Original Article

Impact of mask wearing during high-intensity exercise on post-exercise hemodynamics

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ABSTRACT

Background: Few studies examining face mask wearing during high-intensity interval exercise (HIE) have measured blood pressure (BP) and cardiac output (Q) during exercise and none have examined these variables post-exercise. Methods: Participants were randomly assigned to complete four exercise and two control conditions while wearing different face masks. Participants followed a 4x4 protocol on a cycle ergometer. Participants exercised at 85% of VO_{2max} for 4-min, followed by a 3-min rest, repeated four times. Measurements of Q, systemic vascular resistance (SVR), and BP were measured pre-exercise for 20-min, during exercise, and postexercise for 60-min. Linear mixed models were used to detect differences between conditions. Results: Ten young (20.3 ± 1.4 yr.) male (n = 5) and female (n = 5) participants with an average BMI of 28.1 ± 7.3 kg/m^2 and VO_{2max} of 37.0 ± 7.1 ml.kg^{-1}.min^{-1} completed this. There were no group differences during exercise on outcomes of Q, SVR, HR, SBP, DBP, MAP, or RPE (all $p > .05$). During exercise, EXS-N95 had a lower SV than CON-E ($p = .014$) and EXS-CL ($p = .006$). All mask conditions had a higher post-exercise HR than CON-E (all $p > .05$). Only EXS-SUR differed in post-exercise brachial SBP compared to CON-E (3.1 ± 1.6 mmHg, $p < .043$). Of the exercise conditions, only EXS-N95 differed from CON-E with an increase of 2.0 ± .88 mmHg for brachial DBP ($p = .022$) and 2.1 ± .92 mmHg for central DBP ($p = .022$), SV (-11.8 ± 3.5 mL.min^{-1}, $p < .001$), Q (-.52 ± .26 L.min^{-1}, $p = .045$), and SVR (73.7 ± 29.8 Dyn.s/cm^5, $p = .014$). Conclusion: The current study shows that in healthy populations, wearing a face covering of any type during HIE does not impactfully change the hemodynamic response during exercise or recovery period.

Keywords: Sport medicine, Health, Post-Exercise hypotension, COVID-19, N95, Face covering, Pandemic.

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INTRODUCTION

The Centres for Disease Control and Prevention modelling suggested that, without mitigation, severe acute respiratory syndromecoronavirus2 (SARS-CoV-2), the virus that caused the novel coronavirus disease 2019 (COVID-19), would have infected more than 60% of the US population (Fink, 2020). Social distancing and self-quarantine were advocated to flatten the epidemic curve in the hope of moderating the effects the virus may have had on the healthcare system, morbidity, and mortality. This directive caused grade schools, universities, parks, and non-essential businesses, including gyms, to close. An unintended consequence of this self-quarantine has been increased sedentary behaviour and reported weight gain (Zachary et al., 2020).

As quarantine guidelines began to lessen, many health centres worldwide reopened under new COVID guidelines (Epstein et al., 2020). Because virus particles in respiratory droplets may be transmitted to a greater extent during different forms of physical exertion (Blocken, Malizia, van Druenen, & Marchal, 2020) especially indoor settings (Lendacki, Teran, Gretsch, Fricchione, & Kerins, 2021), face masks have become part of these new guidelines (Gentil et al., 2020). Data on wearing a face mask during exercise has shown to be somewhat contentious (Chandrasekaran & Fernandes, 2020; Greenhalgh, Dijkstra, Jones, & Bowley, 2020). Researchers tested the effects of wearing either a surgical or an N95 mask during maximal exercise and found that ventilation, exercise capacity, and comfort all reduced while wearing a mask (Fikenzer et al., 2020). On the other end of the exercise intensity spectrum, low-intensity exercise, such as walking while wearing an N95 mask, has been shown to either not affect the exercise response (Roberge, Coca, Williams, Powell, & Palmiero, 2010) or have minor alterations (Roberge et al., 2010). However, a recent narrative review (Hopkins et al., 2021) and meta-analysis (Shaw et al., 2021) concluded that wearing a face covering during exercise had minimal impact on physiological outcomes and performance measures. These reviews contained only two studies that measured cardiac output (Q) and found no difference between the mask and non-mask groups. They also reported that only a few studies measured blood pressure (BP) during exercise. Lastly, few studies examined the impacts of wearing face-covering during high-intensity interval exercise (HIE).

