Effects of wearing a cloth face mask on performance, physiological and perceptual responses during a graded treadmill running exercise test

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ABSTRACT

Objectives To (1) determine if wearing a cloth face mask significantly affected exercise performance and associated physiological responses, and (2) describe perceptual measures of effort and participants' experiences while wearing a face mask during a maximal treadmill test.

Methods Randomised controlled trial of healthy adults aged 18–29 years. Participants completed two (with and without a cloth face mask) maximal cardiopulmonary exercise tests (CPETs) on a treadmill following the Bruce protocol. Blood pressure, heart rate, oxygen saturation, exertion and shortness of breath were measured. Descriptive data and physical activity history were collected pretrial; perceptions of wearing face masks and experiential data were gathered immediately following the masked trial.

Results The final sample included 31 adults (age=23.2±3.1 years; 14 women/17 men). Data indicated that wearing a cloth face mask led to a significant reduction in exercise time (−01:39±01:19 min/sec, p<0.001), maximal oxygen consumption (VO_2max) (−818±552 mL/min, p<0.001), minute ventilation (−45.2±20.3 L/min), maximal heart rate (−8.4±17.0 beats per minute, p<0.01) and increased dyspnoea (1.7±2.9, p<0.001). Our data also suggest that differences in SpO_2 and rating of perceived exertion existed between the different stages of the CPET as participant's exercise intensity increased. No significant differences were found between conditions after the 7-minute recovery period.

Conclusion Cloth face masks led to a 14% reduction in exercise time and 29% decrease in VO_2max, attributed to perceived discomfort associated with mask-wearing. Compared with no mask, participants reported feeling increasingly short of breath and claustrophobic at higher exercise intensities while wearing a cloth face mask. Coaches, trainers and athletes should consider modifying the frequency, intensity, time and type of exercise when wearing a cloth face mask.

INTRODUCTION

The onset of the SARS-CoV-2 and subsequent spread of COVID-19 resulted in a global pandemic declaration by the WHO on 11 March 2020. By early April 2020, mandates were emerging globally requiring face masks in many public or workspaces, including during physical activity or exercise. However, recommendations for wearing face masks during exercise vary globally and the physiological impact of wearing cloth face masks during such activity is not well understood.[1–3] Currently, the US Centers for Disease Control and Prevention recommends that all people over 2 years of age wear a cloth face mask, especially when exercising indoors or when social distancing measures are difficult to maintain.[4] The WHO cautions that wearing a face mask when exercising may reduce the ability to breathe comfortably and that sweat can make the mask become wet more quickly, resulting in breathing difficulty and promotion of microorganism growth.[5] In the USA, the requirements for wearing a face mask are similar for high school[6] and collegiate sports[7] which require that athletes wear a face mask when physical distancing is not possible. Similarly, gyms and fitness centres for the general population[8] and clinical therapeutic exercise programmes for those with acute or chronic diseases (eg, cardiopulmonary rehabilitation) have face mask policies to reduce the impact of droplet or aerosol-generating exercises.

Several studies have investigated the impact of wearing N95 and surgical masks on the cardiovascular and subjective response to exercise.[1–3 9] However, it is important to note that due to the shortage of N95 masks, it is recommended that these be reserved for frontline workers and not worn during exercise.[4] Further, surgical masks may become wet during exercise, causing breakdown of the mask and subsequently loss of the ability to block outgoing virus and other germs.[5] Thus, because cloth face masks appear to be the most common type of mask used by the general public, examining the impact of wearing a cloth face mask on subjective and objective cardiopulmonary response to maximal exercise and performance is needed.

To address this gap in the body of knowledge surrounding the effects of wearing cloth face masks during exercise, we completed a prospective, randomised crossover trial, in which participants completed two cardiopulmonary exercise tests (CPETs) on a treadmill (1) wearing a cloth face mask and (2) not wearing a cloth face mask. Our primary aim was to determine if wearing a cloth face mask significantly affected performance (ie, reduction in exercise time) and associated physiological responses (eg, maximal oxygen consumption (VO_2max)). Our secondary aim was to describe perceptual measures of effort (eg, rating

