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FACEMASK USE DURING HIGH INTENSITY INTERVAL EXERCISE IN TEMPERATE AND HOT ENVIRONMENTS.

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Facemask use during high intensity interval exercise in temperate and hot environments.

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ABSTRACT

BACKGROUND: Emerging research suggests a minimal impact on physiological variables across a wide array of exercise intensities and modalities while wearing a surgical mask. However, the literature is lacking investigation of high intensity interval exercise (HIIE) involving surgical mask use in different environmental conditions. Therefore, the purpose of this study was to examine the effects of surgical mask use during HIIE on physiological and perceptual parameters in hot and temperate environments. METHODS: Ten healthy participants (5 females; 5 males) completed a total of four HIIE cycling sessions. Each HIIE session consisted of a 1:3 work/rest ratio with ten high intensity bouts performed at 85% of peak power output for a duration of 30 seconds followed by an active rest period performed at 30% of peak power output that lasted 90 seconds. Each participant completed a randomized HIIE session in both hot (36°C, 14% relative humidity) and temperate environments (26°C, 25% relative humidity) while wearing and not wearing a surgical mask. Heart rate (HR), stroke volume (SV), cardiac output (CO), core temperature, blood oxygen saturation (S_pO_2), muscle tissue oxygenation (MTO), perceived dyspnea, perceived thermal sensation, and Borg's rating of perceived exertion (RPE) were all recorded during HIIE. Urine output and water ingestion were accounted for during each HIIE session to determine sweat rate and dehydration measurements calculated by differences in pre-post exercise nude body weight. Blood lactate concentration [BLa^-] was measured before exercise and 5-minutes post exercise. RESULTS: No differences in physiological variables were found comparing surgical mask use to a no-mask control during HIIE. Perceptual differences comparing surgical mask use to a no-mask control occurred with an increase in reported perceived dyspnea and average RPE. Exercise in hot environmental conditions showed an increase in peak and average HR over the course of exercise compared to temperate environment. Interaction effects showed that the greatest changes in perceived dyspnea and average RPE occurred performing HIIE while wearing a mask in a hot environment. CONCLUSIONS: Wearing a surgical mask during HIIE increases the perception of dyspnea and overall RPE with the greatest effect occurring in hot environments.

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Chapter 1

Introduction

COVID-19, a dangerous and very contagious disease discovered in December 2019, was declared a global pandemic by the World Health Organization (WHO) on March 11th, 2020. It is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus (1). To limit the spread of COVID-19, the United States Centers for Disease Control and Prevention (CDC) and the WHO have recommended that individuals avoid crowded gatherings, wear a mask in public settings, maintain a social distance of at least 6 feet from other individuals, and reduce face touching with unwashed hands (2,3).

Masks have been shown to reduce the spread of respiratory viruses (4); there are several different types of masks that fall into two categories (medical grade and non-medical grade) available for use in public settings (5). Cloth-masks and disposable single-use masks are categorized as non-medical grade masks, while medical grade masks include N95 masks and surgical masks (5). The N95 masks are designed to seal tightly around the nose and mouth and filter out at least 95% of very small (0.3 micron) particles including viruses and bacteria when properly fitted. Surgical masks are regulated by the National Institute for Occupational Safety and Health and may look like non-medical masks. They are looser fitting and create a physical barrier between the mouth and nose of the wearer and potential contaminants in the immediate environment. It has been recommended that N95 masks be specifically reserved for use by health care personnel, as they are at highest risk for exposure to the virus.

Both categories of masks (medical grade and non-medical grade) have become commonplace in public settings. There are several concerns regarding whether it is safe to wear a mask during exercise. One of these concerns is that mask use has the potential to aggravate pre-existing pathophysiological conditions due to hypoxemia from impaired gas exchange (6–8). However, wearing a mask seems to be well tolerated in healthy populations at a low (<3.0 METs) and moderate (3.0 – 5.9 METs) exercise intensities (9, page 3; 10–20). Depending on the severity of disease, mask use appears to be tolerated in some clinical populations (e.g., Chronic Obstructive

Pulmonary Disease) undergoing either a 6-minute walk exercise test (21,22) or performing a ten-minute brisk walk (17).

At higher intensity exercise (77-95% of maximum HR) (9, page 146), the CDC recommends that if an individual is able, a mask should be worn especially when exercising indoors in group settings where a social distance of 6 feet cannot be maintained (5,23). However, the CDC states that if an individual is unable to wear a mask due to difficulty breathing, then wearing a mask is not recommended during high intensity exercise (5) and recommends limiting indoor group training sessions to reduce COVID-19 spread (23). In healthy individuals, wearing a surgical or cloth mask while performing maximal incremental ramp cycling exercise tests to exhaustion did not decrease direct markers of exercise performance such as peak power output or time to test termination (24–26). However, it has been shown that there are instances where direct exercise performance markers are reduced with N95 mask use during these types of exercise tests (24,25). While there was no difference between perceived ratings of exertion (RPE) with surgical- or cloth-mask use (26–28), there was an increase in RPE (24) and overall discomfort (25) with N95 mask use with exercise progressing to maximal effort. However, progressive exercise tests are often reserved for laboratory assessment within a controlled environment and are not typically done as a form of exercise, therefore, it is difficult to translate these findings to more commonly practiced types of training or exercise.

High intensity interval exercise (HIIE) is a popular, common, and time-effective form of exercise used among recreational exercisers and competitive athletes. This type of exercise consists of short high intensity bouts (i.e., 80 - 100% heart rate max), followed by intermittent passive (no exercise) or active (moderate to light exercise) recovery periods (29–31). However, there have been no studies investigating medical- or non-medical grade mask use during HIIE. Further, outdoor settings have been recommended when performing exercise to reduce risk of spreading the virus (23). This recommendation is primarily founded on having enough space to maintain an appropriate social distance from others (23). However, social distancing may not always be possible to maintain. For example, an outdoor setting that uses intermittent bursts of high intensity exercise may necessitate mask wearing by athletes to lower the risk of spreading the virus. As many recreational exercisers and athletes may choose an outdoor location to train, research exploring mask use in hot environments may provide important information for safe exercise. For instance, when exercise is performed outdoors in hot months there may be a synergistic effect between wearing a mask and certain environmental factors (e.g., heat and humidity) that may increase physiological and psychological strain. Previous research has shown that wearing a mask increases the perception of feeling short of breath (dyspnea) (14,20,22) and can lead to the perceptual response of feeling hot even when worn in temperate environments (25). Despite recommendations for exercising outdoors and mask wearing to limit viral spread, no studies have investigated mask use during HIIE or the combined effect of surgical mask use and hot environmental conditions during high intensity exercise.

In summary, the CDC and WHO have endorsed mask use in public settings to reduce the spread of the virus, and they recommend that N95 masks be reserved for health care workers. Several concerns have arisen regarding the safety of wearing a mask during exercise, but current evidence would suggest wearing a mask is well tolerated by the general population, and in some cases clinical settings when exercise is performed at low to moderate intensities. Further, in healthy populations, wearing a surgical mask during progressive cycling exercises to volitional fatigue seems to be tolerated well. Both recreational exercisers and athletes use masks to lower the risk of possible exposure to airborne transmission of SARS-CoV-2 while engaging in HIIE or HIIE-like training in both temperate and hot conditions in indoor and outdoor settings. Therefore, an understanding of mask use during HIIE is important and will extend generalizability of our knowledge of mask efficacy.

Problem Statement

No research has been performed to investigate the effects of mask use with high intensity interval exercise (HIIE). Published studies have been done using various types of masks during low to maximal intensity exercise using incremental ramp protocols. This form of exercise assessment is generally reserved for clinical or fitness evaluations and is not a commonly performed by the public. However, HIIE is a popular form of exercise that both athletes and recreational exercisers perform in indoor or outdoor environments, but it remains unknown whether there may be changes in physiological variables or perception of discomfort with mask use during HIIE. It is common for those performing HIIE to use disposable surgical masks. Since the CDC endorses mask use in public settings to limit the spread of COVID-19 during exercise, it is important to study if the effects of surgical masks change physiological, thermoregulatory, or perceived responses during HIIE in either a temperate or hot environment.

Purpose

The aim of this study is to investigate the effects of surgical mask use on cardiovascular (i.e., heart rate, stroke volume, and cardiac output), thermoregulatory (i.e., core temperature, Δ core temperature, sweat rate, and dehydration), metabolic (i.e., blood lactate, blood oxygen saturation, and muscle tissue oxygenation), and perceptual (i.e., thermal sensation, perceived exertion, and perceived dyspnea) responses to HIIE in temperate and hot environments.

Hypotheses

Main Effect for Environment during HIIE:

Hypothesis 1: There will be no difference in cardiac output when comparing a hot and temperate condition during HIIE.

No difference is anticipated as heart rate increases and stroke volume decreases with exercise in hot environments. This is due to an anticipated increase in skin blood flow and loss of blood volume through sweat loss (34,35). Thus, cardiac output is not anticipated to change.

Hypothesis 2: There will be a decrease in stroke volume when comparing a hot and temperate condition during HIIE.

Exercise in a hot environment creates a thermoregulatory demand for skin blood flow to increase heat loss. A sufficient increase in skin blood flow or loss in blood volume from sweat loss would reduce total peripheral resistance, central venous pressures, and therefore, lead to a decrease in stroke volume (34,35). Thus, a decrease in stroke volume is expected to occur when performing HIIE in a hot environment.

Hypothesis 3: There will be an increase in heart rate for a hot compared to a temperate condition during HIIE.

In addition to the demand of working muscle tissue, the physiological thermal strain from hot environments increases blood flow to peripheral subcutaneous tissue to aid in heat loss (34,35). In combination, the thermal strain and working muscle tissue place a greater demand on cardiac output with greater ambient temperatures (34,35). Compared to a hot environment, a temperate environment provides less thermal strain in conjunction with working muscle tissue. Thus, will be an anticipated increase peak heart rate and heart rate averaged over the course of HIIE will occur in a hot environment compared to a temperate environment.

Hypothesis 4: There will be an increase in thermoregulatory (i.e., peak core temperature, Δ core temperature, sweat rate, sweat loss, or dehydration) measurements when comparing a hot and temperate condition during HIIE.

Previous research has shown a significant increase in core temperatures with repeated sprint training in hot compared to temperate environments (36). As a result of this increase in core temperature it is anticipated that both sweat rate and dehydration will also occur with HIIE in hot compared to temperate environments.

Hypothesis 5: There will be no difference in blood oxygen saturation and muscle tissue oxygenation when comparing a hot and temperate condition during HIIE.

Hypothesis 6: There will be an increase in blood lactate in the hot compared to a temperate environment during HIIE.

An increase in thermal strain from a hot environment has been shown to increase lactate levels during maximal intensity exercise compared to temperate environments (37,38,39). Thus, it is assumed that there will be an increase in lactate in hot environments during HIIE for both mask and no-mask conditions.

Hypothesis 7: There will be an increase in perceived thermal sensation, peak and average Borg's rating of perceived exertion, and perceived dyspnea comparing hot and temperate environment during HIIE.

The surgical mask will be used during HIIE for both temperate and hot environments. A greater thermal sensation and Borg's rating of perceived exertion has been previously shown with exercise in hot conditions (40). Thus, an increase in perceived thermal sensation and Borg's rating of perceived exertion in hot environments to compare temperate environments.

Main Effect for Mask use during HIIE:

Hypothesis 8: There will be no difference in heart rate, stroke volume, and cardiac output when comparing a no-mask condition to surgical mask use during HIIE.

Several studies have found no differences in heart rate, stroke volume or cardiac output with surgical mask use during progressive intensity and continuous exercise (24-26, 28).

Hypothesis 9: There will be no difference in peak core temperature, Δ core temperature, sweat rate, or dehydration when comparing a no-mask condition to surgical mask use during HIIE.

Hypothesis 10: There will be no difference in lactate, blood oxygen saturation, and muscle tissue oxygenation when comparing a no-mask condition to surgical mask use during HIIE.

Several studies have found no differences in lactate, blood oxygen saturation, or muscle tissue oxygenation with surgical mask use during progressive intensity and continuous exercise (24-26, 28).

Hypothesis 11: There will be no change in perceived peak thermal sensation, average thermal sensation, peak Borg's rating of perceived exertion, and Borg's rating of perceived exertion averaged over the course of exercise comparing no-mask condition to surgical mask use during HIIE.

One study found no differences in thermal discomfort with KN95 mask use (20), *and three studies found no difference with Borg's rating of perceived exertion with surgical mask use during exercise (26-28).*

Hypothesis 12: There will be an increase in perceived breathlessness measurements comparing no-mask condition to surgical mask use during HIIE.

Morris et al. (20) investigated KN95 mask use with moderate-intensity physical activity in a hot environment (40°C and 20% humidity), an increase in breathlessness was observed. As the environmental condition remained constant. The effects of a temperate environment should remain constant as well. Thus, it is hypothesized that an increase in breathlessness will occur comparing no-mask to surgical mask use during HIIE in a constant temperate environment.

Scope of Study

Ten (5 males and 5 females) healthy participants that were 18 years or older, free from cardiovascular, renal, metabolic, or chronic respiratory disease, who did not smoke or had quit smoking for at least 6 months and did not require an inhaler to control for exercise-induced asthma were recruited. Female participants of childbearing potential, as defined by the U.S. Department of Health and Human Services, completed a urine pregnancy test prior to any exercise on each visit. An incremental exercise ramp protocol using an electronically braked cycle ergometer was used on the first visit to assess maximal oxygen consumption (VO_2max) and peak power output (Watts). All participants that ranked in the 50th percentile or above for VO_2max according to the American College of Sport Medicine (ACSM) guidelines were included in the study helping to ensure the completion of the HIIE protocol. All participants were assigned a randomized order to complete HIIE in no-mask temperate (HIIE-TEMP/CON), no mask hot (HIIE-HOT/CON), mask temperate (HIIE-TEMP/MASK), and mask hot (HIIE-HOT/MASK) conditions. For each of the HIIE sessions, participants performed a 5-minute warm-up at a self-selected intensity on the electrically braked stationary bike. Then the subjects did 10 intervals with 30 seconds of high intensity exercise and 90 seconds of low intensity exercise recovery. All high intensity bouts were performed at 85% of peak power output followed by an active rest exercise performed at 30% of peak power output. Participants completed two of the four conditions on each visit with a total of 2 visits to complete the HIIE portion of the study. A total of three hours of rest within the same day of testing was provided between HIIE sessions. During these three hours of rest participants were provided water and a small meal (350 calories; 7g of Fat; 64g Carbohydrate; 9g Protein). All participants rested in a seated position for 5 minutes to have resting heart rate and blood pressure measured before any exercise on each visit. Hydration status was assessed by measuring urine specific gravity before any exercise on each visit. Cardiac output, stoke volume, and heart rate were measured during the HIIE sessions using impedance cardiography (PhysioFlow®, NeuMeDex, Bristol, PA). Blood oxygen saturation was measured during HIIE sessions using a non-invasive continuous hemodynamic monitoring device (Caretaker, Caretaker Medical, USA). Muscle tissue oxygenation of the *vastus lateralis* was measured during HIIE sessions using near infra-red spectroscopy (Moxy, Moxy Monitor System, MN, USA). Blood lactate measurements were taken before and 5-minutes after HIIE. Borg's rating of perceived exertion (RPE) and thermal sensation measurements were recorded before, and every 4 minutes during HIIE. Breathlessness was measured using a visual analog dyspnea scale (20,32) before, 10-minutes into exercise, and immediately after HIIE.

Assumptions

This study was conducted based on the following assumptions:

1: Participants followed the pre-testing guidelines before exercise and answered the Health History/Physical Activity Questionnaire honestly.

2: Participants maintained the same lifestyle routine throughout the duration of their participation.

3: Subjects put forth a maximal effort during the maximal oxygen consumption test.