Many organizations have recommended wearing fabric face masks during physical activity (Blocken et al., 2020). To the author's knowledge, there are no organizations that recommend the wearing of tightly fitted masks while exercising (Greenhalgh et al., 2020). Nevertheless, because we have not experienced a time in recent history that has mandated the use of cloth face coverings in public spaces, most research exploring the impact of masks on human physiology has been conducted on surgical masks and N95 respirators (Scheid, Lupien, Ford, & West, 2020). The impact of cloth masks on exercise hemodynamics is less known.

Furthermore, the post-exercise period has been highlighted as an opportunity to maximize cardiovascular health outcomes (Luttrell & Halliwill, 2015). Specifically following an acute exercise session, BP reduces without any symptomatic clinical hypotension; this phenomenon is termed "*Post-Exercise Hypotension*" (PEH) (Kenney & Seals, 1993). PEH has clinical relevance as the magnitude of reduction has been shown to predict chronic training responses (Zeigler et al., 2018), and this reduction lasts upwards of 16 h following exercise (Brito et al., 2018). There are no data on the effects of mask-wearing during exercise on post-exercise hemodynamics. Thus, the purpose of this study is two-fold: first, to assess the impact of different face masks on exercise hemodynamics during HIE, and second, to assess the impact of different face masks on PEH.

METHODS

Participants
Healthy Participants aged 18-30 yr. were recruited for this randomized experimental cross-over study. Participants were excluded if they had known cardiovascular, pulmonary, renal, or metabolic disease, and current smokers were also excluded from the study. Those with hypertension (SBP >130 mmHg or DBP >80 mmHg) were excluded. Participants were also excluded if they were taking oral antihistamine medications, as it is known that the histaminergic pathways are responsible for much of the reduction in BP that is seen following exercise (Halliwill JR, Buck TW, Lacewell AN, Romero SA., 2012). This study was approved by the IRB at the host institution (IRB-2021-4217).

Study design baseline measurements
Figure 1 outlines the study design. The study design included six conditions: 1) Control-no exercise and no mask (CON-NE), 2) Control-no exercise with surgical mask (CON-SUR), 3) control-exercise without a mask (CON-E), 4) exercise with a surgical mask (EXS-SUR), 5) exercise with an N95 mask (EXS-N95), and 6) exercise with a cloth mask (EXS-CL). Participants completed eight total visits to the laboratory.

