Impact of wearing a surgical and cloth mask during cycle exercise

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Abstract

We sought to determine the impact of wearing cloth or surgical masks on the cardiopulmonary responses to moderate-intensity exercise. Twelve subjects (n=5 females) completed three, 8-min cycling trials while breathing through a: non-rebreathing valve (laboratory control), cloth, or surgical mask. Heart rate (HR), oxyhemoglobin saturation (SpO₂), breathing frequency (Fb), mouth pressure, partial pressure of end-tidal carbon dioxide (PₐCO₂) and oxygen (PₐO₂), dyspnea, were measured throughout exercise. A subset of n=6 subjects completed an additional exercise bout without a mask (ecological control). There were no differences in Fb, HR or SpO₂ across conditions (all p>0.05). Compared to the laboratory control (0.9±0.7cmH₂O[mean±SD]), mouth pressure swings were greater with the surgical mask (4.7±0.9; p<0.0001), but similar with the cloth mask (3.6±4.8cmH₂O; p=0.66). Wearing a cloth mask decreased PₐO₂ (-3.5±3.7mmHg) and increased PₐCO₂ (+2.0±1.3mmHg) relative to the ecological control (both p<0.05). There were no differences in end-tidal gases between mask conditions and laboratory control (both p>0.05). Dyspnea was similar between the control conditions and the surgical mask (p>0.05) but was greater with the cloth mask compared to laboratory (+0.9±1.2) and ecological (+1.5±1.3) control conditions (both p<0.05). Wearing a mask during short-term moderate-intensity exercise may increase dyspnea but has minimal impact on the cardiopulmonary response.

Novelty bullets

- Wearing surgical or cloth masks during exercise has no impact on breathing frequency, tidal volume, oxygenation, heart rate
- However, there are some changes in inspired and expired gas fractions that are physiologically irrelevant.
- In young healthy individuals, wearing surgical or cloth masks during submaximal exercise has few physiological consequences.

Key words: airflow resistance, cardiopulmonary exercise, respiratory
Introduction

During the COVID-19 pandemic, many countries have implemented strategies to mitigate viral transmission and infection. Wearing a face mask that covers the nose and mouth is one such strategy. Masks are an effective method of reducing virus particle shed via respiratory droplets during breathing at rest (Leung et al. 2020). Masks are versatile in that they can be worn during activities of daily living or recreation; however, there is a belief among some that wearing a mask may alter the physiological response to exercise and even hinder exercise capacity. The notion that wearing a face mask might negatively impact the ability to exercise may lead some to avoid physical activity in contexts where face masks are required. Since physical activity levels are associated with improved mental health and general mortality, a reduction in physical activity could have serious consequences in terms of mental, cardio-respiratory, and metabolic health of individuals worldwide (Stephens 1988; Blair et al. 2001; Füzéki et al. 2020; Pieh et al. 2020). Thus, it is crucial that individuals continue to perform exercise, even in the face of these restrictions and regulations.

Wearing a face mask could impact the physiological response to exercise by increasing airflow resistance, increasing anatomical dead space, increasing face temperature, increasing the perception of dyspnea or a combination thereof. The supposed rationale for these purported effects is briefly described below. First, an increased airflow resistance would result in a corresponding greater work of breathing. Substantial increases in the work of breathing during exercise can trigger the respiratory muscle metaboreflex, whereby blood flow is redistributed away from the locomotor muscles and towards the respiratory muscles, which increases locomotor muscle fatigue (Harms et al. 1997; Romer et al. 2006; Dominelli et al. 2017). Second, increasing anatomical dead space would lead to rebreathing exhaled gases, which could result in hypercapnia and hypoxemia. Third, a mask may reduce thermoregulatory capacity resulting in greater core temperature during exercise. Fourth, all the aforementioned effects could, individually or in combination, increase the perception of dyspnea.
Despite these purported concerns, there is limited empirical data to support these claims. In fact, recent evidence suggests that cloth or surgical masks have no impact on maximal exercise capacity or oxygenation during vigorous exercise in healthy individuals (Shaw et al. 2020). A recent review corroborated this finding and concluded that the physiological effects of wearing a mask were minimal and unlikely to impact the exercise response, independent of those with severe cardiopulmonary disease (Hopkins et al. 2020). However, conclusions from the Hopkins et al. review were largely based on circumstantial evidence and lacked direct assessment of the impact of facemasks during exercise; therefore, this study was conducted to directly address the lack of evidence in current literature on the impact of face masks during laboratory and ecologically relevant exercise conditions. An ecologically relevant exercise condition is when exercise is performed outside of a traditional standard cardiopulmonary test setup apparatus. Most studies evaluating the effect of masks during exercise have involved high-intensity exercise, often performed to exhaustion in a laboratory setting (Shaw et al. 2020; Fikenzer et al. 2020; Epstein et al. 2021). While (near) maximal exercise testing is an effective method of characterizing the physiological response to exercise, the vast majority of individuals do not exercise at these high intensities; current guidelines typically recommend moderate-to-vigorous physical activity (Arena et al. 2014). Furthermore, when exercising outdoors, ambient airflow, due to the wind or via self-generated movement, may alter the impact of the mask on the physiological response to exercise.