4: Subjects accurately reported their rating of perceived exertion, level of perceived dyspnea, and perceived thermal sensation.

5: All equipment used in the study was correctly calibrated and in good working order.

6: Mechanical efficiency was the same among participants for cycling exercise.

Limitations

Although each visit was separated by 72 hours, during the visit the subject performed two randomized HIIE sessions separated by three hours. Fatigue from the first HIIE session may have been a factor that influenced physiological responses of participant during the second HIIE session. This fatigue may have also been a factor in how participants reported perceived exertion, thermal sensation, and breathlessness. Generalizability was limited as participants were college-aged individuals free from any serious medical condition and categorized at or above the 50th percentile for aerobic fitness according to ACSM guidelines. Additionally, not all participants may have been equally familiar with performing cycling exercise. If this was not their preferred form of exercise this may have been a factor that influenced their physiological or perceptual responses during HIIE sessions. Another limitation is the current study did not control for the timing of the female participant's menstrual cycle and may have influenced thermoregulatory responses. Finally, since participants were instructed to remain seated during the entirety of the HIIE session, this does not entirely represent cycling exercise as cyclists are not limited to contact with the seat of the bike.

Significance of the Study

Infections with the severe acute respiratory syndrome 2 (SARS-CoV-2) virus can cause COVID-19. COVID-19 was declared a global pandemic by the World Health Organization (WHO) on March 11th, 2020 (1). This has led to several non-pharmaceutical interventions (i.e., mask use, isolation, quarantine, good hygiene practices, use of disinfectants, restrictions placed on public gatherings, and social distancing) to reduce the spread of the disease. Several research teams have investigated mask use with graded exercise protocols to exhaustion in a temperate environment (24-28). This type of exercise is often reserved for laboratory settings, and it is uncommon for exercisers to engage in short, graded efforts going from easy to maximal exercise. However, interval training is a popular time-effective form of exercise that both recreational exercisers and competitive athletes use to train across several different sport domains including soccer, basketball, football, tennis, or track & field exercise. To our knowledge there has been no research investigating exercise performance with mask use during interval training in both hot and temperate environments. The findings of this study could provide meaningful information for both recreational exercisers and competitive athletes training for sporting events.

Definitions

Blood oxygen saturation (SpO_2) – the relative portion of oxygen attached to the blood.

Borg's rating of perceived exertion (RPE) – a psycho-physical tool used to measure difficulty of exercise on a scale from 6 (rest) to 20 (maximal effort).

Dyspnea – labored or difficult breathing; shortness of breath.

Heart rate (HR) – the number of contractions of the heart per minute.

High-intensity interval exercise (HIIE) – bouts of high intensity exercise separated by bouts of either active (moderate-light exercise) or passive (no exercise) rest.

Impedance cardiography – the use of electrodes to measure electrical impedance waveforms to non-invasively determine cardiac output, stroke volume, and heart rate.

Oxygen uptake (VO_2) – the maximal rate of oxygen consumption per minute of exercise.

Muscle tissue oxygenation index – the relative portion of oxygenated muscle tissue to deoxygenated muscle tissue.

Muscle tissue oxygenation index = Oxyhemoglobin/Total hemoglobin.

Near infra-red spectroscopy (NIRS) – a tool that measures the absorbance of infra-red light to determine muscle tissue oxygenation.

Stroke volume (SV) – the amount of blood ejected from the ventricles of the heart per beat.

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Chapter 2

This chapter presents a review manuscript, entitled "Mask use during exercise: a look into the cardiorespiratory, thermoregulatory, and perceptual responses". This manuscript is authored by Andrew Wells, Christine Mermier, Bryanne Bellovary, Michael Deyhle, Yu Yu Hsiao, and Fabiano Amorim. This manuscript follows the formatting and style guidelines for Journal of Sports Medicine and Physical Fitness.

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Abstract

The use of masks in public settings and when around people has been recommended to limit the spread of Coronavirus disease 2019 (COVID-19) by major public health agencies. Several different types of masks classified as either medical- or non-medical grade are commonly used among the public. However, anecdotal concerns with difficulty breathing, re-breathing carbon dioxide, and a decrease in blood oxygen saturation have been raised regarding the use of mask during exercise. Thus, the purpose of this review is to present the current knowledge related to the use of masks during exercise on cardiorespiratory, metabolic, thermoregulatory, and perceptual responses. Current evidence from the literature suggests that there are no changes to cardiovascular parameters during mask use while performing maximal intensity cycling exercise ramp protocols to volitional fatigue. Similarly, no differences were found across different metabolic parameters with exercise at low or maximal exercise intensities. However, differences in ventilatory parameters that occurred with maximal intensity exercise to volitional fatigue were found to be dependent on the type of mask used. As for thermoregulatory responses to prolonged moderate intensity activity within a hot environment, no differences were found in core temperature measurements between mask use and no mask conditions. Although no changes in peak rating of perceived exertion occurred with progressive exercise tests with cloth- or surgical-mask use; prolonged moderate intensity exercise in a hot environment increased perceived dyspnea occurred with KN95 mask use.

Introduction

Severe Acute Respiratory Syndrome Corona Virus 2 (SARS-CoV-2) is the virus that can cause the respiratory disease known as Coronavirus disease 2019 (COVID-19). Following the global spread of SARS-CoV-2 infections and COVID-19 cases, the disease was declared a pandemic on March 11th, 2020 (1). To slow the spread of COVID-19 through respiratory pathways (3, 4), wearing a mask in public settings and when around people has been recommended by major public health agencies [i.e., the Centers for Disease Control (CDC)] (3, 4). It is proposed that face masks may filter fine airborne particles including the COVID-19 pathogen and prevent/reduce inter-individual transmission. In fact, a recent systematic review and meta-analysis using observational data suggests that the use of masks and social distance provides protection against COVID-19 infection for the general population (5). During exercise, the use of masks has been recommended in both indoor and outdoor environments (6, 7) and if the mask gathers moisture from sweat, it is recommended replacing that mask with a clean one before continuing to exercise (6). Regarding, exercise intensity, if a healthy individual is unable to wear a mask due to difficulty breathing during high intensity exercise, it is recommended to perform the exercise in an outdoor location that can provide greater ventilation and enough space to maintain at least 6 feet from other individuals in the area. However, if such a location is not available, it is suggested to opt for low-intensity exercise that allows for a mask to be worn (6, 7) as wearing a mask during low intensity is well tolerated within the general population (8–11), which extends to include mask use in hot environments (12). In contrast, wearing a mask at low-intensity exercise may be especially important in populations with an underlying pathophysiological condition. Lee et al. (13) reports cases of sudden cardiac death (SCD) from exercise while wearing facemasks and argues that a possible increase in SCD risk may arise from acute and/or intermittent hypoxia. This raises concerns with mask use in patients performing clinical exercise testing (e.g., 6-minute walk test). In the case of chronic obstructive pulmonary disease (COPD), wearing a mask may be dependent upon the severity of the disease and/or type of mask worn during exercise testing (14, 15).

Currently there are several different types of masks available for the general population (6) such as non-medical grade masks that consist of single-use and cloth-masks, or medical grade masks that consist of surgical- and N95 masks (6). The use of non-medical grade masks with exhalation valves or vents (e.g., elevation training mask) is not recommended to reduce the spread of COVID-19 (6). Additionally, due to supply shortages, the major health agencies have not recommended the use of N95 masks as these are reserved for healthcare workers (6). Consequently, medical grade surgical masks and non-medical grade cloth-masks are used by recreational exercisers and athletes. Although not FDA approved, evidence suggests multiple layer non-medical grade facemasks may provide protection (16). Recent research has targeted N95, surgical- and cloth-mask use in both occupational and exercise settings to assess possible detrimental effects during physical exertion (10, 17–19). There have been concerns raised regarding difficulty breathing, re-breathing carbon dioxide, and the reduction of blood oxygen saturation with mask use (18, 20, 21). These concerns have been objectively measured and monitored in many preliminary studies during exercise with mask use (10, 17–19, 22). In addition, mask use may impair respiratory heat loss through the rebreathing of air warmed by the body in hotter environments (23) and increase the perception of thermal stress due to the high density of thermoreceptors located in the face (24, 25). Finally, other subjective perceptual aspects of N95, surgical-, and cloth-mask use during exercise have been measured using questionnaires (17, 26), rating of perceived exertion (RPE) (19), and by using a visual analog scale for perceived dyspnea (2). Therefore, the purpose of this review is to evaluate mask use on the physiological, thermoregulatory, and perceptual responses during exercise.

Cardiovascular responses

Cardiac output (CO), the product of heart rate (HR) and stroke volume (SV), reflects the ability of the cardiovascular system to deliver oxygenated blood for extraction by working muscle tissues during exercise and other physical activity (27). Of interest, CO can be influenced by any restriction that may affect respiratory air flow (28). For example, breathing through an inspiratory resistance device has been shown to decrease intrathoracic pressure during inspiration, increasing preload, SV, and CO in normovolemic supine humans and increasing tolerance to central hypovolemia induced by lower body negative pressure (28). In a similar fashion, a mask may reduce ventilation by creating resistance to flow and increasing respiratory muscle recruitment (17). If sufficient inspiratory airflow restriction occurs, this opposition could reduce intrathoracic pressure during inspiration and alter hemodynamic variables such as CO, SV, HR, systolic blood pressure (SBP), diastolic blood pressure (DBP), and arterio-venous oxygen difference (a-vO_2) during exercise.

During lower intensity treadmill exercise (2.7 or 4.0 Kph) exercise in healthy individuals, Roberge et al. (10) found no changes in HR comparing a no-mask control to N95 mask use. It would be unlikely that the other hemodynamic variables would change with N95 mask use due to the low exercise intensity employed in this study. In contrast, an increase in HR with different types of N95 masks (i.e., with and without exhalation valves) compared to a no-mask control was found with participants performing an hour of treadmill walking at a 5.6 Kph work rate in a temperate environment (9). However, apart from HR, hemodynamic variables such as SV, CO, SBP, and DBP measurements were not explored. In addition, the generalization of this study is limited as N95 masks are reserved for health care workers and are not widely available to the general population (9).

At higher exercise intensities, Boldrini et al. (29) found no differences in HR comparing surgical mask use to a no-mask control while having participants perform submaximal cycling at 100 watts for 10-minutes and with 3-minutes at 150 watts, while Roberge et al. (31) found that wearing a surgical mask with longer duration treadmill exercise (1 hour at 5.6 Kph) increased HR compared to no-mask control. As the exercise intensities between Roberge et al. (31) and Boldrini et al. (29) can be reasonably compared (~61% of estimated max HR, and ~73% estimated max HR at 100 watts, respectively) after accounting for age differences (23 ± 2.8 yrs, and 34 ± 10 yrs, respectively), apart from the exercise modality, speculation can be made about the increase in HR only occurring with surgical mask use while performing longer duration exercise. In addition to the findings of Boldrini et al. (29) and Roberge et al. (31), Lässing et al. (30) found an increase in HR with 30-minutes of maximal lactate steady state cycling exercise with no differences in either CO or SBP. This may lead to speculation that wearing a surgical mask compared to a no-mask control may only increase HR during short duration exercise if there is a sufficient increase in exercise intensity or if there is a sufficient increase in exercise duration with low intensity.

In contrast to low, moderate, and moderate-vigorous intensity exercise, data from Fikenzer et al. (17) examined healthy individuals that performed an incremental exercise ramp protocol to volitional fatigue on a recumbent cycle ergometer to investigate test duration and hemodynamic parameters across a no-mask control, surgical mask, and N95 mask use. Fikenzer et al. (17) found no differences in SV, CO, SBP, or DBP regardless of mask use with this type of graded exercise test resulting in maximal intensity. Further, no differences were found in HR comparing no-mask control to N95 mask use or between the surgical mask and N95 mask condition (17). Finally, there were no differences found comparing an estimate of a-vO_2 [calculated using Fick's principle (a-vO_2 = CO/VO_2)] between either no-mask and surgical mask use, or between surgical mask and N95 mask use (17). However, HR was greater in the no-mask control compared to the surgical mask use (187 ± 8.3 bpm and 183 ± 9.2 bpm, respectively; $p = 0.031$), a-vO_2 decreased in the N95 mask condition compared to a no-mask control (10.5 ± 2.0% and 12.8 ± 2.8%, respectively;

p = 0.007), and power output was greater in the no-mask control compared to N95 mask use (277 ± 45.9 watts and 263 ± 41.7 watts, respectively; p = 0.005) (17). Fikenzer et al. (17) also reported a decrease in the duration (-52 ± 45 seconds; p = 0.005) when an incremental exercise test was performed with a N95 mask compared to a no-mask control, and no difference in exercise duration (-29 ± 40 seconds; p = 0.07) with surgical mask use compared to a no-mask control. In a similar study to Fikenzer et al. (17), Li et al. (32) found a similar decrease in HR with surgical mask use. However, Shaw et al. (19), Mapelli et al. (33), and Epstein et al. (34) used a graded exercise test protocol using a cycle ergometer and found no differences comparing SpO_2 between surgical and no-mask conditions. In addition, Shaw et al. (19) found no difference in muscle tissue oxygenation index (i.e., a ratio of muscle tissue oxygenation saturation to desaturation) using near infra-red spectroscopy, or HR across no-mask, surgical mask, cloth-mask or N95 mask conditions, suggesting equivocal findings of HR responses with mask use in the literature.

Additionally, both Shaw et al. (19) and Epstein et al. (34) also found no difference in time to exercise termination (p = 0.20 and p-value = 0.30, respectively), power output (Shaw et al. (19): p = 0.49), or SBP (Epstein et al. (34): p = 0.96) comparing surgical mask use to a no-mask control. Taken together, the data from Fikenzer et al. (17), Shaw et al. (19), Epstein et al. (34), Li et al. (32), and Mapelli et al. (33) reveal few changes in hemodynamic parameters or exercise performance outcomes with surgical mask use. In comparison to cycling exercise, Driver et al. (55) found no difference in SBP (p = 0.68) but an increase in HR (p = 0.01) and a decrease in Bruce protocol treadmill exercise test duration (p <0.001) while wearing a surgical mask. As for the drop in estimated $a\text{-}vO_2$, this could be explained as Fikenzer et al. (17) reports a significant decrease in exercise duration (-52 ± 45 s; p = 0.005) with N95 mask use compared to no-mask control which may be due to an increase in perceived exercise difficulty at lower exercise intensities. This higher perceived effort can lead to an early termination of exercise and a decrease of maximal intensity exercise workload with the use of an incremental exercise ramp protocol to volitional fatigue. Thus, the decrease in the maximal workload would result in lower $a\text{-}vO_2$ due to less skeletal muscle recruitment and oxygen requirement. Regardless, there are only rare circumstances where an N95 mask would be used when this type of maximal exertion is required.

Ventilatory responses

In most circumstances, except for exercise induced hypoxemia in elite aerobic athletes, the respiratory system does not limit exercise capacity (35, 36). However, the restriction to inspiratory and expiratory airflow from mask use during exercise in the general population could limit the respiratory system by reducing ventilation (VE) through a decrease in respiratory rate (RR) or tidal volume (TV).