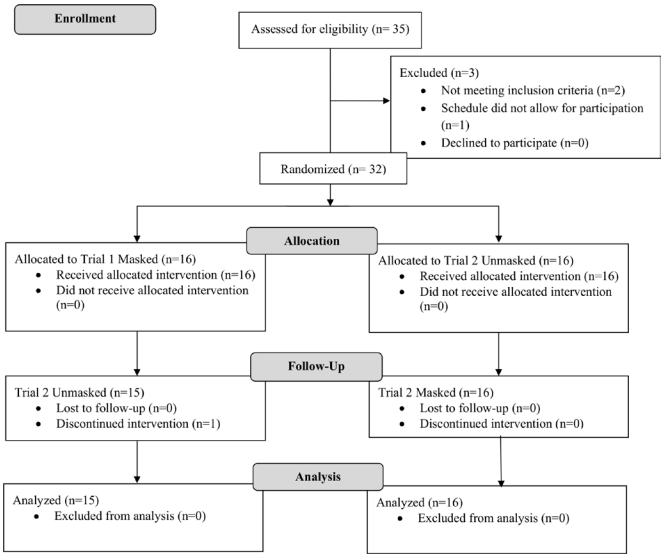

Figure 1 CONSORT diagram displaying eligibility, exclusion and randomisation scheme. Thirty-two individuals were consented and enrolled into the research study. Randomisation allocated participants to either the masked or unmasked condition, followed by crossover to the other condition. Participation was discontinued for one individual, resulting in analysis of 31 participants. CONSORT, Consolidated Standards of Reporting Trials.

of perceived exertion (RPE)) and participants' experiences (eg, comfort, temperature, breathability) while wearing a face mask during the CPET.

METHODS

Participants

Before study initiation, signed informed consent was obtained from all participants. Recruitment occurred through a large healthcare system, sports performance programme and an academic university in the USA. Participation included two visits to the healthcare system's sports therapy and research facility. Recruitment, screening and testing were completed during 3 weeks in September 2020.

Eligibility criteria included participants between 18 and 29 years of age,[10] no contraindications for maximal treadmill exercise testing (ie, cardiopulmonary conditions, orthopaedic or neurological conditions,), diabetes, claustrophobia, pregnancy and history of COVID-19 infection, and screening with the Physical Activity Readiness Questionnaire.[11] Consented participants were reimbursed $50 per assessment ($100 total).

Sample size calculations were performed to detect a medium effect size for a paired sample of 0.55[12] with VO_2max as the primary outcome. With a 5% significance level and 80% power, it was estimated that 28 participants would be needed. Order of testing was assigned using a 1:1 scheme stratified by sex.[13 14] Participants crossed over to the other condition an average of 8.3±1.8 days later (see Consolidated Standards of Reporting Trials diagram in figure 1).

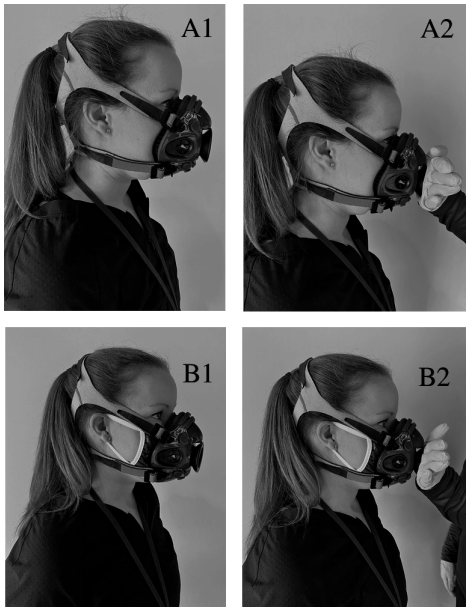

Figure 2 Fit comparison of K5 COSMED masks with and without cloth face masks. (A1) K5 COSMED mask with no cloth face mask; (A2) K5 COSMED mask with no cloth face mask during fit test; (B1) K5 COSMED mask with cloth face mask and (B2) K5 COSMED mask with cloth face mask during fit test.

Cardiopulmonary exercise testing

Cloth face mask and CPET mask fit

All participants wore the same brand and style of cloth face mask: (22×11 cm, 2 layers of 88% polyester/12% elastane, cotton lining, elastic ear straps) (Foco, Team Beans, Somerset, New Jersey, USA). Participants were then fitted for metabolic testing equipment (K5 Wearable Metabolic System, COSMED, Concord, California, USA).[15–18] The fit of the cloth face mask beneath the K5 mask was standardised; correct fit was confirmed through expiration with maximal force before each test to identify air leakage (figure 2) by closing the valve of the mask and stopping air flow. The fit was then checked for leakage (eg, lifting of the mask away from the face or sound of whistling) and during testing breath-by-breath measurements were monitored. For trials without face masks, the same K5 mask equipment fit procedures were used.