As such, the purpose of this study was to determine if wearing a cloth or surgical mask impacts the cardiopulmonary response to exercise at an intensity that is commensurate with moderate-to-vigorous physical activity under ecologically-relevant conditions. To test this, we had healthy individuals exercise at 70% of their maximum heart rate while wearing either a cloth mask, surgical mask, standard laboratory cardiopulmonary exercise testing mouthpiece (laboratory control) or nothing (ecological control). The ecological control group wore a modified mouthpiece (discussed below; see Figure 1) that allowed for subjects to exercise as close to they normally would, while still measuring mouth pressures and gas concentrations. We
hypothesized that the increase in airflow resistance and any exhaled gas rebreathed from the two
masks would be negligible and result in no physiological impact; however, dyspnea may be
increased due to non-physiological factors.

Methods

Subjects. Twelve healthy young adults (5 females; age 26 ± 3 years [mean ± SD]) with a normal
body mass index (24.3 ± 3.1 kg/m²) participated. Subjects were excluded if they had: a history of
smoking, symptoms of cardiovascular, respiratory, or metabolic diseases or were taking
medication that would influence their exercise response. Females were tested at random points in
their menstrual cycle as previous work has shown that menstrual cycle phase has no effect on
exercise ventilation (MacNutt et al. 2011). The study was approved by the Office of Research
ethics review board at the University of Waterloo (#42240) and adheres to the Declaration of
Helsinki, except registration in a database. Subjects were informed of experimental procedures,
potential risks and provided written informed consent.

Experimental protocol. All testing was conducted during a single visit to the laboratory. Subjects
completed three separate bouts of exercise on an electronically braked cycle ergometer (LC7TT,
Monark Exercise AB, Vansbro, Sweden). Prior to testing, subjects performed a 5-8 minute
submaximal exercise bout which involved a progressive increase in ergometer resistance until
heart rate (HR) reached a steady-state of 70% of the predicted maximum HR. Predicted max HR
was calculated using the Tanaka equation (208 – (0.7 x age of subject) (Tanaka et al. 2001). The
relative HR intensity was selected based on a moderate-vigorous exercise zone recommended by
the American College of Sports Medicine (Arena et al. 2014). We elected to use a work rate that
is determined by a predicted HR to ensure the ecological validity and translatability of our
findings to the general population since it is unlikely most individuals would know their true
maximal HR. After the determination of the submaximal exercise intensity, subjects were
instrumented (discussed below) and completed a 10-min rest period in a comfortable chair. This
was followed by a 3-min resting baseline on the cycle ergometer while standard cardiorespiratory variables were measured continuously. Next, subjects exercised under different conditions (discussed below) in a randomized order. Each exercise condition consisted of a 2-min initiation phase to achieve steady state, followed by three minutes of exercise without a fan and three minutes with a fan. Each bout of exercise was separated by at least eight minutes of rest with the following exercise bout only starting once HR returned to within 20% of baseline resting values. A subset of six subjects completed an additional, identical bout of exercise with no mask or mouthpiece (ecological control).

**Experimental conditions.** Exercise was performed under the following conditions: surgical mask, cloth mask, and laboratory control. Additionally, a subset of six subjects performed an ecological control condition. During the surgical and cloth mask conditions, subjects wore a commercially available surgical mask or their own cloth masks that consisted of a minimum of 2-ply cloth material. The same brand of surgical masks (Boomcare Disposable Face Mask, Guangzhou DEYCE Leather Co. Ltd., Guangzhou, China) were used by all subjects, while cloth masks were brought by each subject and varied in manufacturer, size, shape and material. Following national Canadian guidelines, all masks were fitted properly to the participants face, ensuring the mask spanned from the bridge of the nose, where a wire was pinched, to below the chin while looping around the ears (Canada 2020). For the ecological control condition, subjects exercised with no mask. For the mask and ecological control condition, subjects breathed through a modified mouthpiece, which was trimmed to ensure it was flush with the subjects’ lips, so as not to interfere with the mask (see **Figure 1**). The mouthpiece allowed for the collection of mouth pressure and end-tidal gases (as described below). During the laboratory control condition, subjects breathed through large-bore tubing connected to a non-rebreathing valve (2700B, Hans Rudolph, Kansas City, MO). The laboratory control condition was completed to compare the effects of wearing a mask to a standard cardiorespiratory set up used in experimental settings.
To simulate airflow associated with exercising outdoors, we utilized a 38 cm diameter fan that was placed 30 cm in front of the subjects’ face. At 30 cm, the fan generated airflow of 10-15 km·hr\(^{-1}\) (2.8-4.2 m·s\(^{-1}\)), which is a realistic airflow that an individual could experience while cycling or running. The reason for examining the influence of a fan was twofold. First, we were interested in examining how simulating airflow might impact gas pressures at the mouth as it may remove any expired gas that accumulated between the mask and the subject’s face. Second, we wanted to evaluate how airflow on the face may influence dyspnea as previous work demonstrated that in patients with chronic obstructive pulmonary disease, exercising with a fan improved exercise time to failure and decreased dyspnea (Marchetti et al. 2015).

**Mask resistance.** The resistance of the surgical and subjects’ cloth masks was measured using a mannequin with human facial features, to allow for realistic positioning and ‘wearing’ of the mask. To measure resistance, we placed a 35 mm tube through the mannequin so that it was flush with the ‘mouth’ and used a 3L syringe to mimic breathing patterns. Flow was measured using a calibrated pneumotachometer (model 3813; Hans Rudolph, Shawnee, KS, USA) while mannequin ‘mouth’ pressure was measured using a calibrated differential pressure transducer (DP15-32; Validyne Engineering, Northridge, CA, USA). Resistance was expressed as differential mouth pressure over the change in air flow (i.e. cmH\(_2\)O·l\(^{-1}\)·sec\(^{-1}\)) through the tubing. From these measurements, we were able to determine the resistance of the surgical and cloth masks.