Fikenzer et al. (17) found no differences in either RR or TV comparing no-mask to surgical mask use but found a decrease in VE when surgical mask use was compared to a no-mask control ($p = 0.048$) with individuals that performed a maximal graded exercise protocol (17). In parallel, no differences were found in either RR or TV, but a decrease in VE was observed comparing surgical to N95 mask use (17). Fikenzer et al. (17) additionally found a decrease in VE, RR, and TV values with N95 mask use compared to a no-mask control. These data suggest that airflow obstruction occurred with surgical- and N95 mask use that were observed with reductions in VE alone compared to a no-mask control. However, a reduction in VE, RR, and TV was to be expected due to greater airflow obstruction provided by the N95 mask. The decreased VE shown with surgical mask use is perplexing as VE is a product of RR and TV, which individually did not decrease (17). The variance of each measurement in the Fikenzer et al. (17) study may explain the statistical difference found for VE comparing surgical mask and no-mask control. In contrast, Driver et al. (55) found a decrease in VE, RR, and TV when a surgical mask was worn during a Bruce protocol treadmill test. A possible alternative explanation to the decrease in VE, RR, or TV in the Driver et al. (55) and Fikenzer et al. (17) studies may be attributed to having a gas capture mask overlayed onto the mask conditions that may have added additional mechanical load to the respiratory muscles. For example, as the surgical mask is worn under the gas capture mask, the additional airflow resistance may lead to an increase dead space that would lower TV, in addition to extending inspiration and/or expiration times leading to a decrease in RR. This would mean that an increase in airflow resistance would have to disproportionately reduce TV and RR that may allow a difference in VE but no difference between RR or TV. However, both Mapelli et al. (33) and Li et al. (32) found a reduction in VE and TV without a change in RR while wearing a surgical mask. Thus, these data would suggest that surgical masks have a larger impact on TV compared to RR.

Predictably, at lower intensity treadmill exercise, Roberge et al. (10) found no differences in RR, TV, or VE with N95 mask use. This suggests that there are no limiting effects on ventilatory variables with surgical mask use during lower intensity exercise. However, there seems to be a drop in VE (17, 32, 33) and TV (32, 33) with surgical mask use observed with progressive exercise tests to volitional maximal exertion. These incremental exercise tests that end with volitional fatigue are most often reserved for use in a laboratory or clinical settings. Recent findings indicate 30 minutes of continuous moderate-vigorous aerobic exercise increases HR and VO_2, with decreases in a-vO_2, VE, and TV (30) while wearing a surgical mask compared to without a mask. However, extrapolation of these data to other more commonly used forms of high intensity exercise (≥ 6 METs) such as high intensity interval exercise (HIIE) remains speculative.

Metabolic

Metabolic parameters such as blood pH, partial pressure of carbon dioxide (PCO_2), partial pressure of oxygen (PO_2), and lactate [BLa-] may be influenced by use of masks from a possible restriction in airflow and oxygen delivery to active tissues during high intensity exercise. However, Fikenzer et al. (17) found no differences when comparing blood pH, PCO_2, PO_2, and [BLa-] across no-mask control, surgical mask, or N95 mask use with individuals performing a graded exercise test to volitional fatigue. In addition to these findings, Shaw et al. (19) found no differences across no-mask control, surgical mask, or cloth-mask use in either SpO_2 or muscle tissue oxygenation at the *vastus lateralis* muscle with progressive exercise tests. A growing base of evidence in the literature show no changes found in SpO_2, blood pH, PCO_2, PO_2, [BLa^-], or muscle tissue oxygenation index with surgical mask use (17, 19, 22, 34) during heavy exercise. These metabolic findings are expected as no differences were found in exercise performance outcomes (i.e., power output, VO_2max, or time to exhaustion) when a surgical mask is used versus a no-mask control performing a graded exercise test to volitional fatigue on a cycle ergometer (17, 19, 32–34). However, with N95 mask use, while instances of exercise performance outcomes have been observed to be reduced compared to a no-mask control (17, 33), apart from a single observation where there was estimated decrease in a-vO_2 (17). Current evidence suggests no changes to SpO_2, PCO_2, PO_2, [BLa-], or muscle tissue oxygenation index with N95 mask use during progressive exercise tests

(17, 19, 33, 34). Additionally, a recent meta-analysis indicates no changes in metabolic outcomes across a wide array of different exercise intensities or modalities with mask use (22).

Perceptual

Wearing a mask use may change the perception of exertion during low to high intensity exercise (38, 39). Borg's rating of perceived exertion (RPE) is a well-known psycho-physical tool to subjectively assess relative exercise intensity (40, 41). Several studies have shown that no differences were found comparing RPE at the end of a progressive exercise test ending in maximal effort between no-mask control, surgical mask, or cloth-mask use (19, 32, 34). However, it is unclear as to what RPE values were compared. For example, if the highest RPE value was recorded, participants acted as their own controls, and participants achieved a maximal effort for each trial; then by design no difference in RPE should be expected. However, if RPE recorded over the course of each trial and averaged, then RPE may be higher when a mask is worn.

Fikenzer et al. (17) may have anticipated no differences in RPE and opted to investigate several relative subjective sensation measurements of discomfort. These measurements included the individual's perception of "humidity", "heat", "breath resistance", "itchiness", "tightness", "saltiness", "unfit", "odor", "fatigue", and "overall discomfort" (17). In comparing a no-mask control to surgical mask use there were no differences found in sensations of humidity, saltiness, and odor with an increase in the remaining subjective measurements for the sensations recorded 10-minutes post-exercise, including overall discomfort (17). Further, only the odor sensation was found to incur no differences when comparing N95 mask use to no-mask control following exercise. All other subjective sensations increased during N95 mask use compared to a no-mask control (17). In total, these data suggest that mask use increases overall discomfort when performing an incremental exercise test to volitional fatigue (17). However, regardless of discomfort reported from the use of a surgical mask by participants in the Fikenzer et al. study (17), there were no decrements in exercise performance. Combining these with the findings of Shaw et al. (19), there is agreement between the two studies that the surgical mask did not produce decreases in incremental test exercise performance when compared to a no-mask control. However, Shaw et al. (19), Li et al. (32), and Epstein et al. (34) found no differences regarding RPE in their comparison of a surgical mask use to a no-mask control. This suggests that the subjective measurements performed by Fikenzer et al. (17) may be independent of RPE measurements making the psycho-physical tools used by Fikenzer et al. (17) and the other studies difficult to compare.

Though speculative, reported RPE may depend on the form of exercise performed. For example, positive linear relationships occur when observing RPE, VO_2, HR, and VE that often reflect the incremental increase in workload during exercise tests to volitional fatigue without mask use (42–45) should still be observed with mask use. Other examples are reported RPE trends that increase linearly with prolonged cycling exercise (46), and oscillatory RPE trends that occur with HIIE (47).

Apart from RPE, a greater frequency of mask use may produce a psychological adaptation and reduce perceived distress (38). This would improve tolerance to mask use during rest or exercise (38). For example, repeated mask use during a training protocol over several weeks may decrease perceptions of thermal stress, difficulty breathing, and overall discomfort (17, 38). However, the degree of perceived distress or ability to adapt to mask use may depend on the level of anxiety an individual is experiencing. Mask wearing individuals with anxiety have been shown to have a reduction in work performance with physical exertion at 80-85% HRmax compared to less anxious individuals with exercise performed to a volitional end point (39). Over time, repeated mask use may attenuate this distress in anxious mask wearing individuals through a process of exposure, a core component of cognitive behavioral therapy (48). For instance, anxious individuals that can discern and resist anxiety driven perceptions that lead to difficulty breathing could then reduce their distress while wearing a mask during exercise (39, 48, 49).

Thermoregulatory

Mask wearing during exercise in hot environments may impair thermoregulation. The use of masks in hotter environments requiring moderate or vigorous physical activity involved in occupational, recreational exercise, or professional athletic training routines may trap air and prevent heat lost through respiratory pathways. Convective heat loss from VE has been shown to aid in thermoregulation with increasing core temperatures (23). A reduction in respiratory heat loss with mask use in hotter ambient temperatures during exercise may further impair heat loss. However, the contribution of respiratory heat loss is small with evaporative cooling at the skin being the primary pathway for heat loss (23).

Alternatively, as hot air can be trapped by wearing a mask, individuals may have a higher perception of heat stress due to the face having a greater density of thermal receptors compared to the chest (24, 52). Additionally, non-heat-adapted individuals may also have thermal receptors that are more sensitive to hotter ambient environments. However, repeated mask use may physiologically alter rate coding of transient receptor potential cation channels thermoreceptors (TRPV1-TRPV4) responsible for sensing heat (51, 52). Thus, this adaptive response from TRPV channels may reduce the perceived distress during mask use.

Morris et al. (2) investigated KN95 mask use (an N95 mask equivalent), with healthy males performing 45 minutes of moderate intensity activity (~5 Mets) in a hot environment (40°C with 20% humidity). As expected, core and skin temperatures were elevated when comparing rest and following 45 minutes of exercise, regardless of mask use (2). However, no differences were found between core and skin temperatures, nor those measured under the mask, and outside the mask on the face when comparing a no-mask control to KN95 mask use (2). In agreement with Morris et al. (2), Roberge et al. (31) found an increase in core temperature and skin temperatures over the course of 1 hour of treadmill exercise (5.6 Kph), with and without wearing a surgical mask. These data suggest that performing low-to-moderate levels of physical exertion in hot environments while wearing either a KN95 or surgical mask does not impair thermoregulation. However, these data cannot be extrapolated to exercise with surgical mask or cloth-mask use when exercise is performed at a greater intensity. Additionally, this response may also be exacerbated with mask use in warmer environments or with prolonged exercise durations. As greater VE occurs at higher exercise intensities, rapidly rebreathing air warmed by the body with increasing core temperatures in hot environments may reduce the efficacy of evaporative heat loss. Alternatively, if core temperature does change during high intensity exercise regardless of mask use, then the increase in thermal stress may be attributed to an increase in TRPV activity that results in the increased perception of thermal stress. As recreational exercisers and athletes may train or perform in warmer outdoor settings, more research is still needed to establish evidence for or against any possible increase in risk for developing heat illness or heat stroke with surgical mask or cloth-mask use in this environment.

Summary and considerations

Mask use in public settings is recommended by the CDC to reduce the spread of COVID-19 (6, 7). Further, the CDC has endorsed mask use during exercise along with recommendations of limiting indoor activity including indoor group training sessions (6, 7). Because when worn properly, masks cover the nose and mouth, and the restriction of airflow may alter physiological, thermoregulatory, and psychological responses to exercise. Currently, research has been, and is continuing to be performed regarding exercise with medical grade and non-medical grade mask use. Evidence suggests that there is minimal impact of medical grade and non-medical grade mask use on cardiovascular responses in healthy individuals with incremental exercise tests performed to volitional fatigue performed on a cycle ergometer (17, 19, 32-34) or healthy individuals performing a variety of exercises across different intensities (22). In the context of respiration, surgical mask use seems to produce a decrease in VE (17, 32, 33) and TV (32, 33), while one study showed there was no change in RR or TV (17). However, N95 mask use has a greater impact on respiration by reducing VE, RR, or TV at maximal exercise intensity (17, 33). Likewise, N95 mask use reduced power output, VO_2max, or time to exhaustion with incremental exercise testing (17, 33). Surgical mask or cloth-mask have not been shown reduce power output, VO_2max, or incur an early termination of exercise (17, 19, 34). Further, no changes were found in SpO_2 or [BLa-] parameters regardless of mask use (17, 19, 33). Perceptually, during mask wearing there was an increase in feelings of discomfort (17) with maximal intensity exercise. Although contested by Mapelli et al. (33), no change in RPE with surgical mask or cloth-mask use compared to a no-mask control has been found (19, 32, 34) during progressive cycling exercise tests. No differences were found between core and skin temperatures, nor temperatures measured under the mask, and outside the mask on the face comparing no-mask control to KN95 mask use with moderate intensity exercise (2).

As new research continues to emerge on mask use during exercise based on the preliminary data from studies in this new area of interest (2, 17, 18, 19, 26, 29, 30, 32, 33, 34) in response to the COVID-19 pandemic, considerations should be made to continue exploration of different forms and modalities of exercise performed by recreational exercisers and professional athletes. Studies discussed here (17, 19, 32–34) had healthy individuals perform exercise to volitional fatigue on a cycle ergometer in a temperate environment; these studies are limited in exploring mask use by the type of exercise performed, mode of exercise, and the use of temperate environmental conditions. Apart from studies that have investigated progressive exercise tests, Morris et al. (2) has investigated KN95 mask use in a hot environment (40°C and 20% humidity) with moderate physical exertion representing occupational settings; this study is limited by exercise intensity, one type of mask, and does not assess contributions of "breathlessness" from anxiety with mask use. For example, mask use with several other modes of exercise such as resistance training, rowing, treadmill running, arm ergometry, and stair climbing still need to be explored with anxious individuals in mind. Additionally, future research should include circuit training, HIIE, prolonged endurance exercise, superset training, and different types of weightlifting. While other studies have begun to investigate mask use with treadmill, cycling, and resistance exercise across different types of intensities in healthy children and clinical populations (15,52-54); future studies should include studying the effects of mask use across different exercise intensities, modalities, populations, and environments. All these dimensions of exercise have important implications related to both health- and skill-related physical fitness components for recreational exercisers and professional athletes.

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Chapter 3

This chapter presents a research manuscript, entitled "Facemask use during high intensity interval exercise in temperate and hot environments". This manuscript is authored by Andrew Wells, Zachary Fennel, Jeremy Ducharme, Abdulaziz A Masoud, Jon Houck, Bryanne Bellovary, Michael Deyhle, Yu Yu Hsiao, Fabiano Amorim, and Christine Mermier. This manuscript follows the formatting and style guidelines for Journal of Sports Medicine and Physical Fitness.

Facemask use during high intensity interval exercise in temperate and hot environments.

Running header: Facemask use and HIIE

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Abstract

BACKGROUND: Facemask use has been recommended during physical activity to prevent spreading and contracting the virus that causes COVID-19. There have been concerns about negative physiological and perceptual effects of mask-wearing, especially during higher-intensity activities. Emerging research suggests there is a minimal impact of wearing a surgical mask on physiological responses across a wide array of exercise intensities and modalities. However, there are no published data regarding the impact of surgical mask use in hot or temperate environments during high intensity interval exercise (HIIE). Therefore, the purpose of this study was to investigate the effects of surgical mask use during HIIE on physiological and perceptual responses in hot and temperate environments. METHODS: Ten healthy participants (5 females; 5 males) completed a total of four HIIE sessions. In a randomized fashion, each participant completed identical HIIE sessions in both hot (HIIE-HOT) and temperate environments (HIIE-TEMP) while wearing (MASK) and not wearing a surgical mask (CON). RESULTS: No differences in other physiological variables were found between MASK versus CON during HIIE. In regard to environmental conditions, HIIE-HOT showed an increase in peak ($p = 0.012$) and averaged heart rate over the course of exercise ($p = 0.003$). An increase in reported perceived dyspnea ($p < 0.001$) and average RPE ($p = 0.002$) was found during MASK compared to CON. Interaction effects showed that the greatest changes in perceived dyspnea and average RPE occurred during the HIIE-HOT/MASK condition. CONCLUSIONS: Wearing a surgical mask during HIIE increases the perception of dyspnea and exertion with the greatest effect occurring in hot environments. Apart from perceptual changes, these data show that there are no other negative effects of using surgical masks during a short bout of HIIE.

Key words: Masks, Physiology, Physical Exertion, Perception, Environment

Ethics approval: This study was approved by the University of New Mexico Main Campus Institutional Review Board (IRBNet ID: 1680206-2).