CPET protocol

All CPETs were completed within a sports performance diagnostic lab using a motorised treadmill (Woodway Pro XL, Waukesha, Wisconsin, USA) by an exercise physiologist. Prior to each CPET, the participant sat quietly for 5 min, followed by a resting measure of auscultatory arterial blood pressure (BP) (Gold Series DS66 Trigger Aneroids and Flexiport Reusable BP Cuff, Welch Allyn, Skaneateles Falls, New York, USA; MD One Adult Stethoscope, MDF Instruments, Rincón, Puerto Rico), heart rate (HR) (HRM-Dual, Garmin, Kansas City, Missouri, USA), and SpO_2 (Deluxe Oximeter, Innovo Medical, Stafford, Texas, USA).

After a 3-minute walking warm-up (2.7 km/hour-1/0% incline), participants performed an exhaustive incremental CPET using a Bruce treadmill protocol[19] (see table 1). Assessments of BP and SpO_2 were obtained during the last minute of each 3 min stage and immediately prior to exhaustion. RPE (Borg Scale for RPE, scoring 6–20)[20] and dyspnoea (Modified Borg Dyspnoea Scale, scoring 0–10)[21] were obtained and recorded during the last 10 s of each stage. Participants were instructed using a preapproved script to exercise to volitional fatigue. Time to exhaustion was determined by the exercise physiologist as the time from when the participant started the test until they indicated an inability to continue. No verbal or non-verbal encouragement or feedback was provided. After termination, all participants performed a 7-minute standing recovery in both conditions on the treadmill.

Table 1 Number of stages for masked and unmasked trials

CPET stage number	Speed/incline	Predicted MET*	Masked	Unmasked
1	2.7 km/hour/10%	4.6	31 (100%)	31 (100%)
2	4.0 km/hour/12%	7.0	31 (100%)	31 (100%)
3	5.4 km/hour/14%	10.2	29 (93.5%)	31 (100%)
4	6.7 km/hour/16%	12.1	19 (61.3%)	26 (83.9%)
5	8.0 km/hour/18%	14.9	7 (22.6%)	10 (32.3%)
6	8.8 km/hour/20%	17.0	0 (0%)	3 (9.7%)

*American College of Sports Medicine values.[32]
CPET, cardiopulmonary exercise test; MET, metabolic equivalent.

Descriptive and outcome data

Descriptive data and physical activity history were collected pretrial.[22] A Scale of Measuring Subjective Perceptions to mask-wearing[2 9] assessed humidity, heat, breathing resistance, itchiness, tightness, saltiness, feeling unfit, odour and fatigue using a scale of 0 ('not at all') to 10 ('strongly'); overall discomfort was measured on a scale of 0 ('comfortable') to 10 ('extremely uncomfortable'); and brief qualitative questions about their experience were administered immediately following the 7-minute recovery period of the masked trial in which participants were encouraged to sit. Gas analysis was not collected on several participants during recovery as they removed their mask prior to completing the 7-minute standing recovery period due to reported dyspnoea (table 2).

CPET outcomes were measured and recorded during (1) warm-up, (2) the exercise test, and (3) following 7-minute recovery and included time to fatigue, oxygen consumption (VO_2), VO_2/kg, respiratory exchange ratio (RER), minute ventilation (VE)/carbon dioxide production (VCO_2), VE, breathing reserve (BR), VO_2/HR, respiratory frequency (RF) and tidal volume (VT). Expired gases were analysed on a breath-by-breath basis through the K5 device and peak values were averaged using the last 30 s prior to terminating the test. Chronotropic index was calculated for participants in each condition to determine significant differences in cardiovascular response profile.[23]

Data analysis

Continuous data measures were summarised with means and SDs; categorical measures were summarised with counts and percentages. To determine if pretest HR, BP and SpO_2 differed between trials, measures were compared using Wilcoxon rank sum test due to small sample size.[24] To assess the impact of masked versus unmasked trials, potential ordering effects, and interaction between condition and gender, repeated measures analysis of variance was used. For all comparisons, participants' data are only included for a given measure if they were collected under both conditions. All analyses were performed using SAS V.9.4 with level of significance set at $p \leq 0.05$. Due to the exploratory nature of this study, we did not adjust p values for multiple comparisons.