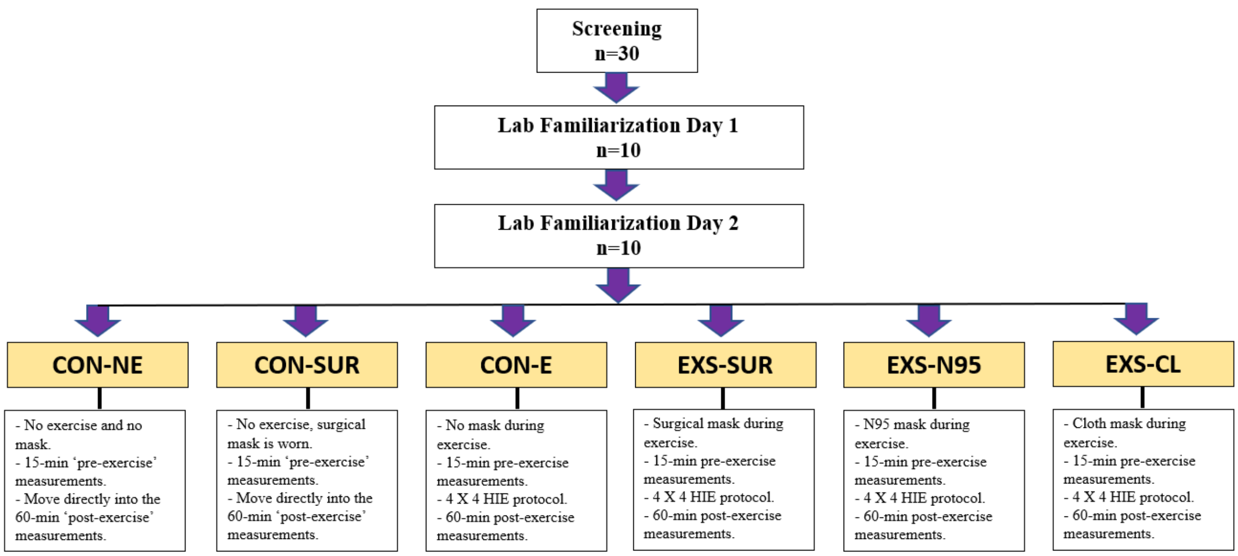


Figure 1. Schematical representation of research design.

Visit one consisted of informed consent administration, health history screening, and BP measurement familiarization. The informed consent was given to potential participants, and adequate time was allowed for them to read over it. Once the potential participant finished reading the informed consent, the investigator allowed the individual to ask questions. Lack of familiarization with BP assessments has been highlighted as a weakness in the PEH literature (de Brito et al., 2019). Thus, all participants were asked to go through a "*run-through*" of the cardiovascular assessments to ensure they were comfortable and understood the research protocol. This data was not collected or recorded.

During visit two, participants completed baseline measurements. Anthropometric measures of body weight and height were taken. Height was measured with the participant standing barefoot to the nearest 0.1 cm using a stadiometer (Tree LS-PS 500). Bodyweight (kg) was measured with minimal clothing using the digital scale attached to the stadiometer. Body composition was determined via whole-body air displacement plethysmography (Bod Pod, COSMED). Bod Pod has been shown to be valid compared to underwater weighing (Fields, Hunter, & Goran, 2000). Participants were asked to wear a bathing suit or tight-fitting shorts and remove their shirts and jewellery to test. Participants were weighed again using the scale associated with the Bod Pod device. Participants were asked to place a cap on their heads to cover their hair and sit in the Bod Pod for two to three measurements of 50-s each. The participants had their BP measured again this day. Data was not recorded as this measurement, as was the first one, served to familiarize participants with the laboratory's procedures and surroundings.

After BP familiarization, participants were asked to complete a VO_{2max} assessment. Participants warmed up at 50 watts for 5-min on a cycle ergometer. After this, power output increased by 30 watts every min until voluntary exhaustion. Oxygen consumption was analysed continuously by the Vmax metabolic cart (CareFusion, Franklin Lakes, NJ) and averaged every ten seconds. VO_{2max} was determined as the average of the two highest consecutive 10-s oxygen consumption values. True VO_{2max} was determined either by a plateau of oxygen consumption (< 150 $ml \cdot min^{-1}$) with an increased watt level OR a respiratory exchange ratio above 1.15 (Howley, Bassett, & Welch, 1995). Heart rate (HR) was measured with a Polar HR monitor (Polar, Lake Success, NY). Ratings of perceived exertion were taken every minute throughout the test. Participants were given a 5-min cooldown on the ergometer at 30 watts. VO_{2max} data is expressed as $ml \cdot kg^{-1} \cdot min^{-1}$.

Experimental conditions

Following visit two, all participants were randomly assigned to complete each of the six conditions one week apart. All visits were conducted at the same time of day (0800 – 1100 h) to account for the diurnal impact on the outcome variables. To prepare for the assessments, participants were asked to be fasted for at least 5-h, refrain from caffeine and alcohol for 24-h, and avoid unaccustomed physical activity 24-h before their visit. Reducing physical activity was advised to avoid potential carry-over effects. Instructions were given to consume the same dinner and amount of fluids the night before and the morning of the laboratory visits. Participants were asked to record their meals to ensure compliance with this requirement.