Abbreviations:

ANOVA – Analysis of variance

a-vO_2 – Arterio-venous oxygen difference

CDC – Centers for Disease Control and Prevention

CO – Cardiac output

COVID-19 – Coronavirus disease 2019 (disease caused by SARS-CoV-2)

DBP – Diastolic blood pressure

FDA – US Food and Drug Administration

F_ECO_2 – Fractional expired carbon dioxide

F_EO_2 – Fractional expired oxygen

HIIE – High intensity interval exercise

HR – Heart rate

HRR – Heart rate recovery

MAP – Mean arterial pressure

MET – Metabolic equivalent of task

MHR – Maximal heart rate

NIRS – Near infra-red spectroscopy

PCO_2 – Partial pressure of carbon dioxide

pH – Potential of hydrogen

P_{max} – Maximal power output

P_{max}/kg – Maximal power output relative to body weight

PO_2 – Partial pressure of oxygen

RPE – Borg's rating of perceived exertion 6-20 scale

RR – Respiratory rate

SARS-CoV-2 – Severe Acute Respiratory Syndrome 2

SBP – Systolic blood pressure

SD – Standard deviation

SpO_2 – Blood oxygen saturation

SV – Stroke volume

TV – Tidal volume

VCO_2 – Rate of carbon dioxide production

VO_2 – Rate of oxygen consumption

VO_2/kg – Rate of oxygen consumption relative to body weight

VE – Ventilation

WHO – World Health Organization

Introduction

Mask use in public settings, endorsed by the Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO), help to limit the spread of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) that causes the disease known as COVID-19 (1,2). Wearing a mask during exercise may have implications for recreational exercisers and competitive athletes that train and compete at a high exercise intensity as wearing a surgical mask has been shown to limit ventilation (VE) during exercise (3–5). For example, N95 masks, designed to be worn tightly around the nose and mouth, have been shown to reduce maximal exercise performance markers compared to a no-mask control for individuals performing an incremental ramp protocol on a cycle ergometer (3,5). In contrast, wearing a surgical mask, certified by National Institute for Occupational Safety and Health and fitting more loosely than the N95, does not appear to reduce maximal power ($P_{max)}$, relative oxygen consumption (mL/kg/min), or test duration during a progressive maximal exercise test on a cycle ergometer (3,6). Further, surgical mask use during the maximal exercise test did not change cardiovascular, metabolic, and pulmonary measurements when compared to a no-mask condition in healthy individuals, with the exception of a decrease in maximal heart rate (MHR) (3). However, another recent study also using a progressive maximal exercise protocol showed no change in MHR using cycle ergometry when surgical mask use was compared to a no-mask condition (6). Importantly, this type of progressive maximal exercise test is frequently used for clinical and laboratory settings to assess cardiovascular, pulmonary, and metabolic markers. As such, this type of exercise protocol is not employed by competitive athletes or recreational exercisers in training or competitive settings. This limits the generalizability from results of the previous studies to medical-grade surgical mask use with short duration exercise (<12 minutes) measured during progressive maximal exercise tests. In fact, a recent meta-analysis concludes that wearing a mask elicits a minimal impact on physiological variables across a wide array of exercise intensities and modalities (4); high intensity interval exercise (HIIE) was not included, nor were hot environmental temperatures. Thus, only speculation can be made as to physiologic and metabolic responses that may occur during medical-grade surgical mask use with HIIE in both temperate and hot environments.

High intensity interval exercise is a popular time-efficient training method that involves short high intensity bouts followed by either active (low/moderate intensity exercise) or passive (no exercise) rest bouts (7–9). High intensity interval exercise has been shown to be safe and effective to increase physical fitness or performance in a diverse population that include exercisers in recreational, competitive, and clinical settings (10–13). Further, as HIIE can be performed in either an indoor or outdoor environment, using a mask may increase the physiological and perceptual strain of the exercise depending on the temperature and humidity. In a hot environment (40°C and 20% humidity), Morris et al. (14) found no difference in skin temperature, under the mask (i.e. a thermistor placed ~1cm to the right of the right nostril inside the mask) or outside the mask (i.e. a thermistor placed on the frontal facing zygomatic bone outside the mask), during 45-minutes of moderate intensity physical activity that mimicked movements required in health care and other related occupational settings in healthy males comparing no-mask to a KN95 mask (an N95 equivalent). Also, while Morris et al. (14) found no difference in whole body thermal discomfort, they found an increase in perceived breathlessness by 36% (14).

To date, no research study has investigated the effects of surgical mask use during HIIE in different environmental conditions. Therefore, the purpose of this study is to investigate the effects of surgical mask use during HIIE on cardiovascular, metabolic, thermoregulatory, and perceptual responses in temperate and hot environments.

Materials and Methods

Participants

Ten participants (5 males; 5 females) were recruited for this study (Table 1). Prior to any exercise and data collection, the study protocol was explained, all participant concerns were addressed, and written consent (Appendix A) was obtained. This study was approved by the university's Institutional Review Board and was in compliance with the Declaration of Helsinki (15).

Screening Procedures/Experimental Design

Participants completed a total of three visits separated by a minimum of 72 hours. Prior to each visit the participant was screened through Zoom, email, or by phone for possible exposure to, and symptoms of COVID-19 using a screening checklist (Appendix E). Additionally, they were instructed to avoid eating a filling meal 1-hour, consuming caffeine 4 hours, and vigorous exercise 24 hours before the first visit.

Either before or on the first visit, each participant filled out a health and physical activity questionnaire (Appendix B). Any participants that reported or indicated any history of a medical condition such as cardiovascular, renal, metabolic, or chronic respiratory disease, less than 150 minutes of moderate-intensity exercise per week, smoking within the last 6 months, inhaler use to control exercise induced asthma, or reported no experience performing HIIE were excluded from the study. Upon arrival for each visit, female participants performed a urine pregnancy test. If any individual tested positive, she was excluded from further participation in the study.

On the first visit, resting blood pressure and heart rate (HR) were assessed following at least 5-minutes of rest in a seated position for participant characterization. Resting blood pressure was assessed at the antecubital space using a sphygmomanometer, and stethoscope. Resting heart rate was measured using a pulse oximeter (Caretaker, Caretaker Medical, USA). Participant hydration status was assessed using a handheld refractometer (Cole-Parmer, RSA-BR90A, Vernon Hills, IL) before all HIIE sessions using urine specific gravity (USG). A USG measurement lower than 1.020 g/cc allowed participants to proceed to the HIIE sessions during the last two visits. If USG was greater than 1.020 g/cc, then participants consumed 500 ml of water, and were reassessed after 30 minutes. This water provision was only repeated twice if USG remained above 1.020 g/cc. All participants completed a graded maximal exercise test (VO_2max) on an electronically braked cycle ergometer to assess maximal power output (P_{max}) in watts and to measure VO_2max using a metabolic analyzer (Parvo Medics Inc, TrueOne 2400, Salt Lake City, UT). Participants that were categorized below the 50th percentile for age and sex according to the ACSM guidelines for aerobic fitness were excluded from further participation in the study (16).

All participants, during HIIE sessions with a mask, were instructed to wear the surgical mask snuggly over their nose and mouth. The participants fitted the flexible metal plate within the surgical mask over the bridge of the nose and had the bottom of the mask cover underneath the chin. During HIIE, no fans were directly facing any of the participants. A repeated measures design was used to compare cardiovascular, thermoregulatory, metabolic, and perceived responses before and during HIIE across four conditions performed during the second and third visits. Each HIIE bout consisting of 10 bouts lasting 30 seconds was performed at 85% P_{max} followed by 90 seconds of active recovery at 30% P_{max}. In a randomized order, the participants completed identical HIIE sessions in a temperate environment (23°C, 25% relative humidity) with (HIIE-TEMP/MASK) and without a surgical mask (HIIE-TEMP/CON), and in a hot environment (36°C, 14% relative humidity) with (HIIE-HOT/MASK) and without a surgical mask (HIIE-HOT/CON). For each of the two experimental visits the participant completed two HIIE sessions separated by 3 hours of rest. During the 3-hour rest period participants were provided a 350-calorie meal (7g of Fat; 64g Carbohydrate; 9g Protein) and water *ad libitum*.

Procedures

Maximal Oxygen Consumption Test – Visit 1

Before the VO_2max test, height was measured using a stadiometer (SECA, seca 216, Chino, CA, USA) and weight was measured using a digital scale (Cardinal DETECTO 758C, Webb City, MO). Participants completed a 5-minute warm-up at a self-selected exercise intensity prior to a VO_2max test on an electrically braked cycle ergometer (Lode, Excalibur Sport, Groningen, The Netherlands). During the VO_2max test, HR was measured using a Polar HR monitor (Polar, Polar H10, USA) with each test designed to last between 10 and 12 minutes. The starting resistance (Watts) and the continuous increase in resistance (between 20-40 watts) throughout the test was based on the participants' self-reported fitness. Termination of the VO_2max test occurred at volitional fatigue or when the participant could no longer maintain a cycling cadence of 60 revolutions per minute or higher. Breath-by-breath gas-exchange was measured and analyzed using an 11-breath rolling average as described by Robergs et al. (17). Primary criteria for a VO_2max was categorized with an observed plateau that varied by less than 150 mlO_2/min (18). To determine a plateau using primary criteria, the mean of the absolute difference from each neighboring data point in last 30 seconds of the 11-breath rolling average VO_2 was compared against 150 mlO_2/min (18); if the average value was smaller, the test was categorized as a VO_2max. In the absence of a plateau, a VO_2max was confirmed if two of the three secondary criteria were met: 1) an RPE ≥17, 2) a respiratory exchange ratio (RER) of

1.1 or greater, and 3) a HR within 10 beats of estimated heart rate max using the Jones et al. (19) equation (202 - 0.72 x age). The highest power output recorded from the VO_2max test was used to calculate the high intensity and active recovery bouts for the HIIE sessions.

Cardiovascular Measurements – Visits 2 and 3

After 5-minutes of seated rest, resting blood pressure was measured using a sphygmomanometer, and stethoscope. A cardiac impedance device (PhysioFlow®, NeuMeDex, Bristol, PA) calibrated per manufacturer guidelines was used to indirectly measure cardiac output (CO), stroke volume (SV), and HR. These measurements were taken continuously using 10-second averaging provided by the PhysioFlow® software during each HIIE session.

Metabolic Measurements

A near infra-red spectroscopy (NIRS) device (Moxy, Moxy Monitor System, MN, USA) was used to measure muscle tissue oxygenation data every second during each HIIE session. The highest muscle tissue oxygenation value from each active rest period (MTO active rest %) was averaged for each HIIE session. Additionally, the lowest muscle tissue oxygenation (MTO during HIIE %) value per high intensity bout was recorded and averaged from each HIIE session. The difference of the average MTO active rest % and MTO during HIIE % was used to calculate the muscle tissue oxygenation difference (MTO difference %). All MTO measurements were taken on the dominant leg at a marked location on the *vastus lateralis* that would allow movement without interruption from the NIRS device. A pulse oximeter (Caretaker, Caretaker Medical, USA) was used to measure SpO_2 during HIIE. Blood lactate measurements (Lactate Plus, NOVA Biomedical, MA) were taken in duplicate at the ear lobe immediately before, and 5-minutes post HIIE.

Perceptual Measurement before and during HIIE

Borg's rating of perceived exertion (6 rest to 20 maximal effort) scale (RPE) (20) and thermal sensation (0 very cold to 8 very hot) (21,22) was measured immediately before and every four minutes into HIIE. A breathlessness scale (0 mm no breathlessness to 200 mm maximal breathlessness) (23) was used immediately before, at 10-minutes, and immediately after exercise to record subjective change in difficulty breathing. The highest measurements for both RPE (peak RPE) and thermal sensation (peak thermal sensation) were recorded per HIIE session performed. Additionally, RPE (RPE avg) and dyspnea scores were averaged over time for every HIIE session.

Thermoregulation Measurements

During each HIIE exercise session with or without a surgical mask, in either temperate (23°C, 25% relative humidity) or hot environments (36°C, 14% relative humidity), continuous core temperature measurements were taken using rectal thermistors (Level 1 esophageal/rectal temperature probe, Smiths Medical, Minneapolis, MN, USA) connected to a thermometer (Precision 4000, YSI Incorporated, Yellow Springs, OH, USA) and monitored to ensure participant safety. Additionally, Δ core temperature (i.e., the difference between peak core temperature and core temperature prior to starting exercise) and peak core temperature were recorded for each HIIE session. Sweat rate (Equation 1) and dehydration (Equation 2) were calculated from pre-exercise nude weight, post-exercise nude weight, water ingestion, and post-exercise urine output measurements. Participants were asked to measure and report their pre-exercise and post-exercise nude weight using a digital scale (Cardinal DETECTO 758C, Webb City, MO) in a private room.

Equation 1

$$Sweat\ Rate = \frac{[((Pre\ Ex.\ Nude\ Wt - Post\ Ex.\ Nude\ Wt) * 1000) + Water\ Ingested + Post\ Ex.\ Urine\ ouput]}{Exercise\ Time\ (hours)}$$

Equation 2

$$Dehydration = \frac{(Pre\ Ex. Nude\ Wt - Post\ Ex. Nude\ Wt)}{Pre\ Ex.\ Nude\ Wt} * 100$$

As nude weights were measured in kilograms, a conversion to grams was made by multiplying by 1000 for both sweat rate and sweat loss calculations. In addition, post-exercise urine output was measured prior to post-exercise nude body weight. Thus, urine output was added back in rather than subtracted for the calculations and dehydration was calculated as a percent loss (Equation 1).

Statistical Analysis

All data is presented as mean ± SD. Female and Male descriptive data was compared using an independent t-test. If normality was violated, a non-parametric Mann-Whitney U test was performed. A 2x2 repeated measures ANOVA was performed to investigate statistical differences for all variables across HIIE-TEMP/CON, HIIE-TEMP/MASK, HIIE-HOT/MASK, HIIE-HOT/CON conditions except for a 3x2 repeated measures ANOVA being performed for perceived dyspnea data. Both main and interaction effects were calculated along with effect size reported as partial η^2. A Bonferroni post-hoc test was used to determine specific differences with significant interaction effects. All statistical tests were performed using JASP (version 0.14.1.0); significance was set at $p < 0.05$.

Results

All participants reported adherence to pre-test guidelines and completed all testing protocols. A significant main effect comparing MASK to CON conditions showed higher perceived dyspnea and average RPE during the HIIE sessions in the mask trials (Table 2). No differences were found between mask and no mask conditions for CO, SV, HR, peak core temperature, Δ core temperature, sweat rate, dehydration, blood lactate 5-minutes post exercise, SpO_2, MTO difference, MTO active rest, MTO during HIIE, peak thermal sensation, and peak RPE (Table 2). A significant main effect comparing hot and temperate environments showed a higher peak HR, average HR, perceived dyspnea, peak thermal sensation, average thermal sensation, and average RPE in the hot environment compared to temperate conditions (Table 2). There were no differences ($p > 0.05$) found for CO, SV, peak core temperature, Δ core temperature, sweat rate, dehydration, blood lactate 5-minutes post exercise, SpO_2, MTO difference, MTO active rest, MTO during HIIE, and peak RPE across hot and temperate environments (Table 2). Effect size for each variable is reported as partial eta squared (η^2) (Table 3). There were two cross-over interaction effects found with Δ core temperature ($p = 0.015$) and MTO difference ($p = 0.045$) (Table 2). A significant interaction was found with perceived dyspnea ($p = 0.035$) (Table 2). A Bonferroni post-hoc analysis revealed greater dyspnea comparing HIIE-HOT/MASK (58 ± 22 mm) to HIIE-HOT/CON (18 ± 15 mm; $p < 0.001$), HIIE-TEMP/MASK (44 ± 17 mm) to HIIE-TEMP/CON (14 ± 13 mm; $p = 0.007$), and HIIE-HOT/MASK (58 ± 22 mm) to HIIE-TEMP/MASK (44 ± 17 mm; p = 0.009). No difference was found for dyspnea comparing HIIE-HOT/CON (18 ± 15 mm) to HIIE-TEMP/CON (14 ± 13 mm; p > 0.05). Further, there was another significant interaction found showing a higher average RPE comparing HIIE-HOT/MASK (14.3 ± 1.3 AU) to HIIE-HOT/CON (13.5 ± 1.2 AU; p <0.001) and in HIIE-HOT/MASK (14.3 ± 1.3 AU) compared to HIIE-TEMP/MASK (13.3 ± 1.2 AU; p =0.012) with no significant difference in average RPE between HIIE-TEMP/MASK (13.3 ± 1.2 AU) and HIIE-TEMP/CON (13.3 ± 1.4 AU; p >0.05) or between HIIE-TEMP/MASK (13.3 ± 1.2 AU) and HIIE-TEMP/CON (13.3 ± 1.4 AU; p > 0.05).