Patient and public involvement

The results of the study will be shared with publicly available resources to inform the audience with regard to exercising with cloth face masks.

RESULTS

Demographic and baseline data

The final sample consisted of 31 individuals (Mage=23.2±3.1 years) who successfully completed both test trials and consisted of 14 women and 17 men who were predominantly white (n=17; 54%), followed by Black (n=6; 19%), Asian (n=4; 12%) and American Indian (n=1; 3%) with 10 (32%) of Hispanic ethnicity. Participants engaged in 170±158 min/week of moderate and 206±205 min/week of vigorous physical activity. No participants reported smoking cigarettes, three participants (10%) reported smoking marijuana and five participants (16%) indicated a history of controlled asthma. Other sample characteristics include height (172±11 cm), weight (74.4±16.5 kg) and body mass index (25.1±5.0 kg/m^2). Most participants reported that they had worn a face mask while exercising prior to enrolling in the study (n=24; 77.4%) and/or that their exercise facility required them (n=19; 61.3%).

CPET data

The number of participants who reached each stage of the CPET for the masked and unmasked condition is presented in table 1. Table 2 reports data for (1) pretrial metrics, (2) each stage of the CPET, (3) the mean maximal values (ie, VO_2, relative VO_2 (VO_2/kg), RER, ventilatory efficiency (VE/VCO_2) slope, BR, O_2 pulse (VO_2/HR), RF and tidal volume (VT), and (4) recovery data. Pretrial results indicated no difference between conditions in HR, BP or SpO_2. For the CPET stage data, no significant differences were observed between conditions in diastolic BP and HR, but significant differences were observed in systolic BP at stages 3 (p=0.04) and 4 (p=0.04), and SpO_2 pulse oximetry at stages 1 (p=0.07), 3 (p<0.001) and 4 (p<0.001).

Participant maximal CPET data indicated a significant difference between conditions including reduced exercise time (p<0.001), VO_2max (p<0.001), RER (p<0.001), VE (p<0.001), BR (p<0.001), VO_2/HR (p<0.001), HR (p=0.01), SpO_2 (p=<0.01), RF (p<0.001), VT (p<0.001) and increased dyspnoea (p<0.001). No significant differences between conditions were found for VE/VCO_2 (p=0.98), RPE (p=0.99), or diastolic (p=0.68) and systolic BP (p=0.27). At the end of the 7-minute recovery period, there was no significant difference between conditions in HR (p=0.15), BP (systolic, p=0.45; diastolic, p=0.20) or SpO_2 (p=0.28). The chronotropic index was determined to be 0.87±0.08 for the masked condition and 0.93±0.09 for the unmasked condition; neither group demonstrated chronotropic incompetence (<0.8).[25] A two-sample paired t-test indicated a statistically significant difference in chronotropic index between the two conditions (p=0.02). Analysis revealed no differences based on the interaction of gender and mask condition (reduced exercise time, maximum HR, maximum BP, systolic BP, diastolic BP, maximum SpO_2, dyspnoea, RPE) or order of test effect.

Subjective ratings of mask comfort

Table 3 reports post-trial responses to cloth face mask comfort. Participants indicated that the cloth face mask was overall uncomfortable and strongly impacted breath resistance. The majority of the sample (n=30; 96.8%) reported to 'agree' (n=8) or 'strongly agree' (n=22) that it was harder to give maximum effort during the trial in which they were wearing the cloth face mask. Online supplemental material summarises the qualitative responses from participants collected following the masked trial. Responses in general indicated that participants felt that the test was more difficult in the cloth face mask ('harder than last time, I fatigued quicker; no effect during the walking stage, affected me during the jog'), especially at increased intensity ('running was harder than normal, breathing got harder as speed/incline increased'). Participants also mentioned feeling 'claustrophobic',

