1986.

5. Dixit S. Can moderate intensity aerobic exercise be an effective and valuable therapy in preventing and controlling the pandemic of COVID-19? Med Hypotheses 143(2020): 1–4, 2020.

6. Dominelli PB, Molgat-Seon Y, Sheel AW. Sex differences in the pulmonary system Influence the integrative response to exercise. Exerc Sport Sci Rev 47(3): 142–50, 2019.

7. Driver S, Reynolds M, Brown K, Vingren JL, Hill DW, Bennett M, et al. Effects of wearing a cloth face mask on performance, physiological and perceptual responses during a graded treadmill running exercise test. Br J Sports Med 56(2): 107–13, 2021.

8. Egger F, Blumenauer D, Fischer P, Venhorst A, Kulenthiran S, Bewarder Y, et al. Effects of face masks on

performance and cardiorespiratory response in well-trained athletes. Clin Res Cardiol 111(3): 264–71, 2022.

9. Epstein D, Korytny A, Isenberg Y, Marcusohn E, Zukermann R, Bishop B, et al. Return to training in the COVID-19 era: The physiological effects of face masks during exercise. Scand J Med Sci Sport 31(1): 70–5, 2020.

10. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39(2): 175–91, 2007.

11. Fikenzer S, Uhe T, Lavall D, Rudolph U, Falz R, Busse M, et al. Effects of surgical and FFP2/N95 face masks on cardiopulmonary exercise capacity. Clin Res Cardiol 109(1): 1522–30, 2020.

12. Grinshpun SA, Haruta H, Eninger RM, Reponen T, McKay RT, Lee SA. Performance of an N95 filtering facepiece particulate respirator and a surgical mask during human breathing: Two pathways for particle penetration. J Occup Environ Hyg 6(10): 593–603, 2009.

13. Hassan SA, Sheikh FN, Jamal S, Ezeh JK, Akhtar A. Coronavirus (COVID-19): A review of clinical features, diagnosis, and treatment. Cureus 12(3): 1–5, 2020.

14. Hopkins SR, Harms CA. Gender and pulmonary gas exchange during exercise. Exerc Sport Sci Rev 32(2): 50–6, 2004.

15. Lässing J, Falz R, Pökel C, Fikenzer S, Laufs U, Schulze A, et al. Effects of surgical face masks on cardiopulmonary parameters during steady state exercise. Sci Rep 10(1): 1–9, 2020.

16. Liguori G. ACSM's guidelines for exercise testing and prescription. 10th ed. Philadelphia, PA: Wolters Kluwer; 2021.

17. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1–8, 2019.

18. Olfert IM, Balouch J, Kleinsasser A, Knapp A, Wagner H, Wagner PD, et al. Does gender affect human pulmonary gas exchange during exercise? J Physiol 557(2): 529–41, 2004.

19. Roberge RJ, Coca A, Williams WJ, Powell JB, Palmiero AJ. Physiological impact of the N95 filtering facepiece respirator on healthcare workers. Respir Care 55(5): 569–77, 2010.

20. Shaw K, Butcher S, Ko J, Zello GA, Chilibeck PD. Wearing of cloth or disposable surgical face masks has no effect on vigorous exercise performance in healthy individuals. Int J Environ Res Public Health 17(21): 1–9, 2020.

21. Wang M, Baker JS, Quan W, Shen S, Fekete G, Gu Y. A preventive role of exercise across the Coronavirus 2 (SARS-CoV-2) pandemic. Front Physiol 11: 1–8, 2020.