Discussion

The purpose of this study was to investigate the physiological and perceptual effects of surgical mask use during HIIE in temperate and hot environments. Data from the current study suggest that wearing a mask during a bout of HIIE has no impact on cardiovascular, thermoregulatory, or metabolic variables (Table 2). In contrast, the environmental data show an increase in peak and average HR comparing a hot (36°C, 14% relative humidity) and temperate environments (23°C, 25% relative humidity) (Table 2). Additionally, comparing HIIE in hot and temperate environments suggest that perceived dyspnea, thermal sensation, and RPE in a hot environment are significantly higher, on average, as well as an increase in peak thermal sensation (Table 2). However, due to significant interaction effects present for perceived dyspnea and average RPE across environmental conditions, these main effects should be interpreted with caution.

Data on surgical mask use from the current study align with the findings of the recent meta-analysis and systematic review published by Shaw et al. (4). The current study also shows that no differences were found in arterial blood oxygenation, MTO, HR, CO, SV, or lactate accumulation while wearing a surgical mask during exercise. These null findings may be explained because the surgical mask while snug along the nose and top of the cheeks, it is loose around the side of the face near the ears potentially allowing for adequate VE. For instance, if VE was impaired, a reduction in gas-exchange would be expected to reduce arterial blood oxygenation which is not shown in the current study. A unique contribution of the current study is that no changes occurred in sweat rate, hydration, peak core temperature, or Δ core temperature during HIIE with or without wearing a surgical mask in hot and temperate environments (Table 2).

In terms of perceptual responses, this study suggests that wearing a surgical mask, on average, increased self-reported dyspnea and RPE. Although this study examined HIIE, these findings generally align across several studies that all assessed exercise with different intensities and durations (5,14,24,25). The conclusions of Shaw et al. (6) and the findings of the current study agree that wearing a surgical mask during vigorous exercise did not change RPE at the end of exercise (labeled peak RPE in the current study). However, the current study did find a significant increase in average RPE while wearing a surgical mask during HIIE. This suggests that wearing a surgical mask increased the perceived difficulty for the whole HIIE session. As it is difficult to separate sensations of dyspnea and RPE, this would explain why both average RPE and perceived dyspnea are greatest in the HIIE-HOT/MASK condition. Second to the HIIE-HOT/MASK condition, perceived dyspnea was greatest in the HIIE-TEMP/MASK condition suggesting that an increase in mechanical load from mask use may be a primary reason for the increase in dyspnea. The increased perceived dyspnea with surgical mask use compared to a no-mask control condition during HIIE aligns with the results of Boldrini et al. (24), Person et al. (25), Morris et al. (14), and the meta-analysis by Shaw et al. (4) despite differences in exercise protocols assigned to participants. Due to interaction effects present in perceived dyspnea and average RPE across mask conditions in the current study, these main effects need to be interpreted with caution.

The interaction effect with perceived dyspnea suggests a synergistic effect between environmental and mask conditions. The findings show that the greatest reported perceived dyspnea (on a scale of 0 mm to 200 mm) occurs while wearing a surgical mask in hot and temperate environments compared to a no-mask condition in either a hot or temperate environment (Table 2), demonstrating that wearing a surgical mask influenced a greater perceived dyspnea. A greater reported perceived dyspnea was found comparing surgical mask use between hot (58 ± 22 mm) and temperate (44 ± 17 mm) environments, with no difference without mask use in either a hot (18 ± 15 mm) or temperate (14 ± 13 mm) environment, signifying an interaction effect. However, a difference was expected to be found without mask use comparing hot and temperate conditions as the literature shows that hot environments tend to lead to an increased dyspnea (26,27). Additionally, wearing a surgical mask in the heat significantly increased the average RPE by approximately 1 unit compared to a no mask control over the course of HIIE with a greater average RPE while wearing a surgical mask in a hot and temperate environment (Table 2), indicating an interaction effect. This is due to the finding of no difference in average RPE with or without surgical mask use within a temperate environment (13.3 ± 1.2 AU and 13.3 ± 1.4 AU, respectively) and no difference between hot and temperate conditions without surgical mask use (13.5 ± 1.2 AU and 13.3 ± 1.4 AU, respectively).

Possible physiological explanations for this increase in perceived dyspnea may be explained by the activation of afferent respiratory mechanoreceptors (28). Previous research has shown that N95 and surgical mask use can disrupt pulmonary parameters by increasing respiratory muscle mechanical load (3,29–32). This increase in workload from wearing a mask would activate mechanoreceptors in the respiratory muscles and may lead to greater sensations of dyspnea (28). For example, these synergistic effects would involve the activation of mechanoreceptors in respiratory muscles from increased mechanical load (28) and from an increase in esophageal temperature (27). A critical threshold for the onset of hyperthermia-induced hyperventilation has been reported at an esophageal temperature of 38°C, which may be related to an elevation in brain stem temperatures (27). In conjunction with an increase in metabolic heat production from HIIE performed in a hot environment, and possibly re-breathing warmed air, this may also provide convective heat gain as well as neural feedback to the medulla that may lead to an increase sensation of dyspnea (27).

Physiological and perceptual response data comparing hot and temperate environments in the current study (i.e., higher HR, thermal sensation, RPE, and perceived dyspnea in hot temperatures) are in agreement with previous exercise studies conducted in the heat compared to temperate environments (14,33–36). However, there was no difference in peak core temperature, Δ core temperature, sweat rate, or dehydration across hot and temperate conditions found in the current study (Table 2). The delay in rectal temperature measurements may have underestimated real-time core temperature (37) or the brevity of time spent performing HIIE may also explain these thermoregulatory findings.

In comparison to physiological responses, significant cross-over interactions showed opposing effects of surgical mask use during HIIE when environmental conditions are matched with Δ core temperature and MTO difference. The surgical mask increased Δ core temperature compared to a no-mask control in a hot environment (Table 2). However, wearing a surgical mask decreased Δ core temperature compared to a no-mask control in temperate environment (Table 2). In the current study, participants performed stationary exercise without fan use and sweat rates were not different between mask or environmental conditions; a possible physiological explanation for this cross-over pattern in Δ core temperature may relate to conductive dry heat loss from increased subcutaneous skin blood flow. In a similar fashion to increasing dyspnea, re-breathing air warmed by the body may increase local environmental temperature of the preoptic area of the hypothalamus. This local warming has been shown in animal models to elicit cutaneous vasodilation (38). For instance, it would be possible for greater skin blood flow to occur due to the local warming of the preoptic area from mask use while exercising in a temperate environment. This greater skin blood flow would allow for greater dry heat exchange before the onset of sweating (39). Thus, a greater dry heat loss while wearing a surgical mask would lower core temperature change compared to a no-mask condition. In contrast, an environment that is near body temperature would reduce the dry heat loss and lead to an increase in core temperature change regardless of elevations in skin blood flow (39). Further, while the surgical mask decreased MTO difference in a hot environment compared to a no-mask control, MTO difference was greater with surgical mask use in a temperate environment compared to a no-mask control (Table 2). Although these cross-over interactions are interesting, within the context of the study changes in MTO and core temperature did not limit the participants' ability to complete the protocol without stopping exercise, moreover, safe core temperatures were maintained in all experimental conditions.

Finally, novel perceptual findings of this study show surgical mask use does not influence reported perceived peak or average thermal sensation during the HIIE protocol in hot or temperate conditions. As the face has a high number of thermoreceptors (40), the warmed air thought to be stagnant near the face from wearing a surgical mask was speculated to be a reasonable explanation for any increase in reported perceived thermal sensation. However, data from the current study suggest otherwise (Table 2).

Practical Applications

The data from the current study suggests surgical masks can be worn by healthy aerobically fit individuals while performing HIIE. In either a hot or temperate environment, healthy aerobically fit individuals (i.e., recreationally trained, or competitive athletes) should be aware that performing HIIE while wearing a surgical mask may increase perceived dyspnea compared to no mask. Because of a greater perceived difficulty when wearing a surgical mask, these individuals may self-select a lower exercise intensity and reduce the intended training stimulus of the HIIE session. This suggests that exercise prescriptions should be based on physiological responses such as HR that were shown to remain unchanged during HIIE with mask use rather than basing them on perceptual outcomes (e.g., RPE). In addition, as indoor gym settings have a temperature-controlled environment, this study has provided a HIIE cycling protocol that can be performed by aerobically trained individuals while wearing a surgical mask in a hot environment.

Conclusions

In summary, the current study suggests wearing a surgical mask does not add additional strain in cardiovascular, thermoregulatory, or metabolic responses during HIIE in an aerobically fit healthy population. However, the current study suggests that wearing a surgical mask increases perceived dyspnea and average RPE to a greater extent in a hot environment. Although research is emerging on the acute effects of mask use on exercise; future research investigations should include whether mask use has any effect on chronic exercise-induced adaptations since perceptions of increased RPE and breathlessness may influence training regimens. This may have implications for exercise performance and physical fitness over time. In conclusion, the current study provides evidence that wearing a surgical mask during HIIE in hot and temperate environments has few negative effects other than to influence the perception of dyspnea and average RPE.

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Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions

AW, CM, and FA conception of the work. AW, ZF, JD, AM, and JH collection of data. AW, BB, and YH data analysis. CM, FA, MD, YH, and BB interpretation. AW, CM, and FA drafting article. AW, CM, FA, MD, YH, and BB critical revision of article. AW, CM, FA, MD, YH, BB, ZF, JD, AM, and JH final approval of the version to be published.

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TABLES

Table 1. Participant Characteristics

Variable	*Total (n = 10)*	*Females (n=5)*	*Males (n=5)*	*p-value*	*ES*
Age (years)	27.8 ± 4.8	27.4 ± 6.2	28.2 ± 3.7	0.811	-0.156
Height (cm)	173.1 ± 7.5	167.4 ± 5.9	178.8 ± 3.1	0.005*	-2.421
Weight (kg)	68.6 ± 11.5	59.6 ± 5.9	77.5 ± 8.0	0.004*	-2.553
Resting SBP (mmHg)	113.0 ± 8.0	111 ± 7	115 ± 9.0	0.507	-0.439
Resting DBP (mmHg)	75.4 ± 5.9	75 ± 8	76.0 ± 3.0	0.556[a]	0.240
Resting HR (bpm)	64 ± 9	62 ± 6	67 ± 12	0.431	-0.524
VO_2max ($mlO_2/kg/min$)	49.4 ± 7.4	46.0 ± 7.1	52.8 ± 6.7	0.162	-0.975
Max Power (Watts)	284.0 ± 78.0	226 ± 44	341 ± 59	0.008*	-2.196

ES – Cohen's d effect size, SBP – systolic blood pressure, DBP – diastolic blood pressure, HR – heart rate, cm – centimeter, kg – kilogram, mmHg – millimeters of mercury, bpm – beats per minute, $mlO_2 \cdot kg^{-1} \cdot min^{-1}$ – milliliters of oxygen consumed per kilogram body weight per minute. *Significant p-values (<0.05). [a] Mann-Whitney test was used due to violation of normality.

Table 2. Main and Interaction Effects During HIIE (N = 10)

Variable	*Temperate Environment*		*Hot Environment*		*Environment*	*Mask*	*Interaction*
	No Mask	*Mask*	*No Mask*	*Mask*	*p-value*	*p-value*	*p-value*
Cardiac Output (L/min)	15.7 ± 2.5	15.8 ± 2.6	15.3 ± 2.4	16.5 ± 2.2	0.749	0.311	0.368
Stroke Volume (mL/min)	109.9 ± 19.5	109.2 ± 15.3	104.5 ± 16.0	101.5 ± 36.4	0.117	0.832	0.879
Average Heart Rate (bpm)	144 ± 21	143 ± 20	148 ± 18	149 ± 18	0.003*	0.933	0.344
Peak Heart Rate (bpm)	164 ± 20	164 ± 17	169 ± 16	169 ± 16	0.012*	0.893	0.969
Peak Core Temperature (°C)	37.76 ± 0.28	37.64 ± 0.29	37.65 ± 0.24	37.71 ± 0.38	0.789	0.739	0.158
Δ Core Temperature (°C)	0.77 ± 0.22	0.54 ± 0.26	0.56 ± 0.20	0.64 ± 0.17	0.394	0.157	0.015*
Sweat Rate (mL/hour)	2097 ± 1258	1921 ± 690	2262 ± 1199	1793 ± 1254	0.960	0.073	0.503
Dehydration (%)	-0.76 ± 0.32	-0.77 ± 0.26	-0.81 ± 0.25	-0.67 ± 0.28	0.786	0.18	0.239
Lactate 5 min Post (mmol/L)	4.3 ± 1.7	4.2 ± 2.0	4.9 ± 2.2	4.5 ± 1.9	0.134	0.621	0.553
S_pO_2 (%)	93.5 ± 3.63	93.7 ± 1.5	93.8 ± 2.3	94.0 ± 1.4	0.461	0.877	0.919
MTO Difference (%)	25.6 ± 10	27.5 ± 10.2	32.4 ± 12.4	27.4 ± 13.7	0.290	0.527	0.045*
MTO Active Rest (%)	56.7 ± 10.4	58.8 ± 15.9	55.8 ± 12.7	62.0 ± 11.4	0.375	0.178	0.533
MTO During HIIE (%)	31.0 ± 17.8	31.4 ± 21.5	23.5 ± 18.8	34.7 ± 21.7	0.466	0.186	0.080
Perceived Dyspnea (mm)	14 ± 13	44 ± 17	18 ± 15	58 ± 22	0.018*	<0.001*	0.035*
Peak Thermal Sensation (AU)	5.9 ± 0.9	5.9 ± 0.9	7.0 ± 0.5	7.1 ± 0.6	<0.001*	0.678	0.678
Thermal Sensation (AU)	5.3 ± 0.7	5.4 ± 0.7	6.5 ± 0.4	6.6 ± 0.4	<0.001*	0.487	0.790
Peak RPE (AU)	15 ± 2	15 ± 1	15 ± 2	16 ± 2	0.089	0.297	0.111
Average RPE (AU)	13.3 ± 1.4	13.3 ± 1.2	13.5 ± 1.2	14.3 ± 1.3	0.024*	0.002*	0.014*

Cardiac Output, Stroke Volume, blood oxygen saturation (S_pO_2), Average Borg's rated perceived exertion (RPE), Thermal Sensation, and Average Heart Rate values were averaged over the 20 minutes of each high intensity interval exercise (HIIE) session. Peak Heart Rate, Peak RPE, Peak Thermal Sensation, and Peak Core Temperature were the highest value recorded for each HIIE session. All variable values are reported as Mean ± Standard Deviation, bpm – beats per minute, °C – degrees Celsius, mm – millimeters, L/min – liters per minute, mL/min – milliliters per minute, mmol/L – millimoles per liter, AU – arbitrary unit. MTO Difference – the difference of muscle tissue oxygenation (MTO) calculated from the subtracting the average of the highest MTO proportion values from each HIIE portion from the average smallest proportion values from each active rest portion. Δ Core Temperature was calculated by subtracting the peak core temperature from resting core temperature. MTO Active Rest – the average proportion of muscle tissue oxygenation during active rest. MTO During HIIE – the average proportion of muscle tissue oxygenation during HIIE. Perceived Dyspnea – a 200-millimeter scale with 0 representing no difficulty breathing and 200 mm representing that breathing was very difficult was averaged over three time points (before exercise, 10 minutes into exercise, and post exercise). Thermal Sensation – a scale from 0 (very cold) to 8 (very hot). Borg's rated perceived exertion – a scale from 6 (no exertion) to 20 (maximal exertion). *Significant p-values (<0.05).