Table 2 Summary of CPET data—pretrial, staged, maximal and recovery

Measure	CPET stage	N*	Masked	Unmasked	Difference (95% CI)	Cohen's d effect size	P value
HR (bpm)		31	64.1±14.8	65.1±15.4	−1 (−5.7 to 3.7)	0.07	0.67
Systolic BP		31	106.5±6.9	106.8±7.3	−0.3 (−2.3 to 1.7)	0.05	0.80
Diastolic BP		31	62.5±6.1	61.7±7.5	0.8 (−2.5 to 4.1)	0.09	0.65
SpO_2		31	97.8±1.5	97.9±1.5	−0.1 (−0.6 to 0.4)	0.07	0.73
Systolic BP (mm Hg)							
	1	31	122.4±13.3	121.0±16.2	1.4 (−4 to 6.8)	0.09	0.58
	2	31	138.6±16.3	136.7±19.5	2 (−5.4 to 9.4)	0.1	0.47
	3	28†	157.6±19.4	150.1±22.6	7.5 (0.8 to 14.2)	0.41	0.04
	4	17†	172.4±21.7	163.8±22.6	8.6 (−0.1 to 17.3)	0.47	0.04
	5	5‡	178.0±14.1	179.6±29.1	−1.6 (−32.7 to 29.5)	0.05	§
Diastolic BP (mm Hg)							
	1	31	64.6±6.7	66.0±9.2	−1.4 (−4.8 to 2)	0.14	0.45
	2	31	67.9±7.1	67.5±8.2	0.4 (−2.5 to 3.3)	0.05	0.72
	3	28†	71.2±9.1	69.2±10.0	2 (−2.5 to 6.5)	0.17	0.32
	4	17†	74.4±10.5	70.1±12.1	4.2 (−2.6 to 11)	0.29	0.32
	5	5	74.4±15.4	68.8±10.8	5.6 (−4.3 to 15.5)	0.5	
HR (bpm)							
	1	30¶	100.7±18.1	101.3±18	−0.5 (−4.4 to 3.4)	0.05	0.76
	2	30¶	124.9±21.4	119.1±21.5	5.7 (−3 to 14.4)	0.24	0.25
	3	28¶	153.0±21.5	151.2±23.5	1.8 (−5.8 to 9.4)	0.09	0.81
	4	18	170.4±13.1	167.6±15.6	2.9 (−1.9 to 7.7)	0.28	0.81
	5	5	172.0±7.6	178.2±4.7	−6.2 (−10.7 to 1.7)	1.22	
SpO_2							
	1	30**	96.6±1.8	97.3±1.3	−0.6 (−1.3 to 0.1)	0.3	0.07
	2	29**	96.4±1.8	96.9±1.7	−0.4 (−1.1 to 0.3)	0.22	0.15
	3	27†**	94.6±1.9	96.5±1.6	−1.9 (−2.7 to 1.1)	0.86	<0.001
	4	16¶	91.9±2.1	94.6±2.3	−2.8 (−4, to 1.6)	1.17	<0.001
	5	4**	92.3±3.3	93.5±3.1	−1.3 (−3.2 to 0.6)	0.68	
RPE							
	1	31	9.3±2.5	7.4±1.9	1.9 (1 to 2.8)	0.73	<0.01
	2	31	11.2±3.0	9.9±2.7	1.3 (0.4 to 2.2)	0.5	0.01
	3	28†	14.3±2.8	12.9±3.0	1.4 (0.5 to 2.3)	0.56	0.01
	4	18	17.0±2.1	15.6±2.7	1.4 (0.6 to 2.2)	0.82	0.01
	5	5	18.0±3.5	17.6±3.6	0.4 (−0.4 to 1.2)	0.44	
Dyspnoea							
	1	31	1.6±1.4	0.5±0.8	1 (0.5 to 1.5)	0.71	<0.001
	2	31	2.6±1.8	1.4±1.3	1.2 (0.7 to 1.7)	0.92	<0.001
	3	28†	4.8±2.8	2.8±1.8	2 (1.3 to 2.7)	1.05	<0.001
	4	18	7.2±2.6	4.8±2.6	2.4 (1.3 to 3.5)	1	<0.001
	5	5	7.6±2.6	5.4±2.8	2.2 (−0.2 to 4.6)	0.81	
Bruce test duration		31	10:58±02:16	12:38±02:17	−01:39 (−02:07 to −01:11)	1.25	<0.001
VO_2 (mL/min)		30	2398±881	3216±767	−818 (−1015.5 to 620.5)	1.48	<0.001
VO_2/kg (mL/min/kg)		30	32.2±9.0	43.9±8.1	−11.6 (−14.4 to 8.8)	1.51	<0.001
RER		30	1.00±0.10	1.09±0.08	−0.09 (−0.1 to 0.1)	1.13	<0.001
VE/VCO_2		29	26.2±4.1	26.1±4.8	0.1 (−1.6 to 1.8)	0.02	0.98
Dyspnoea		30	7.2±2.9	5.5±2.3	1.7 (0.7 to 2.7)	0.59	<0.001
RPE		30	16.9±3.0	16.8±3.0	0.1 (−1.1 to 1.3)	0.03	0.99
VE (L/min)		30	54.2±21.0	99.4±24.7	−45.2 (−52.5 to 37.9)	2.23	<0.001
Breathing reserve (%)		30	63.1±10.8	34.6±13.8	28.5 (23.2 to 33.8)	1.94	<0.001
VO_2/HR (mL/beat)		30	14.0±5.1	17.7±4.5	−3.6 (−4.9 to 2.3)	0.97	<0.001
HR (bpm)		30	175.3±10.0	183.7±10.8	−8.4 (−14.5 to 2.3)	0.49	0.01
Systolic BP (mm Hg)		31	169.0±22.7	171.0±26.4	−2 (−10.3 to 6.3)	0.08	0.68
Diastolic BP (mm Hg)		31	76.2±10.7	73.9±14.5	2.3 (−3.6 to 8.2)	0.14	0.27
SpO_2		31	93.4±3.1	95.1±2.4	−1.7 (−2.8 to 0.6)	0.55	<0.01
Respiratory frequency		30	35.4±8.2	44.8±6.5	−9.4 (−12.5 to 6.3)	1.09	<0.001
Tidal volume		30	1.8±0.7	2.4±0.6	−0.6 (−0.7 to 0.5)	1.5	<0.001