**Measurements.** Throughout the mask and ecological control conditions, HR was measured using a telemetric sensor (Model T34, Polar Electro Inc., Kempele, Finland). Respiratory excursions were measured via respiratory inductance plethysmography (Model 10.9000, Ambulatory Monitoring Inc., Ardsley, NY, USA) placed over the shirt of subjects, in the middle of the thorax, at the level of the diaphragm. Continuous measures of hemoglobin oxygen saturation (%SpO\(_2\)) was obtained with a pulse oximeter on the ear (Nonin 7500, Nonin Medical Inc.,
Plymouth, MN, USA) and face temperatures were measured with a thermistor (RET-1, Physitemp Instruments LLC., Clifton, NJ) placed just above the mouth. Dyspnea was assessed at the end of steady state exercise without a fan, and again after exercise with a fan using a modified Borg scale (Borg 1982). Mouth pressure was measured from a small port on the side of the mouthpiece connected to a calibrated differential pressure transducer (DP15-32; Validyne Engineering, Northbridge, CA, USA). Breath-by-breath oxygen and carbon dioxide concentrations were measured with calibrated gas analyzers (S-3-A/I and CD-3Am, respectively; Applied Electrochemistry, Bastrop, TX, USA) from a port on the other side of the mouthpiece. The thermistor and sampling tubing were taped flush against the skin of the subjects to ensure they did not interfere with the mask. To maintain the translatability of our findings to the general population, we only performed techniques that would not alter how a mask is regularly worn. Thus, for the two mask and ecological control condition, we did not measure parameters that would interfere with the proper function of a mask. For example, we could not have participants breathe through large bore tubing in order to determine minute ventilation, oxygen uptake and carbon dioxide output for the mask and ecological control conditions.

For the laboratory control condition, mouth pressure and gas concentrations were collected from sampling ports in the mouthpiece of a non-rebreathing valve. Expired and inspired flows were measured with two independent, calibrated pneumotachometers (model 3813, Hans Rudolph, Shawnee, KS, USA) from which tidal volume, breathing frequency and minute ventilation were derived. During the final 30 seconds of exercise, the gas sampling port was moved to a mixing chamber which allowed for the calculation of oxygen uptake and carbon dioxide output for the laboratory control condition.

Data and statistical analysis.

The partial pressure of inspired oxygen (P_{1}O_{2}) and carbon dioxide (P_{1}CO_{2}) were determined based on the peak fraction of oxygen and nadir fraction of carbon dioxide during inspiration. Using measured barometric pressure and ambient vapour pressure, gas fractions were
converted to partial pressures. The partial pressure of end-tidal oxygen ($P_{\text{et}}O_2$) and carbon dioxide ($P_{\text{et}}CO_2$) were determined based on the nadir fraction of oxygen and peak fraction of carbon dioxide during expiration. Gas fractions were converted to partial pressures based on barometric pressure and water vapour pressure at exhaled breath temperature (i.e., 47 mmHg; 37°C). For the mask and ecological control conditions, breathing frequency was determined via the period of oscillations for the respiratory inductance plethysmography while tidal volume was estimated from the peak-to-valley excursion of the voltage signal. Relative respiration depth, expressed as a % of rest, was calculated as the quotient of the magnitude of excursion during steady state exercise and the magnitude of excursion at rest, thereby reflecting a % change in tidal volume from rest. Mouth pressure swings were calculated as the magnitude of change (peak to nadir) in pressure over one respiration cycle. For the laboratory control, breathing frequency, tidal volume, ventilation and oxygen uptake were measured using open-circuit spirometry as previously described (Mann et al. 2020). Face temperature, HR, $\text{SpO}_2$, end-tidal gas and inspired gas pressures, and mouth pressure swings were averaged over the final minute of steady-state exercise and compared between control and mask conditions. Dyspnea measures taken at the end of each steady state exercise period were compared between both control and mask conditions. Measures of mask resistance were compared using an unpaired t-test. Face temperature, HR, $\text{SpO}_2$, end-tidal gas and inspired gas pressures, and mouth pressure swings, and dyspnea were compared between the mask conditions and the laboratory control condition using a two-way (mask condition x fan use) repeated-measures analysis of variance (ANOVA). Main effects and interactions were further examined by Bonferroni post hoc tests. A separate two-way repeated-measures ANOVA was used to compare the subset of subjects who completed the ecological control condition to the mask conditions. Main effects and interactions were probed by Bonferroni post hoc tests and comparisons of surgical and cloth mask conditions were only made to the ecological control. All analyses were performed using GraphPad Software (Version 8.4.3, La Jolla, CA, USA). Significance was set at $p<0.05$. Values are expressed at mean ± standard deviation.
Results

Subjects. Subject characteristics are presented in Table 1. All subjects completed the laboratory control; however, a subset of six individuals performed the additional ecological control condition. The percent of predicted max HR during exercise was 75 ± 4% (range: 69 – 82%).

Mask resistance measures. Resistances through the mannequin was assessed at a flow of 2 L·s⁻¹. The resistance without any mask was 0.07 ± 0.05 cmH₂O·l⁻¹·sec⁻¹. The surgical mask resistance was significantly lower than the cloth mask (0.22 ± 0.16 vs 1.07 ± 1.23 cmH₂O·l⁻¹·sec⁻¹, p<0.05 for the surgical and cloth masks, respectively). For comparison, the resistance of a standard breathing apparatus used for cardiorespiratory exercise testing is 0.7-1.0 cmH₂O l⁻¹·sec⁻¹ at similar flows (Hopkins et al. 2020).