The six conditions consisted of control-no exercise and no mask (CON-NE), control-no exercise with a surgical mask (CON-SUR), control-exercise without a mask (CON-E), exercise with a surgical mask (EXS-SUR), exercise with an N95 mask (EXS-N95), and exercise with a cloth mask (EXS-CL). Besides the CON-NE and CON-SUR, the remaining conditions were identical, with the only difference being the mask being worn. During the mask-wearing conditions, a mask was worn pre-, during-, and post-exercise. On the two no-mask-wearing days (CON-NE & CON-E), participants were not wearing a mask during the pre- or post-exercise assessments.

Upon arrival at the laboratory, the participant was asked to lie supine for 20-min to achieve hemodynamic stability. All pre- and post-exercise measurements were taken while the participant was lying supine. Two BP readings were taken with an automated cuff (Welch Allyn, Connex ProBP 3400) to ensure hemodynamic stability. Following this, pre-exercise measurements were taken for 15-min. Pre-exercise measurements of brachial BP, central BP, carotid-femoral pulse wave velocity (cfPWV), pulse wave analysis (PWA), ankle-brachial index (ABI), cardiac output (Q), and systemic vascular resistance (SVR) were taken.

Experimental measurement procedures

Central/brachial BP, cfPWV, and PWA measurements were taken using the validated methodology of the SphygmoCor XCELTM (AtCor Medical, Sydney, NSW, Australia) (Hwang et al., 2014; Van Bortel et al., 2012). Central BP was automatically derived from ten sequential, high-quality waveforms, which undergo a validated generalized transfer function to generate the corresponding central aortic pressure waveform. Augmentation Index (Aix) was calculated as the difference between the first and second systolic peaks of the ascending aortic waveform expressed as a percentage of the central pulse pressure and normalized for a HR of 75 beats·min^{-1} (Aix@HR75). Aix can also be expressed in absolute terms as augmentation pressure (Ap). Three pre-exercise measurements were taken 5-min apart.

Carotid-femoral PWV (cfPWV) was determined by recording the carotid artery and femoral artery waveforms simultaneously. Distances from the carotid sampling site to the suprasternal notch and from the suprasternal notch to the femoral cuff were measured. The distance from the femoral arterial pulse to the femoral cuff was obtained and subtracted from the total distance (D; in meters). The time (t; in seconds) between the onset of femoral and carotid waveforms was determined as the mean from 10 consecutive cardiac cycles. Carotid femoral PWV was calculated as follows: cfPWV = D/t (m·s^{-1}). Two pre-exercise measurements were taken, separated by 15-min.

The ankle-brachial index (ABI) was measured using the PADnet (Biomedix) device. The PADnet device uses an air-inflated cuff and photoplethysmography to obtain systolic BP measurements from the upper and lower extremities. The ankle SBP reading is divided by the brachial SBP reading. Two pre-exercise measurements were taken, separated by 15-min.

Cardiac output and SVR were measured continuously during the entire visit (pre- during- and post-exercise) using impedance cardiography (PhysioFlowTM; Manatec Biomedical, Paris, France) (Charloux et al., 2000). The device uses changes in transthoracic impedance during cardiac ejection to calculate stroke volume (SV). Brachial/central BP was measured in the laboratory every 5-min while the participants were supine. These values were entered into the PhysioFlow software, and SVR was automatically calculated.

Following the 15-min pre-exercise assessments, participants were directed to a cycle ergometer and were asked to participate in an HIE session. The specific protocol was a 4 x 4 protocol (Kessler, Sisson, & Short, 2012). Participants performed a light warm-up for 3-min, and then exercise intensity increased to 80-95% of VO_{2max}. Participants maintained this intensity for 4-min. Ratings of perceived exertion (RPE), HR, Brachial BP, Q, and SVR were measured following every high-intensity bout during exercise. BP was taken manually using the auscultatory method with a mercury sphygmomanometer. A 3-min active recovery followed each interval, and intervals were repeated four times. Participants were given a 3-min cooldown on the ergometer. Immediately following the cooldown, participants were directed to lie supine again for post-exercise measurements.