Continued

Table 2 Continued

Measure	CPET stage	N*	Masked	Unmasked	Difference (95% CI)	Cohen's d effect size	P value
Completed n (%)			22†† (71)	29†† (93.5)	22.5		0.02
HR (bpm)			107.2±17.5	111.0±18.6	−3.8 (−10 to 2.4)	0.26	0.15
Systolic BP (mm Hg)			112.5±18.3	110.9±21.8	1.6 (−9.1 to 12.3)	0.06	0.45
Diastolic BP (mm Hg)			63.1±8.8	60.7±8.0	2.5 (−1.7 to 6.7)	0.26	0.20
SpO_2			96.6±1.6	96.2±1.6	0.3 (−0.6 to 1.2)	0.14	0.28

*Comparison included only for participants who reached the given CPET stage for both masked and unmasked trials.
†Missing datapoint(s) due to participant reaching exhaustion and terminating test before data could be gathered.
‡Table 2 stage 5 n differs from table 1 stage 5 n due to two participants reaching exhaustion in stage 5 when unmasked and reaching exhaustion in stage 4 when masked.
§Insufficient n for analysis.
¶Missing datapoint due to HR monitor malfunction.
**Missing datapoint(s) due to pulse oximeter malfunction.
††N<31 due to participants removing the COSMED mask prior to completing the 7-minute recovery period.
BP, blood pressure; bpm, beats per minute; CPET, cardiopulmonary exercise test; HR, heart rate; RER, respiratory exchange ratio; RPE, rating of perceived exertion; VCO_2, carbon dioxide production; VE, minute ventilation; VO_2, oxygen consumption.

'suffocated' and 'anxious' while wearing the mask and taking 'shorter, more shallow breaths with the face covering'. Following the test, no participants indicated that moisture or weight of the mask inhibited their performance or resulted in terminating the exercise test.

DISCUSSION

Our data indicate that wearing a cloth face mask significantly impaired participant performance during a CPET. The observed significant differences in key performance variables (ie, reduced exercise time), physiological variables (eg, VO_2max, VE, HR, SpO_2) and perceptual variables (ie, RPE, dyspnoea) suggest that exercising while wearing a cloth face mask negatively impacted the exercise performance of our sample. Further, our data suggest that differences in SpO_2, RPE and dyspnoea (figure 3) existed between different stages of the CPET as participants' exercise intensity increased. Table 4 compares our results with previous research in this area.