Heart rate, oxyhemoglobin saturation, respiration pattern, dyspnea and face temperature. Steady state exercise variables with and without a fan during the laboratory control, surgical mask and cloth mask conditions are presented in Figure 2. Heart rate, SpO₂, breathing frequency, and relative respiration depth were not different between the laboratory control and both mask conditions (all p>0.05). The perception of dyspnea was higher with a cloth mask than the surgical mask (p=0.02) and laboratory control (p=0.004), but the surgical mask was not different from laboratory control (p=0.99). Surgical mask face temperatures tended to be greater without the fan (p=0.08) and were significantly higher compared to the laboratory control condition when the fan was on (p<0.0001). In contrast, wearing a cloth mask resulted in face temperatures being significantly higher without (p=0.003) and with a fan (p<0.0001) relative to the laboratory control condition. No differences in face temperature were observed between the surgical and cloth mask conditions with and without the fan (both p>0.05).

Steady state exercise variables during the ecological control are presented in Figure 3. Similar to the laboratory control, heart rate, SpO₂, breathing frequency and relative respiration...
depth were not different between the ecological control and mask conditions (all \( p > 0.05 \)).

Dyspnea was similar between the ecological control and surgical mask condition \( (p=0.67) \), but greater in with the cloth mask \( (p=0.01) \). Compared to the ecological control, face temperature while wearing a surgical mask was significantly greater with the fan \( (p=0.008) \) and tended to be higher without the fan \( (p=0.08) \). Wearing a cloth mask increased face temperature compared to the ecological control regardless of whether a fan was present \( (p=0.004) \) or not \( (p=0.01) \).

*Mouth pressures.* Mouth pressures swings during the laboratory control, surgical mask and cloth mask conditions are shown in Figure 4A. Mouth pressure swings were not different between the laboratory control and cloth mask conditions \( (p=0.99) \). However, mouth pressure swings were lower during the surgical mask condition relative to the laboratory control \( (p=0.03) \) and cloth mask condition \( (p=0.05) \). In contrast, no differences in mouth pressure swings were noted between the ecological control and both mask conditions (Figure 4B; both \( p > 0.05 \)).

*Laboratory control respired oxygen and carbon dioxide gases.* Inspired and end-tidal gas pressures during the laboratory control and both mask conditions are shown in Figure 5. With the fan, no difference in \( P_{\text{I}O_2} \) was observed between the laboratory control and both mask conditions \( (all \ p > 0.05) \). Without the fan, there was no difference in \( P_{\text{I}O_2} \) between the surgical and cloth mask conditions \( (p=0.25) \), but \( P_{\text{I}O_2} \) was lower in the surgical and cloth mask conditions relative to the laboratory control \( (both \ p < 0.05) \). The mean difference in \( P_{\text{I}O_2} \) from the laboratory control condition was \(-4 \pm 2 \text{ mmHg} \) and \(-2 \pm 3 \text{ mmHg} \) for surgical and cloth masks, respectively. During exercise with a fan, there was no difference in \( P_{\text{I}CO_2} \) between the laboratory control and two mask conditions \( (both \ p > 0.05) \). Without a fan, both surgical \( (p=0.001) \) and cloth mask \( (p=0.009) \) conditions had higher \( P_{\text{I}CO_2} \) \( (both \ 1 \pm 1 \text{ mmHg} \) compared to the laboratory control. There is a significant effect of fan increasing \( P_{\text{et}O_2} \) and decreasing \( P_{\text{et}CO_2} \) pressures \( (both \ p < 0.05) \). The mean difference in \( P_{\text{et}O_2} \) between the no fan and fan condition was \( 1 \pm 3 \text{ mmHg} \), \( 3 \pm 3 \text{ mmHg} \) and \( 2 \pm 3 \text{ mmHg} \) for the laboratory control, surgical and cloth mask,
respectively. Additionally, mean differences in $P_{et}\text{CO}_2$ with the fan on were -1±2 mmHg for the laboratory control, -1±1 mmHg with the surgical mask and -1±1 mmHg with the cloth mask.

*Ecological control respired oxygen and carbon dioxide gases.* Inspired and end tidal concentrations of $O_2$ and $CO_2$ concentrations during the ecological control are presented in Figure 6. We found a main effect of fan increasing $P_{I}O_2$ and decreasing $P_{I}CO_2$ pressures (both $p<0.05$). Mean differences in $P_{I}O_2$ without and with a fan were 0±2 mmHg for the ecological control, 2±2 mmHg for the surgical and 2±2 mmHg for the cloth mask. Additionally, mean differences in $P_{I}CO_2$ pressures without and with a fan were 0±1 mmHg, -1±1 mmHg and -1±1 mmHg for the ecological control, surgical and cloth mask, respectively. Wearing a cloth mask significantly decreased $P_{et}O_2$ by 4±4 mmHg ($p=0.05$) and increased $P_{et}CO_2$ by 2±1 mmHg ($p=0.008$) relative to the ecological control. In contrast, no difference in $P_{et}O_2$ or $P_{et}CO_2$ was observed between the surgical mask and ecological control conditions (both $p=0.99$). Additionally, a main fan effect was observed to have mediated a decrease in $P_{et}CO_2$ pressures ($p<0.05$).