Post-exercise. Brachial/central BP and PWA were measured every 5-min for 60-min following the exercise. Pulse wave velocity and ABI were measured every 15-min for 60-min following the exercise. Cardiac output and SVR were measured continuously for 60-min following the exercise.

Participants duplicated the above exercise protocol four times, once while wearing no mask (CON-E), a surgical mask (EXS-SUR), an N95 mask (EXS-N95), and a cloth mask (EXS-CL). Each condition was separated by one week. During the CON-NE and CON-SUR, participants completed identical pre-exercise and post-exercise measurements as described above during these conditions. The only difference was that the participants did not exercise.

Table 1. Average pre-exercise values between conditions.

	CON-NE	CON-SUR	CON-E	EXS-SUR	EXS-N95	EXS-CL	*p*-value
Stroke Volume (mL.min^{-1})	92.7 ± 25.5	108.4 ± 18.4	98.4 ± 7.6	101.7 ± 12.8	98.0 ± 18.8	105.1 ± 18.1	.052
Cardiac Output (L.min^{-1})	5.8 ± 1.5	6.8 ± 1.1	6.8 ± 1.6	6.7 ± 1.4	6.4 ± 1.4	7.2 ± 1.4*	.012
Systemic Vascular Resistance (Dyn.s/cm^5)	1062.5 ± 232.4	1082.6 ± 6	966.9 ± 252.1	983.4 ± 223.7	1061.9 ± 169.8	877.3 ± 260.4*	<.001
Heart Rate (bpm)	60.5 ± 6.9	62.9 ± 6.9	63.0 ± 7.0	60.9 ± 6.9	62.8 ± 7.0	61.0 ± 6.9	.634
Brachial Diastolic Blood Pressure (mmHg)	66.6 ± 5.6	70.3 ± 6.5	68.9 ± 7.3	66.4 ± 5.3	69.9 ± 8.0	68.5 ± 5.5	.118
Brachial Systolic Blood Pressure (mmHg)	113.9 ± 9.7	121.4 ± 10.7	117.9 ± 12.8	117.3 ± 9.7	118.1 ± 16.9	118.4 ± 11.7	.216
Brachial Mean Arterial Pressure (mmHg)	82.3 ± 5.4	86.6 ± 4.7	84.7 ± 7.3	83.2 ± 5.2	85.1 ± 9.7	85.0 ± 5.7	.059
Central Systolic Blood Pressure (mmHg)	99.3 ± 6.6	103.9 ± 8.2	102.0 ± 10.7	99.9 ± 5.7	102.5 ± 13.5	101.8 ± 8.8	.184
Central Diastolic Blood Pressure (mmHg)	68.4 ± 3.9	72.0 ± 6.3	70.6 ± 7.3	67.7 ± 4.8	71.0 ± 9.3	70.2 ± 5.1	.096
Central Mean Arterial Pressure (mmHg)	78.7 ± 4.0	82.0 ± 5.0	81.0 ± 7.7	78.2 ± 4.0	81.1 ± 10.1	80.7 ± 5.3	.065
Augmentation Pressure (mmHg)	-1.0 ± 2.9	-.42 ± 2.0	-.14 ± 2.3	-.80 ± 1.9	.50 ± 2.4	-1.1 ± 2.5	.161
Augmentation Index @HR75 (%)	-11.1 ± 10.4	-6.1 ± 6.9	-6.6 ± 10.3	-10.9 ± 7.4	-5.1 ± 10.0	-9.4 ± 7.8	.086
Pulse Wave Velocity (m.sec^{-1})	5.6 ± .61	5.4 ± .58	5.2 ± .45	5.5 ± 1.0	5.3 ± .68	5.4 ± .64	.893
Ankle Brachial Index	1.1 ± .07	1.2 ± .09	1.1 ± .15	1.1 ± .11	1.1 ± .07	1.1 ± .08	.561

*Note. *Represents a value that is statistically different than CON-NE ($p < .005$).*

Table 2. Average exercise values between conditions.