Table 3. Partial η^2 for Main and Interaction Effects (N=10)

Variable	*Environmental Partial η^2*	*Mask Partial η^2*	*Interaction Partial η^2*
Cardiac Output (L/min)	0.012	0.114	0.091
Stroke Volume (mL/min)	0.192	0.005	0.003
Average Heart Rate (bpm)	0.631	$8.2 \cdot 10^{-4}$	0.100
Peak Heart Rate (bpm)	0.521	0.002	$1.8 \cdot 10^{-4}$
Peak Core Temperature (°C)	0.008	0.013	0.209
Δ Core Temperature (°C)	0.082	0.210	0.501
Sweat Rate (mL/hour)	$2.96 \cdot 10^{-4}$	0.313	0.051
Dehydration (%)	0.009	0.190	0.150
Lactate 5 min Post (mmol/L)	0.231	0.028	0.040
S_pO_2 (%)	0.062	0.003	0.001
MTO Difference (%)	0.123	0.046	0.375
MTO Active Rest (%)	0.088	0.192	0.045
MTO During HIIE (%)	0.060	0.186	0.302
Perceived Dyspnea (mm)	0.524	0.808	0.447
Peak Thermal Sensation (AU)	0.767	0.020	0.020
Thermal Sensation (AU)	0.829	0.055	0.008
Peak RPE (AU)	0.288	0.120	0.257
Average RPE (AU)	0.449	0.664	0.505
$PetCO_2$ (mmHg)	0.132	$8.93 \cdot 10^{-4}$	0.015
VE STPD (L/min)	0.055	0.022	0.094
VCO_2 STPD (L/min)	0.100	0.025	0.057
VO_2 (mlO_2/kg/min)	0.137	0.044	0.058

Cardiac Output, Stroke Volume, blood oxygen saturation (S_pO_2), Average Borg's rated perceived exertion (RPE), Thermal Sensation, and Average Heart Rate values were averaged over the 20 minutes of each high intensity interval exercise (HIIE) session. Peak Heart Rate, Peak RPE, Peak Thermal Sensation, and Peak Core Temperature were the highest value recorded for each HIIE session. All variable values are reported as Mean ± Standard Deviation, bpm – beats per minute, °C – degrees Celsius, mm – millimeters, L/min – liters per minute, mL/min – milliliters per minute, mmol/L – millimoles per liter, AU – arbitrary unit. MTO Difference – the difference of muscle tissue oxygenation (MTO) calculated from the subtracting the average of the highest MTO proportion values from each HIIE portion from the average smallest proportion values from each active rest portion. Δ Core Temperature was calculated by subtracting the peak core temperature from resting core temperature. MTO Active Rest – the average proportion of muscle tissue oxygenation during active rest. MTO During HIIE – the average proportion of muscle tissue oxygenation during HIIE. Perceived Dyspnea – a 200-millimeter scale with 0 representing no difficulty breathing and 200 mm representing that breathing was very difficult was averaged over three time points (before exercise, 10 minutes into exercise, and post exercise). Thermal Sensation – a scale from 0 (very cold) to 8 (very hot). Borg's rated perceived exertion – a scale from 6 (no exertion) to 20 (maximal exertion). End Tidal Carbon Dioxide ($PetCO_2$), Ventilation Standard Temperature Pressure Dry (VE STPD), Carbon Dioxide Production Standard Temperature Pressure Dry (VCO_2 STPD), Oxygen Consumption (VO_2), and the ratio of VE to Carbon Dioxide Production Body Temperature Pressure Saturated (VE/VCO_2 BTPS) were averaged over the 5 minutes of passive rest following each high intensity interval exercise (HIIE) session.

FIGURE

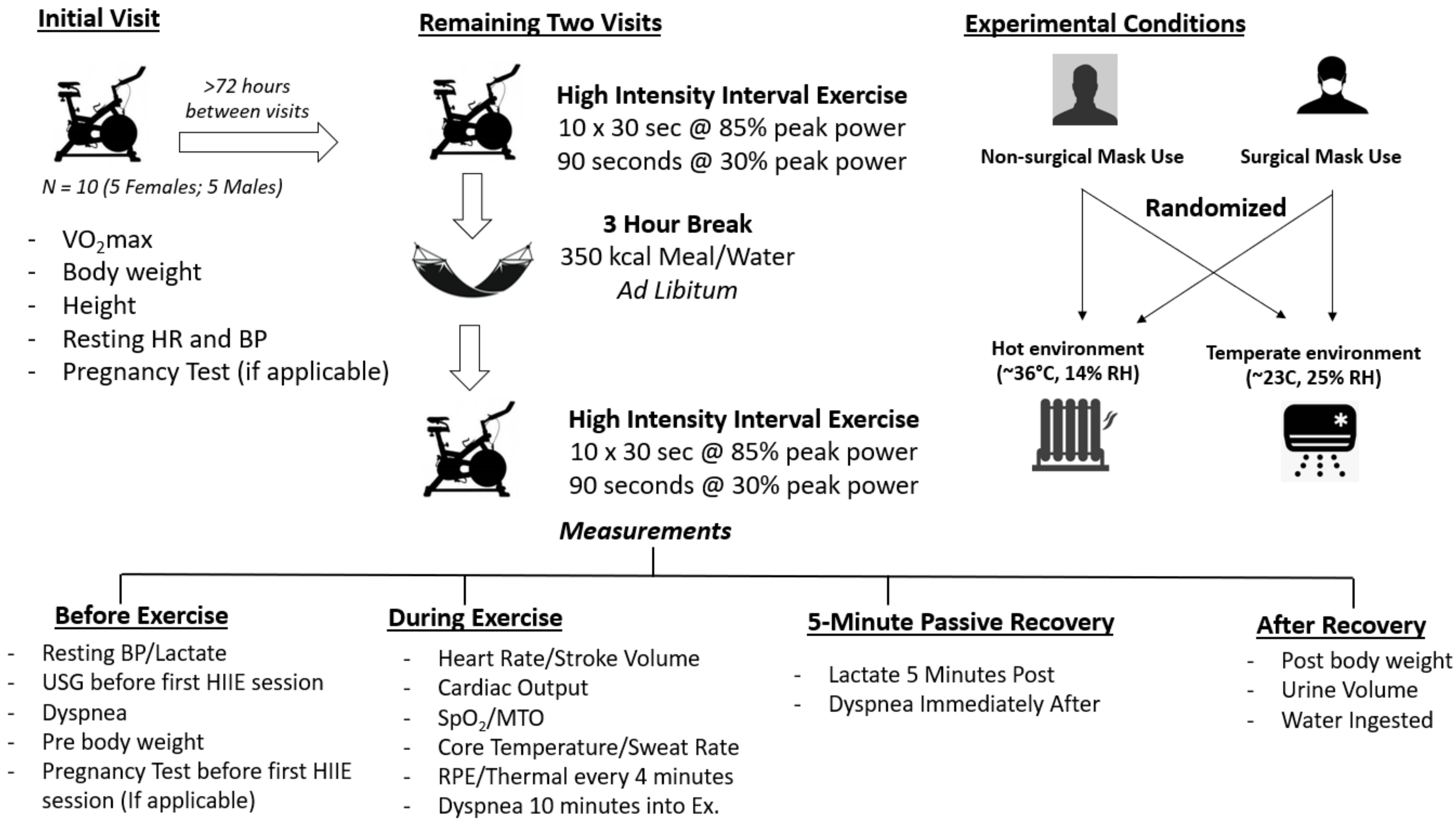

Figure 1. Study Design

CHAPTER 4

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

To our knowledge this was the first study to investigate the effects of wearing a surgical mask during acute HIIE across hot and temperate environments. In short, this study presents data that wearing a surgical mask has minimal impact on physiological responses during HIIE on a bike. However, surgical mask use during HIIE does seem to increase the perception of dyspnea, and RPE averaged over the course of exercise. Chapter 2 provides a background of literature on the acute effect of wearing N95, surgical-, and cloth-masks during a wide array of different exercise intensities and modalities. This paper provides evidence that during exercise the N95, surgical- and cloth-mask use has minimal impact on physiological responses. However, while the N95 mask did reduce exercise performance (2,4), pooling results from multiple studies revealed no effect on exercise performance (8). Chapter 3 provides experimental data that there is minimal impact on physiological responses during HIIE while wearing a surgical mask use in different environments. Surgical mask use increased perceived dyspnea and overall RPE, with the greatest increase occurring in hot environments.

Conclusions

Following the study of surgical mask use compared to a no-mask control in hot and temperate environments in healthy participants performing 10 bouts of 30 second of high intensity exercise with 90 seconds of intermittent active rest the subsequent conclusions were found:

- There were no differences in cardiovascular, thermoregulatory, or metabolic responses comparing surgical mask use to a no-mask control condition.
- Surgical mask use increased both perceived dyspnea and average RPE compared to a no-mask control.
- Hot environments and surgical mask use provided a synergistic effect that increased perceived dyspnea and average RPE.

- Hot environments increased peak and average heart rate over the course of HIIE cycling exercise compared to HR responses in temperate environments.
- Hot environments increased both perceived average and peak thermal sensation compared to thermal sensations in temperate environments.
- Hot environments increased perceived dyspnea and average RPE compared to perceptual responses in temperate environments.

Recommendations

Research is still emerging on the acute effects of mask use during exercise (1–8). More research on the use of various types of masks is needed to clarify findings across the array of different exercise types, intensities, durations, modalities, and frequency of exercise sessions. In addition, more training studies are needed to investigate chronic mask use on exercise performance and how a change in perceptual responses to exercise may influence training over time, including variables such as adherence. Finally, research is needed to investigate how perceptual responses change with repeated mask use. This is useful because if a habituation effect is present, recreational exercisers, individuals working in demanding occupations, and athletes may be more willing to wear a mask during exercise.

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APPENDICES

Appendix A

Informed Consent

Facemask use during High Intensity Interval Exercise in temperate and hot environments

Consent to Participate in Research
11/02/20

Purpose of the research: You are being asked to participate in a research project that is being done by Dr. Christine Mermier and Andrew Wells, from the Health, Exercise, and Sport Science (HESS) department and their associates. The purpose of this research is to compare changes in heart function and perceived difficulty during high intensity interval exercise (HIIE) while wearing a mask in both a normal room temperature and a hot environment. You are being asked to join because you are a regular exerciser (including high intensity exercise), English speaking, 18 years or older, have no serious medical conditions, do not smoke, or have quit smoking for at least 6 months, and do not use an inhaler to control for exercise induced asthma. You should not have symptoms of COVID-19 nor have been exposed to anyone who has tested positive for the disease for at least two weeks.

This consent form contains important information about this project and what to expect if you decide to participate. Please consider the information carefully. Feel free to ask questions before making your decision whether or not to participate. Your participation in this research is voluntary.

Key information for you to consider:

- After reading the consent form and discussing the details with a research team member, you will be asked to sign this consent form only if you decide to take part in the study.
- Three visits will take place at the Exercise Physiology Lab in Johnson Center (Room #B143) where you will be tested for your aerobic fitness and perform four high intensity interval exercise sessions.
- The first visit will take about a 1.5 hour and will include paperwork and the assessment of your aerobic fitness.
- The second and third visits will take about 4 hours. During each visit you will perform two high intensity interval exercise sessions with a long rest between sessions. Two of the four exercise bouts will be in a hot room (95-99°F)
- Risks include discomfort, stress, nausea, dizziness, lightheadedness, fainting, muscle soreness, and fatigue from exercise as well as an increased risk of exposure to COVID-19.
- Time commitment for participation in this project will take a total of 10 of hours over a period of three visits.

What you will do in the project:

After reading the consent form and discussing the details with a research team member over the phone, email, or Zoom, if you decide to participate, you will be asked to fill out a health history questionnaire and a University of New Mexico COVID-19 Symptoms Screening Checklist that will be sent to you via email. You will send them back to the research team via email the day before your first visit. You will sign the consent form during your first visit. If you never come to Visit 1 or do not sign the informed consent, your completed health history questionnaire and COVID-19 Symptoms Screening Checklist will be deleted permanently within 4 weeks of receipt.

For each visit, a research team member will call you and inquire whether you have any COVID-19 symptoms using the COVID-19 symptoms checklist for the final two visits. You will also be asked if you have been exposed to anyone with suspected or known COVID-19. You will be approved to come to the laboratory if you have no signs and symptoms of COVID-19, haven't traveled outside the state, and if you have not been exposed to anyone who has COVID-19 symptoms or has tested positive for the virus within the past 14 days. Before entering the lab, a no-touch forehead thermometer will be used to measure your body temperature. If your temperature is over 37.5 °C (99.5 °Fahrenheit) you will not be allowed to continue with the visit and will be provided information on COVID-19 testing. Following a negative COVID-19 test you will be able to continue the study if you wish to do so and your visit will be rescheduled. The information you provide from your COVID-19 test will not be kept on file. During each visit, all research team members will wear a N95 mask, a face shield, and a lab coat. You will be provided and asked to wear a surgical mask at all times with the exception of two of the HIIE sessions and for five minutes following each HIIE session. You have the right to withdraw from the study at any time and are not required to provide a reason. If you withdraw, all the data gathered from your visits will be promptly destroyed.

(Female participants only) Before beginning testing on each visit, if you are of childbearing potential, you will be asked to complete a urine pregnancy test before performing exercise for each visit. You will have access to a private bathroom. After a research team member reads the test result, if the test is negative you will be able to continue with the research study. If the test is positive, you will be thanked for your time, withdrawn from the study, and will be advised to see your health care provider. Results will be to you provided privately.

<u>Visit 1</u>

You will report to the Exercise Physiology Lab in the University of New Mexico in Johnson Center after being asked to: (a) avoid eating a filling meal within 1 hour, (b) avoid having caffeine for 4 hours, (c) avoid performing vigorous exercise for 24 hours before your first visit, and (d) wear exercise attire (women will be required to wear a sports bra underneath a workout shirt). Upon arrival, your temperature will be measured with a no-touch thermometer. If is below 37.5°C (99.5° Fahrenheit), you will be able to continue. You will be asked to complete the consent form, and a state trait anxiety index questionnaire.

- *Resting Measurements*

If needed, a private room with an interior door lock for additional privacy will be provided to change into workout clothes. After, your height and weight will be measured in workout clothes with empty pockets and your shoes removed. You will then be asked to rest in a seated position for five minutes followed by resting heart rate and blood pressure measurements. Next you will be asked to fill out an anxiety questionnaire. Before the maximal effort exercise test on a stationary bike, you will be provided a heart rate monitor strap to wear around your chest. The resting measurements and questionnaire should take between 10 and 15 minutes to complete.

- Maximal effort exercise test (aerobic fitness test)

*All equipment will be sanitized before and after this test. All research team members administering this test will wear an N95 mask, lab coat, and face shield at all times.

Up until the time you are hooked up to our equipment, you are required to wear a surgical facemask at all times. Before the test you will be permitted to temporarily adjust your surgical facemask to drink water. You will be asked to perform a 5-minute warm-up on a stationary bike at a self-selected difficulty. After completion of the warm-up you will be fitted with head gear where you will breathe through a device with a mouthpiece (like a snorkel mask) and a nose clip at rest for approximately 1 minute. At the start of this test, you will be asked to achieve and then maintain a pedaling rate between 60 and 100 revolutions per minute throughout the test. The pedaling rate will be displayed on the stationary bike. As the exercise continues, it will become more difficult until you cannot maintain this pedaling rate and the test will end. The exercise portion of the test typically takes 8-12 minutes. As this is a maximal effort test, you will be instructed to try to exercise as hard as you can. Following this test, we will remove the mask and nose clip, you may drink water before you put your surgical facemask back on. You will stay on the bike for a 5 to 10-minute cool-down at a self-selected difficulty. This maximal effort exercise test will take between 18 and 30 minutes to complete accounting for set-up and any questions you may have before the test.