**Discussion**

The present study examined the impact of wearing a surgical or cloth mask on cardiopulmonary and sensory responses to short duration steady state submaximal cycling exercise. The major findings are threefold. First, only a cloth mask increased mouth pressure swings during exercise. However, the magnitude of these swings was comparable to those generated during a standard cardiopulmonary exercise test with a mouthpiece, and are unlikely to be of physiological significance. Second, compared to the ecological control wearing a cloth mask decreased $P_{et}O_2$ and increased $P_{et}CO_2$ during exercise, but no difference was found with the surgical mask. Additionally, wearing a surgical mask during exercise reduced $P_{I}O_2$ but not $P_{I}CO_2$ relative to the laboratory control condition. Yet in both mask conditions, no differences in HR, $SpO_2$, breathing frequency and relative respiration depth were observed relative to the laboratory
or ecological control, suggesting differences in respiratory gas pressures were inconsequential
during exercise. Third, wearing a cloth or surgical mask increased face temperatures, but
dyspnea was only significantly higher when wearing a cloth mask relative to both ecological and
laboratory controls. In agreement with conclusions from the Hopkins and colleagues review
(2020), we interpret our findings to indicate that wearing a surgical or cloth mask during a
relatively short bout of moderate-to-vigorous exercise has no impact on the physiological
response. While inspired and end-tidal gas pressures were statistically different with the masks,
they were small (e.g., mean differences of -4±4 mmHg and 2±1 mmHg for \( P_{etO_2} \) and \( P_{etCO_2} \)
when wearing a cloth mask relative to the ecological control) and had minimal physiological
bearing and would not impact the exercise response in healthy individuals.

Mouth Pressures. Mouth pressures provide an indication of the added work required by the
respiratory muscles to overcome the external resistance of a breathing apparatus, such as a
mouthpiece or mask, (Figure 4). We found that a cloth mask increased mouth pressure similarly
as breathing through a standard breathing valve used for cardiopulmonary exercise testing
(Figure 4A). Whereas wearing a surgical mask resulted in smaller changes in mouth pressure
compared to the laboratory control and cloth mask conditions and was not different from the
ecological control condition (Figure 4B). The greater mouth pressure in the cloth mask condition
is due to the greater mask resistance (see Mask resistance measures). However, the cloth mask
resistance was similar to the resistance of a standard breathing apparatus used for
cardiorespiratory exercise testing (Hopkins et al. 2020). Differences in measured resistance
between cloth and surgical mask is due to different properties of the masks, such as material,
shape, size and fit (Jung et al. 2014; Hopkins et al. 2020).

The slight increase in work of breathing from wearing a cloth mask is comparable to the
standard breathing apparatus used for cardiorespiratory exercise testing e. Such small increases
in the work of breathing from wearing a mask are unlikely to impact a healthy individual’s
ability to perform exercise. Likewise, wearing a mask of similar resistance to the surgical and
cloth masks used in the present study, did not influence ventilation, breathing frequency and tidal volume after 1 hour of light to moderate treadmill exercise (Roberge et al. 2013). In fact, much higher airflow resistance and exercise intensity (i.e., >90% VO_{2max}) are required to activate the respiratory muscle metaboreflex and divert blood flow away from the locomotor muscle, influencing an individual’s exercise performance (Harms et al. 1997; Dempsey et al. 2006; Dominelli et al. 2017).

**Inspired gas pressures.** Wearing a mask increased P_{i}CO_{2} and decreased P_{i}O_{2} relative to the laboratory control during exercise without a fan. The altered inspired gas composition is due to the additional external dead space from wearing a mask that results in the rebreathing of some expired air. Increasing dead space typically increases ventilation due to higher arterial CO_{2} concentrations (Ward and Whipp 1980) with even 160 mL of deadspace increasing ventilation at rest and during light exercise (Toklu et al. 2003). In the present study, the laboratory control condition used a mouthpiece and a 3-way non-rebreathing valve that increased external dead space by 102.9 mL (Hans Rudolph 2019). Since no differences breathing frequency, relative respiration depth, or end-tidal gases were observed between mask and laboratory control conditions (Figures 2 and 5), it is reasonable to assume that wearing a mask increased external dead space by no more than ~100-150 mL (Hopkins et al. 2020). Such an increase in dead space resulted in small but significant alteration in inspired gas fractions but had minimal (if any) physiological effects. When the fan was used (simulating outdoor exercise), any differences in P_{i}O_{2} or P_{i}CO_{2} between conditions were eliminated. Presumably, the added ‘wind speed’ would ‘flush’ the masks of any exhaled gases and eliminated any difference.

**Expired gas pressures.** We found P_{et}CO_{2} and P_{et}O_{2} was not different between the laboratory control and mask conditions (Figure 5). The lack of difference in end-tidal gases between the laboratory control and mask conditions was expected since a similar amount of dead space added in both. As such, the lack of change in end-tidal gases suggests that wearing a mask has a similar
minimal physiological impact as a standard breathing apparatus used for cardiorespiratory
exercise testing. Due to minimal gas exchange impairments during rest and moderate exercise,
\( P_{et}CO_2 \) is a reasonable surrogate measure for arterial carbon dioxide in healthy adults (Stickland
et al. 2013). Whereas due to increased, yet individually variable, gas exchange impairments,
\( P_{et}O_2 \) does not accurately reflect arterial oxygen tensions (Stickland et al. 2013). The minimal
increase in \( P_{et}CO_2 \) did not alter \( P_{et}CO_2 \) pressure or the change was too small to cause a detectable
increase in ventilation. Indeed, others found no difference in capillary pressure of oxygen, carbon
dioxide, or pH during a maximal exercise test when wearing surgical or N95 masks compared to
a standard laboratory control (Fikenzer et al. 2020). However, it is likely that the difference in
arterial \( PCO_2 \) may be undetectable during higher-intensity exercise since the ratio of dead space
to tidal volume is reduced, thereby minimizing the impact of the additional external dead space
(Sun et al. 2002).