	CON-E	EXS-SUR	EXS-N95	EXS-CL	*p*-value
Stroke Volume (mL.min^{-1})	117.3 ± 32.4	109.0 ± 30.4	98.9 ± 25.2*	118.0 ± 28.0	.004
Cardiac Output (L.min^{-1})	16.4 ± 5.7	15.4 ± 5.2	14.2 ± 4.3	16.6 ± 4.7	.065
Systemic Vascular Resistance (Dyn.s/cm^5)	493.4 ± 201.0	515.5 ± 182.5	577.6 ± 138	486.4 ± 185.6	.066
Heart Rate (bpm)	171.2 ± 10.7	171.4 ± 12.5	177.0 ± 10.4	175.8 ± 10.0	.621
Brachial Diastolic Blood Pressure (mmHg)	69.1 ± 12.0	69.2 ± 8.7	74.5 ± 7.4	66.5 ± 10.1	.169
Brachial Systolic Blood Pressure (mmHg)	154.7 ± 28.1	159.6 ± 22.7	157.4 ± 21.7	160.6 ± 27.0	.348
Brachial Mean Arterial Pressure (mmHg)	97.6 ± 15.3	99.3 ± 10.9	102.1 ± 11.0	97.8 ± 12.9	.055
Rating of Perceived Exertion (RPE)	15.2 ± 1.9	15.4 ± 1.3	15.6 ± 1.8	15.6 ± 2.2	.947

*Note. *Represents a value that is statistically different than CON-E and EXS-CL ($p < .05$).*

Table 3. Average post-exercise values between conditions.

	CON-NE	CON-SUR	CON-E	EXS-SUR	EXS-N95	EXS-CL	*p*-value
Stroke Volume ($mL.min^{-1}$)	91.3 ± 23.0†	105.4 ± 15.7*	103.7 ± 17.8*	107.3 ± 26.6*	91.8 ± 21.1†	99.2 ± 26.6*	< .001
Cardiac Output ($L.min^{-1}$)	5.7 ± 1.4†	6.5 ± 1.0*†	7.9 ± 1.9*	8.6 ± 2.0*	7.4 ± 1.8*†	7.6 ± 1.3*	< .001
Systemic Vascular Resistance ($Dyn.s/cm^5$)	1116.4 ± 160.7†	1086 ± 147.2†	856.6 ± 240.0*	779.6 ± 197.3*	929.9 ± 139.5*†	808.1 ± 175.9*	< .001
Heart Rate (bpm)	59.1 ± 8.2†	62.1 ± 9.4*†	77.4 ± 11.7*	80.8 ± 12.6*†	82.7 ± 12.0*†	82.6 ± 11.9*†	< .001
Brachial Diastolic Blood Pressure (mmHg)	68.7 ± 5.6†	72.8 ± 5.8*†	66.8 ± 6.5*	66.6 ± 7.3*	68.8 ± 5.8†	67.4 ± 5.4	< .001
Brachial Systolic Blood Pressure (mmHg)	115.2 ± 11.8	122.4 ± 9.5*†	113.9 ± 11.4	110.7 ± 9.6*†	112.9 ± 13.3	115.3 ± 12.4	< .001
Brachial Mean Arterial Pressure (mmHg)	83.9 ± 6.8	90.6 ± 5.3*†	82.3 ± 6.8	81.0 ± 6.8*	83.4 ± 6.9	83.2 ± 6.5	< .001
Central Systolic Blood Pressure (mmHg)	101.1 ± 10.2†	107.9 ± 9.0*†	98.3 ± 10.2*	96.4 ± 8.5*	99.6 ± 99.6	99.7 ± 10.6	< .001
Central Diastolic Blood Pressure (mmHg)	70.2 ± 5.4	74.1 ± 6.0*†	69.3 ± 7.5	70.2 ± 7.6	71.5 ± 6.1†	70.4 ± 5.0	< .001
Central Mean Arterial Pressure (mmHg)	80.5 ± 5.1	85.4 ± 5.3*†	79.0 ± 7.8	78.9 ± 7.4	80.6 ± 6.7	80.2 ± 7.0	< .001
Augmentation Pressure (mmHg)	-.71 ± 2.9	-.75 ± 2.9	-.71 ± 2.9	-1.41 ± 2.6	-1.27 ± 3.0	-.81 ± 2.9	.244
Augmentation Index @HR75 (%)	-12.6 ± 11.1†	-9.8 ± 9.3†	-3.2 ± 11.5*	-3.8 ± 9.9*	-2.4 ± 10.1*	-.79 ± 9.4*	.002
Pulse Wave Velocity ($m.sec^{-1}$)	5.6 ± .72	5.5 ± .66	5.4 ± 1.10	5.5 ± .98	5.8 ± 1.46	5.5 ± 1.30	.497
Ankle Brachial Index	1.10 ± .10	1.14 ± .12	1.16 ± .10	1.10 ± .10	1.18 ± .09	1.13 ± .10	.085