*As this study requires high intensity exercise sessions, if you are categorized below the 50^{th} percentile for aerobic fitness for your age and sex based on this test, you will be thanked for your time and withdrawn from the study. We will give you your results of the maximal test and your results will not be kept on file.

- *Number of sessions and conditions*

After the first visit, to complete the study you will perform high intensity interval exercise (HIIE) four times, two times each visit. One HIIE session will be in a room temperature environment (68-72°F) wearing a disposable surgical facemask provided to you, one HIIE session in a room temperature environment without a surgical facemask, one HIIE session in a hot temperature environment (95-99°F) with a disposable surgical facemask provided to you, and one HIIE session in a hot temperature environment without a surgical facemask. The order of these high intensity interval exercise sessions will be randomly selected, meaning the order will be chosen based on chance, like flipping a coin.

Visits 2 and 3

Prior to arrival to the Johnson Center Exercise Physiology Lab you will be instructed to avoid a filling meal 1 hour and vigorous exercise 24 hours before the HIIE sessions. You will also be reminded to bring workout attire (females will be required to wear a sports bra underneath a workout shirt). Before each HIIE session, you will be asked to take a 20 question anxiety questionnaire. The two visits will be separated by at least 72 hours. During each visit you will have a three-hour rest period between the two HIIE sessions where you will be provided with water and a small 350 calorie meal*. You may remain in the lab for the entire duration of your visit and will be provided a room for you to read or work on your computer. Your mask will stay on the entire rest period except when eating or drinking. However, you are free to leave and return to the lab during the three-hour rest period. If you decide to leave, you will be asked to abstain from any exercise and food and beverage other than water outside the lab. Each of the HIIE sessions will take 20 minutes to perform.

*Please alert the research team members to any food allergies.

- *Hydration measurements and core temperature measurement setup*

Before performing any exercise, if needed, a private room will be available for you to change into workout clothing for all visits. After, you will be asked to use the private restroom to provide a small urine sample to test to see if you are hydrated. If you are dehydrated, you will be provided with 500 ml of water to consume. After consuming the 500 ml of water you will be asked to rest for 30 minutes and provide another urine sample to test to see if you are hydrated. If you are still dehydrated after the second urine sample, you will be provided with another 500 ml of water to consume asked to rest for another 30 minutes followed by a third urine sample to test for hydration. If after the third urine sample you are still dehydrated, you will be asked to reschedule and instructed to drink plenty of water the day before the rescheduled visit. During this portion of your visit you will be required to wear a surgical facemask at all times with the exception to drink water. Next, in a locking private room you will be provided lubricant gel to insert a rectal thermistor approximately 10 cm into the rectum. This rectal thermistor will remain in place during the exercise to continuously measure your body temperature. After the first high intensity interval exercise bout, you will be able to remove this thermistor in a private room. You will be provided gloves, disinfectant (70% alcohol) and paper towels to disinfect the thermistor and then asked to place it in a plastic bag. After the three-hour rest period, you will be asked to re-insert the thermistor before the next HIIE session. This portion of the visit will take a minimum of 15 minutes and a maximum of 80 minutes to complete depending on hydration status.

After the second of the two HIIE sessions you will be asked to remove, disinfect, and place the thermometer in a plastic bag identified with your study participant number to be stored for the next visit. If you ask, or if the thermistor is damaged, we will provide you with a new thermistor. After your final HIIE session on your last visit, you will be asked to place the thermistor in the plastic bag and discard it.

- *Cardiovascular measurements*

In a private room a research team member will ask you to remove your shirt in order to apply electrodes to several spots on the upper body. If you are male, a research team may provide you with a disposable razor and may ask you to shave hair from your chest at the site of electrode placement before using an abrading gel and alcohol pad to clean the sites for electrode placement. If you are female, a research team member may ask you to adjust your sports bra to use an abrading gel and alcohol pad to clean the sites for electrode placement. Two electrodes will be placed on the left side of the neck, two on the back, one near the left armpit, and one on the chest. You may put your shirt back on after being hooked up to the equipment. After all the electrodes are placed and connected, you will be asked to sit and rest for 5-minutes. Next your resting blood pressure will be measured, and you will be fitted with a small finger cuff that will inflate with a small amount of pressure to continuously measure your blood pressure, and a finger clamp that will measure your blood oxygen saturation (how much oxygen in your blood) will be attached. Finally, on your dominant leg you will be fitted with a near infrared spectrometry device. This device uses infra-red light to measure your blood oxygen saturation during the HIIE sessions. This setup should take about 30 minutes to complete.

*You will be able to request a male or female research team member to apply electrodes.

- *Rated perceived exertion, thermal sensation, and dyspnea scale measurements*

Before each HIIE session, you will also be instructed or reminded on how to use a rating of perceived exertion (RPE) scale and asked to report the difficulty of exercise rated from 6 (resting) to 20 (maximal effort). You will be asked to report your RPE (exercise difficulty) after every 4 minutes of HIIE. Additionally, you will also be asked to rate how cold or hot you are on a scale of 1 (very cold) to 7 (very hot) after every 4 minutes of the HIIE session. Finally, before, mid-way through, and immediately after the HIIE you will be asked to place a mark on a line that indicates how difficult it is for you to breathe.

- *Sweat rate estimation*

Before and after each HIIE session, before putting in the thermistor and after taking out the thermistor you will be asked to measure your nude body weight (in the locking private room). After each HIIE session, you will be asked to dry off as much as possible and measure another nude body weight in the private room. If you need to urinate before the second body weight measurement, a research team member will provide you with a container and asked to empty your bladder into the container in the restroom so we may measure the urine volume. These measurements should take about 15 minutes to complete.

- *Blood Lactate and exercise gas exchange recovery measurements*

Before, immediately after, and 5-minutes after each high intensity exercise session, your ear lobe will be cleaned using an alcohol wipe. Then a sterile lancet will be used to poke your ear lobe so a small drop of blood for lactate can be measured. Additionally, after exercising (at rest) you will be asked to breathe into a mouthpiece with a nose clip (like you did for the maximal test) for 5-minutes to measure gas-exchange during exercise recovery.

- *High Intensity Interval Exercise Sessions*

*All equipment will be sanitized before and after high intensity interval exercise session. All research team members administering this test will wear an N95 mask, lab coat, and face shield at all times.

Before exercising you will perform a 5-minute warm-up on the stationary bike. Next you will be asked to perform 10 separate bouts of HIIE. Each high intensity bout will last 30 seconds with 90 seconds of light intensity exercise in between bouts. The high intensity bout will be at 85% of your maximum power output generated during your VO_2max test. The light intensity exercise in between high intensity bouts will be 30% of your maximum power output generated by your VO_2max test. Following the ten bouts, you will remove your surgical facemask (if applicable) and will breathe into a mouthpiece with a nose clip to measure gas exchange for five minutes. After removal of the mouthpiece and nose clip you will be required to immediately put your surgical facemask back on. Including warm-up and gas exchange measurements, each HIIE session will take a total of 30 minutes. You will be able to remove or adjust your surgical facemask to drink water during the HIIE session. After taking a drink of water you will put your surgical facemask back on or adjust your surgical facemask to cover both your nose and mouth.

You then will go into a room to consume the provided meal and water, and may remain there until the second portion of the test, or you may leave and come back three hours after the end of the first session of exercise. We ask you to keep on the electrodes (unless they are coming off) to use for the next session. We will remove them at the end of the second exercise trial

Risks:

The risks associated with high intensity exercise both in the heat and in regular room temperature may include discomfort, stress, nausea, dizziness, lightheadedness, fainting, muscle soreness, muscle injury, and fatigue. You will be allowed to terminate the high intensity exercise at any point. You will perform a 5-minute warm-up at a self-selected intensity prior to exercise. If your body temperature gets too hot (at a pre-determined temperature) during exercise in the heat, you will be removed immediately from the heat and will be given wet towels to drape on your body and will sit in front of a fan until your body temperature drops. You will not resume the exercise trial.

The risks associated with blood lactate measurements include mild discomfort and soreness. You will be allowed to opt out or discontinue blood lactate measurements at any time during the study.

There is also a risk of embarrassment with use of a rectal thermometer to measure your core temperature. One end of the thermistor will be exposed outside your clothing to hook up to a thermometer for core body temperature measurement.

There is a risk of exposure and infection of COVID-19 with the participation in this study. The risk of exposure or infection of COVID-19 can occur during your visit to campus and/or during traveling to and from campus. In order to minimize the risk during your visit, the room and all equipment will be disinfected before and after each high intensity interval exercise session using whole-room disinfectant equipment (Clorox® Total 360®). The research team members will wear N95 masks, lab coats, and face shields at all times during your visit. They will keep at least 6 feet away from except when necessary to place equipment or take measurements. They will complete a COVID-19 screening before they are allowed to work with you. You will also be asked to wear a surgical mask at all times during each visit with the with the exception of two of the high intensity interval exercise sessions. Hand sanitizer will be available at all times and used before any physical contact with you or the equipment used for the study.

Benefits:

The only benefit to you is that you will receive results of your aerobic fitness test. This information can be used to develop or adjust your workout program. Societal benefit from this study is that it will provide information for individual exercisers and to inform policy on performing high intensity exercise in both normal room temperature (68-72°F) and hot (95-99°F) environments while wearing a surgical facemask.

Confidentiality of your information:

The loss of confidentiality or privacy is a risk present with participation in research studies. Loss of privacy will be minimized as only you will have access to a restroom or a locker room offering a private environment. Privacy curtains are also available to section off testing rooms to maintain privacy upon your request. Further, the Laboratory has multiple rooms equipped with doors that can be closed for privacy during the consent process, state trait anxiety questionnaire screening, and all exercise testing. You will be given a participant number that will be used on all paperwork for the study to ensure confidentiality of your data. Only approved research team members will have access to your information through a password protected computer, with hard copies of any data sheets and questionnaires stored in a locked file cabinet. We will take measures to protect the security of all your personal information, but we cannot guarantee confidentiality of your data. The University of New Mexico Institutional Review Board (IRB) that oversees human subject research may be permitted to access your records.

*You should understand that the researcher is not prevented from taking steps, including reporting to authorities, to prevent serious harm of yourself or others.

Research related injury:

If you are injured or become sick as a result of this study, any emergency treatment will be at your cost. UNM makes no commitment to provide free medical care or money for injuries to participants in this study.

It is important for you to tell the Principal Investigator Dr. Christine Mermier immediately if you have been injured or become sick because of taking part in this study. She may be reached Monday-Friday 8:00 a.m. – 5:00 p.m. at (505) 277-2658, or anytime via email at cmermier@unm.edu. If you have any questions about these issues, or believe that you have been treated carelessly in the study, please contact the Office of the IRB at (505) 277-2644 for more information.

Research involving biospecimens:

The blood taken for measurement of lactate will not be used for any genetic sequencing.

Future use of biospecimens:

Your urine used to assess hydration status will be disposed of promptly after measurement on the same day of your trial.

Use of your information for future research:

All identifiable information (e.g., your name and contact information) will be removed from the information or samples collected in this project. After we remove all identifiers, the information or samples may be used for future research or shared with other researchers without your additional informed consent.

Payment: You will not be compensated for your participation in this study.

Right to withdraw from the research:

Your participation in this study is completely voluntary. You have the right to choose not to participate or to withdraw your participation at any point in this study without penalty. If you are a student at UNM, your standing will not be impacted by withdrawing from the study. When withdrawn from the study, you will be marked as withdrawn and will no longer be contacted in relation to this study. Any data collected will be excluded from analysis and will be destroyed. In addition, the research team will stop your participation in the study if you are not willing to wear a mask when required or do not follow other COVID-safe practices.

If you have any questions, concerns, or complaints about the research study, or contract COVID-19 (including showing symptoms or testing positive) within 14 days of a visit to the lab please contact the principal investigator **immediately**: Christine Mermier, Ph.D., Department of Health, Exercise & Sport Sciences, 1 University of New Mexico, Albuquerque, NM, 87131. She may be reached Monday-Friday 8:00 a.m. – 5:00 p.m. at (505) 277-2658, or anytime via email at cmermier@unm.edu.

If you would like to speak with someone other than the research team to obtain information, offer input, or if you have questions regarding your rights as a research participant, please contact the IRB. The IRB is a group of people from UNM and the community who provide independent oversight of safety and ethical issues related to research involving people: UNM Office of the IRB, (505) 277-2644, irbmaincampus@unm.edu. Website: http://irb.unm.edu/

CONSENT

You are making a decision whether to participate in this research. Your signature below indicates that you have read this form (or the form was read to you) and that all questions have been answered to your satisfaction. By signing this consent form, you are not waiving any of your legal rights as a research participant. An electronic copy of this consent form will be provided to you.

I agree to participate in this research.

Name of Adult Participant	Signature of Adult Participant	Date

Researcher Signature (to be completed at time of informed consent)

I have explained the research to the participant and answered all of their questions. I believe that they understand the information described in this consent form and freely consents to participate.

Name of Research Team Member	Signature of Research Team Member	Date

Appendix B

HEALTH & PHYSICAL ACTIVITY QUESTIONNAIRE

Family history questions are included because certain conditions of your first degree relatives can incur risk to you during maximal exercise.

Subject # (researcher will fill in) ___________ Date _____/_____/_____

Age ____ yrs Sex _____

Emergency contact (**first** name, phone #) ____

♦♦

INITIAL SCREENING

Do you engage in **at least** 150 minutes of exercise per week? ____Yes ____No

Do you have a ruptured ear drum? ____Yes ____No

Are you claustrophobic? ____Yes ____No

Are you anemic? ____Yes ____No

Are you pregnant or planning on getting pregnant? ____Yes ____No ____N/A

How long have you lived in the Albuquerque area? _________ months

♦♦

HEALTH HISTORY

Physical injuries:

____

Current Limitations

____

Have you ever had any of the following? Please check all that apply.

High blood pressure _____ High Triglycerides _____ Irritable Bowl Syndrome _____

Asthma	______	High cholesterol	______	Acute Mountain Sickness	______
Diabetes (specify type)	______	Liver disease	______	Crohn's Disease	______
Emphysema	______	Kidney disease	______	Celiac Disease	______
Stroke	______	Heat illness	______		

Have you ever had any of the following cardiovascular problems? Please check all that apply.

Heart attack	______	Heart surgery	______	Valve problems	______
Chest pain or pressure	______	Swollen ankles	______	Dizziness	______
Arrhythmias/Palpitations	______	Heart murmur	______	Shortness of breath	______
		Congestive heart failure			______
Pacemaker	______				

Do immediate blood relatives have any of the conditions listed above? _____Yes _____No

If yes, list the problem, and family member age at diagnosis ____

____

____

Do you currently have any other medical condition not listed? _____Yes _____No

If yes please explain ____

____

____

Are you taking any medications, vitamins or dietary supplements now? _____Yes _____No

If yes, list the medication of supplement ____

____

____

Are you allergic to latex? ____Yes ____No

Have you ever experienced any adverse effects during or after exercise (fainting, vomiting, shock, palpitations, hyperventilation)? ____Yes ____No

If yes, please elaborate ____

____

____

♦♦

LIFESTYLE FACTORS

Do you now or have you ever used tobacco including e-cigs, vape? ____Yes ____No

If yes: type ________________ How long did you use these products? ______ years

Quantity ____/day Months/Years (circle one) since quitting _______________

♦♦

EXERCISE HISTORY

Endurance exercise

Days per week (circle one): 0 1-2 3-5 6-7

Minutes per exercise session (circle one): <30 30-60 60-240 240-360 >360

Resistance exercise

Times per week (circle one): 0 1-2 3-5 6-7

Minutes per day (circle one): 30-60 60-240 240-360 >360

Appendix C

Flyer

Research Study:

Facemask use in High-Intensity Interval Exercise in temperate and hot environments

If you are interested in being a participant, contact Andrew Wells via email at anwells@unm.edu.