Notably, the ventilatory efficiency for CO_2 was unaffected by wearing a mask. This suggests that there was not a greater ventilatory demand associated with removal of CO_2 and that, up to the point of exhaustion, ventilation was adequate to maintain arterial oxygen content at near-normal levels.[26] SpO_2 was reduced by 2% which would reduce peak VO_2 (VO_{2peak}) (~1 mL/kg/min) but is not considered clinically significant exercise-induced hypoxaemia.[26 27] The perception of exertion can be associated with ventilation, as well as to metabolic efficiency. This is consistent with the lack of effect of mask-wearing on VO_2 and VE at exhaustion. Similarly, RPE at the point of exhaustion was unaffected by mask-wearing. As our results do not fully explain how mask-wearing might directly limit cardiovascular function, our conclusion is that the discomfort associated with mask-wearing, as evidenced by the higher ratings of dyspnoea in the mask condition and participants' qualitative feedback, directly led to the reduction in performance. Further, VO_{2peak}, peak HR and peak VE were lower because of the early termination of exercise. Results also indicated a significant difference in ventilation between conditions, (ie, VT and RF were lower in the masked condition)[28] which may also have contributed to early termination of exercise. This difference in the masked condition may potentially be due to an increased difficulty in breathing at higher intensities as evidenced by reduced number of breaths per minute (RF) and VT (amount of air moved with each breath). Qualitative data potentially support participants this notion based on responses including 'felt hard to breathe, felt like I couldn't get a deep breath' and 'had to breathe deeper to get the same amount of air'.

In the present study, RPE at the point of exhaustion was the same in the mask and no mask conditions and dyspnoea was

Table 3 Summary of responses to post-trial mask survey

Rate the following sensations while wearing the face covering during the test	0 (not at all)–10 (strongly)
Humid	5.0±3.1
Hot	5.9±2.4
Breath resistance	8.6±1.3
Itchy	1.0±1.5
Tight	5.9±3.1
Salty	0.5±0.9
Unfit	1.9±2.4
Odour	0.6±1.5
Fatigue	6.9±1.8
Overall discomfort	6.4±2.7

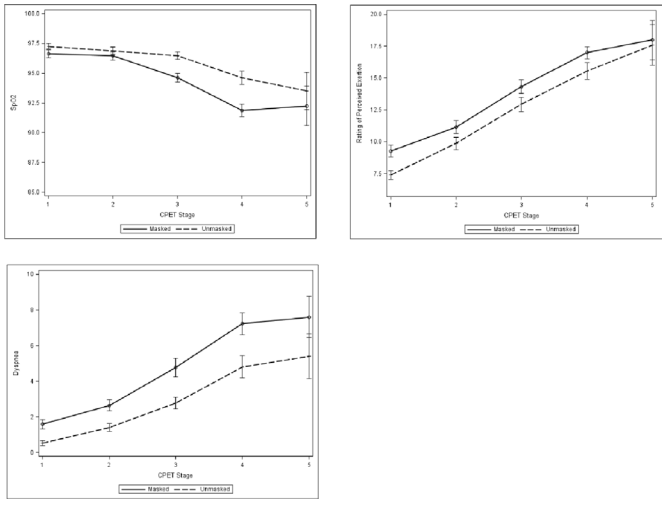

Figure 3 Participant SpO_2, RPE and dyspnoea at each CPET stage. Data suggest that differences in SpO_2, RPE and dyspnoea existed between different stages of the CPET as participants' exercise intensity increased. CPET, cardiopulmonary exercise test; RPE, rating of perceived exertion.

Table 4 Comparison of face mask and exercise research

Authors	Design and mask	Number of participants	Age of participants	Test protocol	Results
Driver *et al*	Randomised crossover design: cloth face mask, no mask	N=31 (14 women, 17 men)	*M*age=23.2±3.1 years	Incremental CPET using a Bruce treadmill protocol	Impaired participant performance in key performance variables (ie, reduced exercise time), physiological variables (eg, VO_2max, VE, HR, SpO_2) and perceptual variables (ie, RPE, dyspnoea).
Li *et al*[9]	Randomised: surgical, N95	N=10 (5 women, 5 men)	*M*age=28.0±6 years	Intermittent treadmill test	HR was lower during exercise testing in the surgical mask condition. Participants rated the surgical face masks less favourably on perceived humidity, heat and breath resistance.
Fikenzer *et al*[2]	Crossover design: surgical, N95, no mask	N=12 men	*M*age=38.1±6.2 years	Incremental test on semirecumbent cycle ergometer	Significantly reduced ventilation, VO_2max, and comfort in the conditions with surgical and N95 masks compared with no mask.
Epstein *et al*[1]	Crossover design: surgical, N95, no mask	N=16 men	*M*age=34±4 years	Ramped test on cycle ergometer	No significant difference in exercise time, HR, arterial blood oxygen saturation (SAO_2) or blood pressure responses across conditions. End-tidal carbon dioxide level during the N95 mask condition (43 mm Hg) was significantly higher compared with surgical mask (40 mm Hg; p=0.04) and no mask (35 mm Hg; p=0.001).
Shaw *et al*[3]	Randomised crossover design: surgical, cloth face mask, no mask	N=14 (7 women, 7 men)	*M*age28.2±8.7 years	Maximal cycle ergometer test	No significant effect of wearing a surgical or cloth mask on exercise time, peak power, SAO_2, RPE or HR. No cardiopulmonary or ventilatory data were collected under the cloth mask condition.