*Note. *Represents statistically different from CON-NE. †Represents a value that is statistically different from CON-E.*

Statistical analysis

All data were analysed using SPSS statistical software version 26 (IBM Corp., Armonk, NY). All data are expressed as means ± standard deviation unless otherwise specified. Descriptive statistics were used to describe the study population. Data were analysed for normality, and values with skewed distribution were transformed to achieve normality. All *P* values were calculated assuming a two-tailed hypothesis; $p < .05$ was considered statistically significant. A one-way ANOVA was used to determine the mean group pre-exercise and exercise differences. Pre-exercise measurements of brachial/central BP, measures of arterial stiffness, Q, and SVR were averaged over the 15-min pre-exercise period. Exercise data was averaged and included both during the high intensity and the active recovery session. Tukey post-hoc analysis was used to determine where the group differences, if any, were found. In the case of violation of homogeneity, the Welch ANOVA was used. In these cases, Games-Howell post hoc tests were used. Linear mixed models were used to detect differences in brachial/central SBP and DBP, measures of arterial stiffness, Q, and SVR by treatment condition over the post-exercise measurement period. The analysis was conducted in a hierarchical fashion using the Restricted Maximum Likelihood model and 'autoregressive heterogeneous 1' covariance error structure. Both fixed and random effects were explored in the model. Treatment condition, baseline hemodynamic values, time, age, sex, and BMI were used as fixed effects, and time was also used as a random effect to account for both interindividual and diurnal variations in BP. The primary comparison is between CON-E and the other exercise conditions.

RESULTS

Pre-Exercise

Ten young (20.3 ± 1.4 yr.) male (n = 5) and female (n = 5) participants with an average body fat percentage of 25.6 ± 9.8 %, BMI of 28.1 ± 7.3 kg/m^2 and VO_{2max} of 37.0 ± 7.1 ml.kg^{-1}.min^{-1} completed this study. Table 1 details the average pre-exercise values between groups. There were no statistically significant pre-exercise group differences in outcomes of SV (p = .05), HR (p = .63), brachial DBP (p = .12), brachial SBP (p = .22), brachial mean arterial pressure (MAP) (p = .06), central SBP (p = .18), central DBP (p = .09), central MAP (p = .07), Ap (p = .16), Aix@HR75 (p = .09), cfPWV (p =.89), or ABI (p = .56). There were pre-exercise group differences in Q (p = .01) and SVR (p < .01). Post hoc analysis revealed that EXS-CL had a significantly higher pre-exercise Q than CON-NE (p = .04). Lastly, only EXS-CL statistically differed from CON-NE (p = .04) for SVR during the pre-exercise period.

Exercise

Table 2 details the exercise values. There were no group differences during exercise on outcomes of Q (p = .07), SVR (p = .07), HR (p = .62), brachial DBP (p = .17), brachial SBP (p = .35), brachial MAP (p =.06), and RPE (p = .95). Only SV showed group statistical differences, with EXS-N95 having a lower SV than both CON-E (p = .01) and EXS-CL (p < .01).