We are looking for volunteers age 18 or over that:

- *Exercise on a regular basis*
- *Do not smoke or have any serious medical conditions*
- *Do not use an inhaler for exercise induced asthma*
- *Have not had symptoms of, or been exposed to COVID-19*

➢ This study requires 10 hrs. of your time over 3 visits

➢ Requires you to perform high intensity exercise in hot and room temperature environments- both with and without wearing a face mask

Appendix D

Data Collection Sheets

Data Collection Sheet

First Visit:

Has the COVID-19 clearance checklist been filled out and filed for the visit:

Yes No

On arrival was the no-touch forehead thermometer reading below 37.5°C (99.5°F):

Yes No

If No, provide the participant with COVID-19 testing information and discuss a possible reschedule.

If Yes, provide the participant with a surgical face mask to wear during the visit and begin consenting process.

Consent form and Questionnaire checklist:

Forms	Completed/Filed in Participant Folder
Consent Form	
Health History/Physical Activity Questionnaire	
State Trait Anxiety Index Questionnaire	

If Female, has a urine pregnancy test been completed: Yes No

Resting Hemodynamic, Height, and Weight Measurements:

Resting Heart Rate: beats/min Resting Blood Pressure: mmHg

Height: cm Weight: kg

Participant Identification number: __________

VO_2max Test:

Heart Rate Monitor Provided: Yes No

Time (min)	Speed/Grade	RPE	HR (bpm)	VO_2 (ml/kg/min)
Rest (1 min)	[redacted]			
1	[redacted]			
2	[redacted]			
3	[redacted]			
4	[redacted]			
5	[redacted]			
6	[redacted]			
7	[redacted]			
8	[redacted]			
9	[redacted]			
10	[redacted]			
11	[redacted]			
12	[redacted]			
13	[redacted]			
14	[redacted]			
15	[redacted]			
16	[redacted]			
Maximum Values (Single Breath)				

Save Data File as Single Breath for 11-Breath Averaging: Yes No

Peak Power Output for VO_2max: ________________________

Second Visit:

Has the COVID-19 clearance checklist been filled out and filed for the visit:

Yes No

On arrival was the no-touch forehead thermometer reading below 37.5°C (99.5°F):

Yes No

If No, provide the participant with COVID-19 testing information and discuss a possible reschedule.

If Yes, provide the participant with a surgical face mask to wear during the visit.

Hydration Measurement:

1st Urine Specific Gravity Assessment: _______________

Is urine specific gravity below 1.020 g/cc?

Yes No

If No, provide participant with 500 ml water bottle and re-assess after 30 minutes.

2nd Urine Specific Gravity Assessment: _______________

Is urine specific gravity below 1.020 g/cc?

Yes No N/A

If No, provide participant with 500 ml water bottle and re-assess after 30 minutes.

3rd Urine Specific Gravity Assessment: _______________

Is urine specific gravity below 1.020 g/cc?

Yes No N/A

If No, reschedule participant with instructions to drink plenty of water the day before the next visit.

Equipment Checklist:

Thermistor:	Yes	No	Metabolic Cart:	Yes	No
PhysioFlow:	Yes	No	Nose clip:	Yes	No
Caretaker:	Yes	No	Blood Lactate/Strips:	Yes	No
RPE Scale:	Yes	No	Moxy O2 monitor	Yes	No

High intensity – Peak Power Output x 0.85

Nude Body Weight Before: _________kg

Participant Identification number: __________

Low intensity – Peak Power Output x 0.30

Nude Body Weight After: __________kg

Power Output (Watts) during high intensity: _____________

Urine Volume: __________mL

Power Output (Watts) during low intensity: _____________

Water Ingested: _________mL

Blood Lactate Before: ____________mmol/L

Condition: No Mask Hot Mask Hot No Mask Room Temp Mask Room Temp

Calibrate/Mark Starting Point for PhysioFlow/Caretaker/NIRS at start of HIIE

1st HIIE Data Environmental Data Collection Sheet (30 second HI bout followed by 1:30 LI recovery):

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Bulb Temp °C	Wet Bulb Temp °C
Rest					
Warm-up (5 min)					
1:30 (LI)					
2:00 (HI)					
3:30 (LI)					
4:00 (HI)					
5:30 (LI)					
6:00 (HI)					
7:30 (LI)					
8:00 (HI)					
9:30 (LI)					
10:00 (HI)					
11:30 (LI)					
12:00 (HI)					

Participant Identification number: __________

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Blub Temp °C	Wet Bulb Temp °C
12:30 (LI)					
14:00 (HI)					
15:30 (HI)					
16:00 (HI)					
17:30 (LI)					
18:00 (HI)					
19:30 (LI)					
20:00 (HI)					

Blood Lactate Immediately After: ______________mmol/L

Exercise Recovery:

Time (min)	Ventilation (L/min)	VO_2 (ml/kg/min)	F_ECO_2%	F_EO_2%
1				
2				
3				
4				
5				

Blood Lactate (End of minute 5) Recovery: ________________ mmol/L

Exercise End Time: _______________min

Participant Identification number: __________

2nd HIIE session Dyspnea Scales – Visit 2

1st Rest	2nd 10 Minute	3rd Immediately After
No Difficulty	No Difficulty	No Difficulty
Most Difficult	Most Difficult	Most Difficult

Participant Identification number: __________

Provide Participant with water and a 350-calorie meal
Three Hour Break

Exercise Start Time: __________________

Core Temp/Electrodes Checked: Yes No

Condition: No Mask Hot Mask Hot No Mask Room Temp Mask Room Temp

High intensity – Peak Power Output x 0.85

Low intensity – Peak Power Output x 0.30

Power Output (Watts) during high intensity: _____________

Power Output (Watts) during low intensity: _____________

Nude Body Weight Before: _________

Nude Body Weight Before: _________

Urine Volume: __________

Water Ingested: _________

2nd HIIE Data Collection Sheet (30 second HI bout followed by 1:30 LI recovery):

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Blub Temp °C	Wet Bulb Temp °C
Rest					
Warm-up (5 min)					
1:30 (LI)					
2:00 (HI)					
3:30 (LI)					
4:00 (HI)					
5:30 (LI)					
6:00 (HI)					
7:30 (LI)					
8:00 (HI)					
9:30 (LI)					
10:00 (HI)					
11:30 (LI)					
12:00 (HI)					

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Bulb Temp °C	Wet Bulb Temp °C
12:30 (LI)					
14:00 (HI)					
15:30 (HI)					
16:00 (HI)					
17:30 (LI)					
18:00 (HI)					
19:30 (LI)					
20:00 (HI)					

Blood Lactate Immediately After: ______________

Exercise Recovery:

Time (min)	Ventilation (L/min)	VO_2 (ml/kg/min)	F_ECO_2%	F_EO_2%
1				
2				
3				
4				
5				

Blood Lactate (End of minute 5) Recovery: ________________mmol/L

Exercise End Time: _______________min

Participant Identification number: __________

2nd HIIE session Dyspnea Scales – Visit 2

1st Rest	2nd 10 Minute	3rd Immediately After
No Difficulty	No Difficulty	No Difficulty
Most Difficult	Most Difficult	Most Difficult

Participant Identification number: __________

Third Visit:

Has the COVID-19 clearance checklist been filled out and filed for the visit:

Yes No

On arrival was the no-touch forehead thermometer reading below 37.5°C (99.5°F):

Yes No

If No, provide the participant with COVID-19 testing information and discuss a possible reschedule.

If Yes, provide the participant with a surgical face mask to wear during the visit.

Hydration Measurement:

1st Urine Specific Gravity Assessment: _______________

Is urine specific gravity below 1.020 g/cc?

Yes No

If No, provide participant with 500 ml water bottle and re-assess after 30 minutes.

2nd Urine Specific Gravity Assessment: _______________

Is urine specific gravity below 1.020 g/cc?

Yes No N/A

If No, provide participant with 500 ml water bottle and re-assess after 30 minutes.

3rd Urine Specific Gravity Assessment: _______________

Is urine specific gravity below 1.020 g/cc?

Yes No N/A

If No, reschedule participant with instructions to drink plenty of water the day before the next visit.

Equipment Checklist:

Core Temp:	Yes	No	Blood Lactate/Strips:	Yes	No
PhysioFlow:	Yes	No			
Caretaker:	Yes	No			
Metabolic Cart:	Yes	No			
Nose clip:	Yes	No			

Participant Identification number: __________

RPE Scale: Yes No

High intensity – Peak Power Output x 0.85

Nude Body Weight Before: _________

Low intensity – Peak Power Output x 0.30

Nude Body Weight Before: _________

Power Output (Watts) during high intensity: _____________

Urine Volume: __________

Power Output (Watts) during low intensity: ______________

Water Ingested: _________

Condition: No Mask Hot Mask Hot No Mask Room Temp Mask Room Temp

Calibrate/Mark Starting Point for PhysioFlow/Caretaker/NIRS at start of HIIE

1st HIIE Data Collection Sheet (30 second HI bout followed by 1:30 LI recovery):

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Blub Temp °C	Wet Bulb Temp °C
Rest					
Warm-up (5 min)					
1:30 (LI)					
2:00 (HI)					
3:30 (LI)					
4:00 (HI)					
5:30 (LI)					
6:00 (HI)					
7:30 (LI)					
8:00 (HI)					
9:30 (LI)					
10:00 (HI)					
11:30 (LI)					
12:00 (HI)					

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Bulb Temp °C	Wet Bulb Temp °C
12:30 (LI)					
14:00 (HI)					
15:30 (HI)					
16:00 (HI)					
17:30 (LI)					
18:00 (HI)					
19:30 (LI)					
20:00 (HI)					

Blood Lactate Immediately After: ______________

Exercise Recovery:

Time (min)	Ventilation (L/min)	VO_2 (ml/kg/min)	F_ECO_2%	F_EO_2%
1				
2				
3				
4				
5				

Blood Lactate (End of minute 5) Recovery: ________________mmol/L

Exercise End Time: _______________min

Participant Identification number: ___________

Core Temp/Electrodes Checked: Yes No

Condition: No Mask Hot Mask Hot No Mask Room Temp Mask Room Temp

High intensity – Peak Power Output x 0.85 Nude Body Weight Before: __________kg

Low intensity – Peak Power Output x 0.30 Nude Body Weight Before: __________kg

Power Output (Watts) during high intensity: ______________ Urine Volume: ___________mL

Power Output (Watts) during low intensity: ______________ Water Ingested: __________mL

2nd HIIE Data Collection Sheet (30 second HI bout followed by 1:30 LI recovery):

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Blub Temp °C	Wet Bulb Temp °C
Rest					
Warm-up (5 min)					
1:30 (LI)					
2:00 (HI)					
3:30 (LI)					
4:00 (HI)					
5:30 (LI)					
6:00 (HI)					
7:30 (LI)					
8:00 (HI)					
9:30 (LI)					
10:00 (HI)					
11:30 (LI)					
12:00 (HI)					

Participant Identification number: __________

Time (Min:Sec)	RPE	Thermal Sensation	Core Temp °C	Dry Blub Temp °C	Wet Bulb Temp °C
12:30 (LI)					
14:00 (HI)					
15:30 (HI)					
16:00 (HI)					
17:30 (LI)					
18:00 (HI)					
19:30 (LI)					
20:00 (HI)					

Blood Lactate Immediately After: ______________mmol/L

Exercise Recovery:

Time (min)	Ventilation (L/min)	VO_2 (ml/kg/min)	F_ECO_2%	F_EO_2%
1				
2				
3				
4				
5				

Blood Lactate (End of minute 5) Recovery: ________________mmol/L

Exercise End Time: _______________min

Participant Identification number: __________

Visit 2:

1st HIIE Data Collection Sheet (30 second HI bout followed by 1:30 LI recovery)

Condition: No Mask Hot Mask Hot No Mask Room Temp Mask Room Temp

Exercise Start Time: _____________

Time (Min:Sec)	Stroke Volume	Heart Rate	Muscle Tissue Oxygenation% NIRS	S_pO_2% Finger Clamp	Mean Arterial Pressure	Systolic BP	Diastolic BP
Rest							
Warm-up (5 min)							
1:30 (LI)							
2:00 (HI)							
3:30 (LI)							
4:00 (HI)							
5:30 (LI)							
6:00 (HI)							
7:30 (LI)							
8:00 (HI)							
9:30 (LI)							
10:00 (HI)							
11:30 (LI)							
12:00 (HI)							

Participant Identification number: __________

Time (Min:Sec)	Stroke Volume	Heart Rate	Muscle Tissue Oxygenation% NIRS	S_pO_2% Finger Clamp	Mean Arterial Pressure	Systolic BP	Diastolic BP
12:30 (LI)							
14:00 (HI)							
15:30 (HI)							
16:00 (HI)							
17:30 (LI)							
18:00 (HI)							
19:30 (LI)							
20:00 (HI)							

Exercise Recovery:

Time (Min:Sec)	Stroke Volume	Heart Rate	Muscle Tissue Oxygenation% NIRS	S_pO_2% Finger Clamp	Mean Arterial Pressure	Systolic BP
1						
2						
3						
4						
5						

Exercise End Time: _______________

Provide Participant with water and a 350-calorie meal
Three Hour Break

Participant Identification number: __________

2nd HIIE Data Collection Sheet (30 second HI bout followed by 1:30 LI recovery)

Condition: No Mask Hot Mask Hot No Mask Room Temp Mask Room Temp

Exercise Start Time: _____________

Time (Min:Sec)	Stroke Volume	Heart Rate	Muscle Tissue Oxygenation% NIRS	S_pO_2% Finger Clamp	Mean Arterial Pressure	Systolic BP	Diastolic BP
Rest							
Warm-up (5 min)							
1:30 (LI)							
2:00 (HI)							
3:30 (LI)							
4:00 (HI)							
5:30 (LI)							
6:00 (HI)							
7:30 (LI)							
8:00 (HI)							
9:30 (LI)							
10:00 (HI)							
11:30 (LI)							
12:00 (HI)							

Participant Identification number: __________

Time (Min:Sec)	Stroke Volume	Heart Rate	Muscle Tissue Oxygenation% NIRS	S_pO_2% Finger Clamp	Mean Arterial Pressure	Systolic BP	Diastolic BP
12:30 (LI)							
14:00 (HI)							
15:30 (HI)							
16:00 (HI)							
17:30 (LI)							
18:00 (HI)							
19:30 (LI)							
20:00 (HI)							

Exercise Recovery:

Time (Min:Sec)	Stroke Volume	Heart Rate	Muscle Tissue Oxygenation% NIRS	S_pO_2% Finger Clamp	Mean Arterial Pressure	Systolic BP
1						
2						
3						
4						
5						

Exercise End Time: _______________

Participant Identification number: __________

Appendix E

Modified UNM Affiliate COVID-19 Screening Checklist form.

Please type or write clearly and answer honestly. Thank you.

Participant Number: _________

Will you be physically on-site at the University?

Yes No

What Campus will you be coming into today?

Main Campus – Albuquerque (Johnson Center Exercise Physiology Lab)

You understand that when you are on campus you are required to wear a cloth face covering and maintain social distancing?

Yes No

When you arrive at the Johnson Center Exercise Physiology Lab you understand you will be provided a surgical mask to wear during your visit?

Yes No

Today, or in the past 24 hours, have you had any of the following symptoms?

- Fever
- New onset cough
- New onset shortness of breath or difficulty breathing
- New loss of taste or smell
- Sore throat
- More physical exhaustion than normal (fatigue)
- Unexplained muscle or body aches
- Chills (repeated shaking)
- New onset or unusual headache
- New onset nasal congestion or runny nose
- Nausea or vomiting
- Diarrhea

Yes No

Have you traveled outside of New Mexico within the past 14 days?

Yes No

Have you been exposed to anyone with suspected or known COVID-19 within the past 14 days?

Yes No