Conversely, the cloth mask resulted in a higher \( P_{et}CO_2 \) and lower \( P_{et}O_2 \) compared to the
ecological control condition (Figure 6). This difference in end-tidal gas pressures is due to the
increased external dead space with a cloth mask. Compared to the ecological control, the
differences in surgical and cloth mask end-tidal gases were due to the different mask properties.
The cloth masks used in the present study, which were brought by participants, fit well to their
face, thereby trapping a greater amount of expired air. Alternatively, the surgical masks used are
one-size fits all and may not fit a given individual’s face as well or create as much external dead
space as the cloth masks (Jung et al. 2014). The addition of a fan during exercise increased \( P_{et}O_2 \)
and decreased \( P_{et}CO_2 \), minimizing the impact of increasing external dead space when wearing a
mask. These results support the previous conclusion that airflow to the face minimizes the
rebreathing of expired air by ‘flushing’ out any air trapped behind a mask.

Perspectives on gas pressure changes. Although there were statistically significant changes in
gas concentrations between the masks, it is important to discuss the physiological context. The
differences in \( P_{t}O_2 \) and \( P_{t}CO_2 \) ranged from 1 to 4 mmHg, respectively (Figures 5 and 6). At sea
level (barometric pressure = 760 mmHg), these changes amount to a 0.5% reduction in the inspired fraction of oxygen, and a 0.1% increase in the inspired fraction of carbon dioxide. Physiologically, this drop in inspired oxygen is insignificant as it does not reach levels that elicit a ventilatory response (Weil et al. 1970; Teppema and Dahan 2010). Furthermore, a 4 mmHg reduction in P_{\text{I}O_2} regularly occurs due to variations in weather or minor changes in elevation. For example, barometric pressure can vary by ~30 mmHg at a fixed elevation due to normal weather variations and this would alter P_{\text{I}O_2} by ~6 mmHg (Crippen 1993). Similarly, going from sea level (e.g., Vancouver, BC) to approximately 300 m above sea level (e.g., Waterloo, ON) will translate to a ~4 mmHg decrease in P_{\text{I}O_2}. A drop in barometric pressure of at least 50 mmHg (corresponding to a ~10 mmHg decrease in P_{\text{I}O_2}) is required for decreasing \dot{V}O_2^{\text{max}} and can significantly reduce SpO_2 in aerobically trained individuals (Gore et al. 1996). In the present study, subjects were not aerobically trained and the drop in P_{\text{I}O_2} was smaller while wearing a surgical or cloth mask. Thus, it is not surprising that we did not observe a change in SpO_2 or breathing pattern during exercise (Figures 2 and 3).

In contrast, relatively small changes in P_{\text{I}CO_2} can impact ventilation. For example, breathing air with inspired CO_2 fraction of 1% (~8 mmHg) will increase arterial carbon dioxide by 1 mmHg, which increases ventilation at rest (Ellingsen et al. 1987). However, we saw an increase in the inspired fraction of CO_2 of ~1 mmHg, thus it is unsurprising that ventilation did not change across the conditions. Finally, performing locomotor likely exercise outdoors diminishes any effect that wearing a mask has on gas concentrations due to enhanced airflow. Altogether, our results suggest that the small differences in respired gases that occur while wearing a mask are inconsequential to an individual’s exercise performance or capacity.

**Facial temperature.** There are some concerns that wearing a mask may impact the ability to properly thermoregulate during exercise. During exercise without airflow to the face, wearing a cloth mask increased face temperature by ~2°C from the laboratory control (Figure 2). However, when a fan was added to simulate airflow, wearing a cloth or surgical mask attenuated the
decline in facial temperature, which amounted to a greater magnitude difference in face
temperature for surgical (+~4°C) and cloth (+~5°C) masks relative to the laboratory control
condition. It is generally accepted that increased surface area coverage will add additional
challenges in maintaining core body temperature thermoregulation during exercise (Gavin 2003).
However, wearing a facemask is more likely to impair thermoregulation through the reduction of
convective and evaporative heat loss (Roberge et al. 2012). Indeed, others have found that
wearing a KN95 mask did not increase rectal temperatures at rest or following 45 minutes of
light exercise (Morris et al. 2020).

Dyspnea. We found that dyspnea increased with a cloth mask when compared to the control
conditions (Figures 2 and 3). It has been proposed that respiratory muscle work will contribute
to the perception of dyspnea. However, dyspnea only increased with a cloth mask when
compared to the laboratory control despite no difference in mouth pressure swings (Figures 2
and 4). Similarly, others have found that physiologically-relevant alterations in resistance (i.e.,
increases between 2.7-5.7 cmH2O·l⁻¹·s⁻¹) have no influence on dyspnea during exercise (Lane et
al. 1987; Molgat-Seon et al. 2019). Another proposed explanation for the increase in dyspnea
while wearing a mask is that it may be the result of rebreathing carbon dioxide (Banzett et al.
1990). Nevertheless, similar changes in PₐCO₂ and PₐCO₂ when wearing a surgical or cloth mask
relative to the laboratory control cannot explain the increased dyspnea that was observed only
with a cloth mask. Others have attributed the increase in dyspnea to the perceived increase in
ventilation rather than the increase in arterial PCO₂ from increased rebreathing of carbon dioxide
(Lane et al. 1990). However, our findings that breathing frequency and relative respiration depth
did not change between the control and mask conditions suggest that the increased perception of
dyspnea with a mask is unrelated to the increased perception of ventilation. Finally, an increased
face temperature from wearing a mask could increase dyspnea (Kim et al. 2016). However, our
findings indicate that temperature may not be a primary factor in determining dyspnea when
wearing a mask as there was no change in dyspnea despite a drop in face temperatures with a
fan. (Figures 2 and 3). Additionally, we observed similar increases in face temperature for both the surgical and cloth masks, yet dyspnea only increased while wearing a cloth mask relative to both control conditions. Therefore, our assessment of dyspnea may simply reflect the increased humidity, heat, and or general discomfort/unpleasantness that comes with wearing a mask. Overall, the minimal increase in dyspnea when wearing a cloth mask does not appear to be of physiological origin and others have come to similar conclusions (Kim et al. 2016; Person et al. 2018).