CPET, cardiopulmonary exercise test; HR, heart rate; RPE, rating of perceived exertion; VE, minute ventilation; VO_2max, maximal oxygen consumption.

significantly different. We conject that the perception of effort and sense of dyspnoea provided the perceptual cue to terminate exercise in the masked condition. Regardless of the work rate, elapsed time, metabolic demand or ventilatory response, exercise was terminated when the exercise was perceived as 'very hard' (on average) and level of dyspnoea was 'very severe' (on average).

Implications for exercise performance

Our results have several implications for training and performance while wearing a cloth face mask. First, as wearing a cloth mask reduced exercise performance, VO_{2peak} and related variables, training variables of frequency, intensity, time and type of activity should be modified accordingly. Second, exercise goals can be modified to reflect the reduced performance and psychological impact of wearing a cloth mask while still promoting safe goal attainment.

Limitations and future research

It is important to note the study limitations. Our sample reflects young, apparently healthy, physically active adults, and thus results may not be applicable to other populations (eg, children, older adults, sedentary population, individuals with medical conditions). Next, despite following a thorough process for pretest mask fit, leakage may have occurred during the CPET, especially at higher workloads/stages when ventilation increased. Additionally, while we standardised the cloth face mask for the purposes of the study, there is significant variability in masks used by the public (eg, size, shape, material, design), each of which may impact the effect of masks on exercise responses. Further, resting measurements of dyspnoea would provide insight into the effect of wearing a cloth face mask at rest and measurement of lactate would provide insight into the explanation of reduced VO_2 to account for differences associated with effort versus physiological limitations. Finally, participants did not undergo a 'preparatory' exercise test, nor were the study team blinded to masked or unmasked conditions (eg, use of a sham). Future research should examine the effect of those specific mask configurations on exercise performance and related physiological variables and whether 'acclimatisation'—or even improved exercise performance[29]—to wearing masks during exercise occurs, as well as quantitative resting rates of dyspnoea. Further, increased RPE and dyspnoea across all stages during the masked condition warrant future investigation of implications for individuals with history of conditions such as chronic obstructive lung disease, chronic heart failure[30] and asthma.[31] Future research should examine

What are the findings?

- Cloth face masks reduced exercise time by 14% and maximal oxygen consumption by 29%.
- Compared with no mask, participants reported feeling increasingly short of breath and claustrophobic at higher exercise intensities while wearing a cloth face mask.
- These results may be attributed to termination of exercise due to perceived discomfort associated with mask-wearing.

How might it impact on clinical practice in the future?

- Coaches, trainers and athletes should consider modifying the frequency, intensity, time and type of exercise when wearing a cloth face mask.
- Athlete goals should be modified to reflect the reduced performance.
- Athlete goals should account for the psychological impact of wearing a cloth face mask while exercising.

cognitive capacity to tasks while wearing a mask during exercise, as well as the relationship between VO_2 data and CPET stages.

CONCLUSION

Our data suggest that wearing a cloth face covering negatively impacts exercise performance in healthy adults during a maximal treadmill test. As both physiological and perceptual factors were negatively impacted, coaches, trainers and athletes should be aware of the effect of cloth face coverings as the population continues to exercise safely during the global pandemic.

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Contributors Study concept—SD, MR, KB, JLV and DWH. Study design—SD, MR, LC, MB, KB, JLV and DWH. Literature search—SD, MR, EM, KB, TG, JLV and DWH. Data acquisition—SD, MR, KB, TG, EM and LC. Data analysis—MB and LC. Manuscript preparation—SD, MR, KB, JLV, DWH, LC and MB. Manuscript editing—SD, MR, KB, MB, LC, TG, EM, ER, JLV, DWH, NB, JJM, CC and AJ. All authors read and approved the final manuscript.

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