Limitations. Our study has limitations that merit comment. First, we did not utilize a metabolic testing system during the mask or ecological control conditions; however, this was done intentionally to preserve external validity. While the effects are minor, any mouthpiece or similar system to measure ventilation and/or mixed expired gases would increase both external resistance and dead space, which would contaminate the effect of the masks. Therefore, to ensure we only introduced the mask effects, we utilized non-intrusive measurements (i.e., respiratory inductance plethysmography). Despite no direct measure of ventilation, we could estimate ventilation (via respiratory inductance plethysmography) during the mask and ecological control and compared this to the laboratory control where we measured ventilation directly. Given breathing frequency and thoracic excursions were not different between all conditions, we are confident our ventilation of $\sim 40-45 \text{ l min}^{-1}$ (measured during laboratory control) is accurate for all trials. Second, we only utilized a single submaximal workload. Recent work demonstrated surgical or cloth masks have no impact on maximal exercise capacity or oxygenation (Shaw et al. 2020). However, only a minority of individuals regularly exercise at maximal intensities. We therefore elected to use a commonly prescribed exercise intensity (i.e., 70% of maximal heart rate, Third, we did not directly measure respiratory muscle work. However, we measured the specific mask resistance ahead of subject testing and knew a priori that the added resistance was similar to that of a typical breathing apparatus used for cardiopulmonary exercise testing, thus there was no physiological rationale for why we would observe a greater work of breathing with
a mask. Fourth, our exercise tests were relatively short for each condition (~6 mins) and it is possible that longer duration exercise may exacerbate some aspects such as dyspnea or face temperature. Finally, we only investigated young healthy individuals. In individuals with severe diseases (e.g., severe COPD) it is possible that the minimal added dead space and resistance may impact their ability to exercise (Hopkins et al. 2020).

Conclusions. We sought to investigate the impact of wearing a surgical or cloth mask on mouth pressure, respired gases, dyspnea, and face temperature during exercise. We observed comparable increases in mouth pressure swings in the laboratory control and cloth mask conditions that was insufficient to have physiological implications. Wearing a cloth mask decreased $P_{\text{etO}_2}$ and increased $P_{\text{etCO}_2}$ when compared to the ecological control condition. Yet no differences in HR, $\text{SpO}_2$, breathing frequency and relative respiration depth were observed, suggesting differences in respired gas concentrations were trivial. Dyspnea was significantly greater when wearing a cloth mask relative to both ecological and laboratory controls; however, we found no physiological explanation for this difference. Overall, we interpret our findings to indicate that wearing a surgical or cloth mask during exercise has minimal impact on the physiological response to submaximal exercise in healthy young individuals.

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Data Availability. The data that support the findings of this study are available from the corresponding author upon reasonable request.
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Figure Legends

Figure 1. Representative image of an original mouthpiece and the modified mouthpiece. An original mouthpiece attaches to a non-rebreathing 3-way valve to measure end-tidal gases and mouth pressure. The modified mouthpiece is trimmed to be flush with the subject’s lips while mouth pressure and end-tidal gases are measured directly from the mouthpiece.

Figure 2. Heart rate, breathing frequency, oxygen saturation, relative respiration depth, dyspnea and facial temperature during exercise for each condition with and without a fan. Laboratory control refers to the condition where subjects are equipped with a standard laboratory set-up for a cardiopulmonary exercise test. SpO₂, oxygen saturation from pulse oximetry. * significant main effect of mask, †, significantly different from no fan for the same mask. p<0.05

Figure 3. Heart rate, breathing frequency, oxygen saturation, relative respiration depth, dyspnea and facial temperature during exercise for each condition with and without a fan. Ecological control refers to the condition where the subject is not wearing any masks and replicates exercising outside of laboratory settings. SpO₂, oxygen saturation from pulse oximetry. * significant main effect of mask, †, significantly different from no fan for the same mask p<0.05

Figure 4. Mouth pressure swings during each exercise condition. Laboratory control refers to the condition where subjects are equipped with a typical laboratory set-up for a cardiopulmonary exercise test. Ecological control refers to the condition where the subject is not wearing any masks and replicates exercising outside of laboratory settings. Δ, change. * significant main effect of mask, p<0.05

Figure 5. Inspired (Panels A & B) and end-tidal (Panels C & D) oxygen and carbon dioxide tensions during exercise for both mask conditions and laboratory control. Laboratory control
refers to the condition where subjects are equipped with a typical laboratory set-up for a cardiopulmonary exercise test. PO\textsubscript{2}, partial pressure of oxygen; PCO\textsubscript{2}, partial pressure of carbon dioxide. * significant main effect of mask, †, significantly different from no fan for the same mask. \( p<0.05 \)

**Figure 6.** Inspired (Panels A & B) and end-tidal (Panels C & D) oxygen and carbon dioxide tensions during exercise for both mask conditions and ecological control. Ecological control refers to the condition where the subject is not wearing any masks and replicates exercising outside of laboratory settings. PO\textsubscript{2}, partial pressure of oxygen; PCO\textsubscript{2}, partial pressure of carbon dioxide. * significant main effect of mask, \( p<0.05 \)
| Baseline characteristics | Laboratory control n=12 | Ecological control n=6 |
|--------------------------|-------------------------|-----------------------|
| Age, y                   | 25 ± 2                  | 26 ± 4                | 23 ± 1                  | 27 ± 4                  |
| Height, cm               | 163 ± 4                 | 175 ± 4               | 165 ± 3                 | 176 ± 2                 |
| Weight, kg               | 61.5 ± 12.7             | 78.1 ± 6.4            | 64.3 ± 17.7             | 78.6 ± 8.7              |
| Body mass index, kg·m⁻²  | 22.9 ± 3.9              | 25.4 ± 2.0            | 23.5 ± 5.7              | 25.3 ± 2.8              |
| Face temperature, °C     | 32.0 ± 1.1              | 32.4 ± 2.1            | 32.5 ± 1.3              | 33.0 ± 1.6              |
| Heart rate, beats·min⁻¹  | 74 ± 7                  | 78 ± 8                | 82 ± 1                  | 74 ± 7                  |
| Pulse oximetry, %        | 99.3 ± 0.5              | 99.3 ± 0.9            | 99.0 ± 0.6              | 99.2 ± 0.9              |
| Breathing frequency, breaths·min⁻¹ | 15 ± 6             | 12 ± 6                | 20 ± 6                  | 12 ± 5                  |

| Laboratory control ventilation variables |
|------------------------------------------|
| Work rate, W                             | 74 ± 20                  | 107 ± 11               | 60 ± 14                 | 109 ± 10.3              |
| \( V_{E} \), L·min⁻¹                     | 40.2 ± 4.8               | 44.9 ± 10.1            | -                       | -                       |
| \( V_{CO_2} \), L·min⁻¹                  | 1.33 ± 0.24              | 1.65 ± 0.21            | -                       | -                       |
| \( V_{O_2} \), L·min⁻¹                   | 1.37 ± 0.21              | 1.72 ± 0.22            | -                       | -                       |
| Tidal volume, L                         | 1.42 ± 0.29             | 1.99 ± 0.32            | -                       | -                       |

**Abbreviations**: \( V_{E} \), minute ventilation; \( V_{CO_2} \), carbon dioxide output; \( V_{O_2} \), oxygen uptake.
Non-rebreathing 3-way valve attached here

Original

3-way valve to measure:
1. End-tidal gases
2. Pressures

Modified

Modified mouthpiece flush to subject’s face and underneath mask

Mouth pressure and end-tidal gases measured here
Heart rate (beats min\(^{-1}\))

- Lab Control: p = 0.344
- Surgical Mask: p = 0.056
- Cloth Mask: p = 0.464

Breathing frequency (breaths·min\(^{-1}\))

- No Fan: p = 0.082
- With Fan: p = 0.246

SpO\(_2\) (%)

- No Fan: p = 0.120
- With Fan: p = 0.961

Relative respiration depth (%)

- No Fan: p = 0.855
- With Fan: p = 0.297

Dyspnea

- Lab Control: p = 0.004
- Surgical Mask: p = 0.294
- Cloth Mask: p = 0.435

Face temperature (°C)

- No Fan: p < 0.001
- With Fan: p < 0.001
A) Heart rate (beats·min\(^{-1}\))

- Ecological Control
- Surgical Mask
- Cloth Mask

Mask effect: \( p = 0.411 \)
Fan effect: \( p = 0.582 \)
Interaction: \( p = 0.946 \)

B) Breathing frequency (breaths·min\(^{-1}\))

- No Fan
- With Fan

Mask effect: \( p = 0.097 \)
Fan effect: \( p = 0.838 \)
Interaction: \( p = 0.191 \)

C) \( \text{SpO}_2 \) (%)

- Ecological Control
- Surgical Mask
- Cloth Mask

Mask effect: \( p = 0.742 \)
Fan effect: \( p = 0.529 \)
Interaction: \( p = 0.493 \)

D) Relative respiration depth (%)

- Ecological Control
- Surgical Mask
- Cloth Mask

Mask effect: \( p = 0.875 \)
Fan effect: \( p = 0.890 \)
Interaction: \( p = 0.708 \)

E) Dyspnea

- Ecological Control
- Surgical Mask
- Cloth Mask

Mask effect: \( p = 0.019 \)
Fan effect: \( p = 0.999 \)
Interaction: \( p = 0.751 \)

F) Face temperature (°C)

- No Fan
- With Fan

Mask effect: \( p < 0.001 \)
Fan effect: \( p < 0.001 \)
Interaction: \( p = 0.004 \)
A

Mouth pressure (cmH$_2$O)

Lab Control | Surgical Mask | Cloth Mask

No Fan | With Fan

Mask effect: p = 0.017
Fan effect: p = 0.164
Interaction: p = 0.162

B

Mouth pressure (cmH$_2$O)

Ecological Control | Surgical Mask | Cloth Mask

Mask effect: p = 0.269
Fan effect: p = 0.356
Interaction: p = 0.743