Post-exercise

Table 3 details the average post-exercise values while Figure 2 highlights the post-exercise values over the 60-min measurement period. Figure 3 shows individual HR responses during each condition. All exercise conditions had higher post-exercise HR values when compared to the two non-exercise conditions (all p < .01). Additionally, EXS-SUR (4.8 ± 1.5 (SE) bpm, p = .01), EXS-N95 (4.0 ± 1.6 (SE) bpm, p = .01), and EXS-CL (5.2 ± 1.6 (SE) bpm, p < .01) all had significantly higher post-exercise HRs than CON-E (Figure 2C).

Figure 2A illustrates that of the exercise conditions, only EXS-SUR differed in post-exercise brachial SBP reduction when compared to CON-E (3.1 ± 1.6 (SE) mmHg, p = .04). Figure 4 shows individual SBP responses during each condition. CON-SUR had a statistically higher brachial SBP over the entire post-exercise measurement period than all other conditions (all $p < .05$). There were no central SBP differences between CON-E and EXS-SUR ($p = .17$), EXS-N95 ($p = .36$), and EXS-CL ($p = .32$). CON-SUR had a significantly higher central SBP than all other conditions (all $p < .05$).

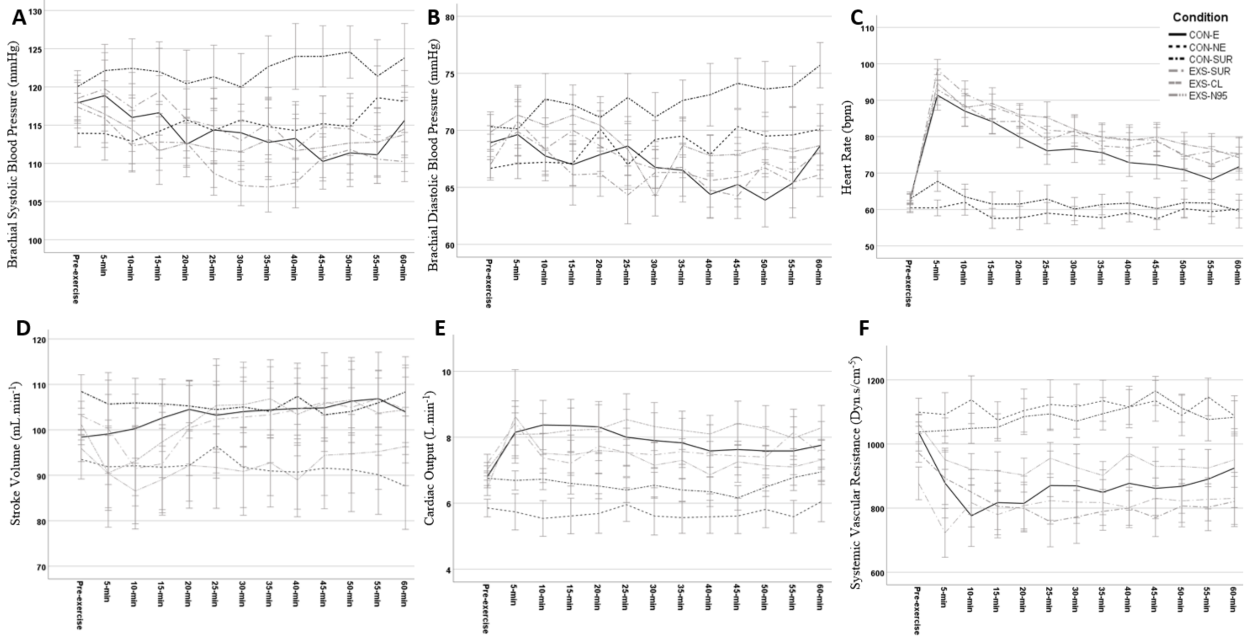
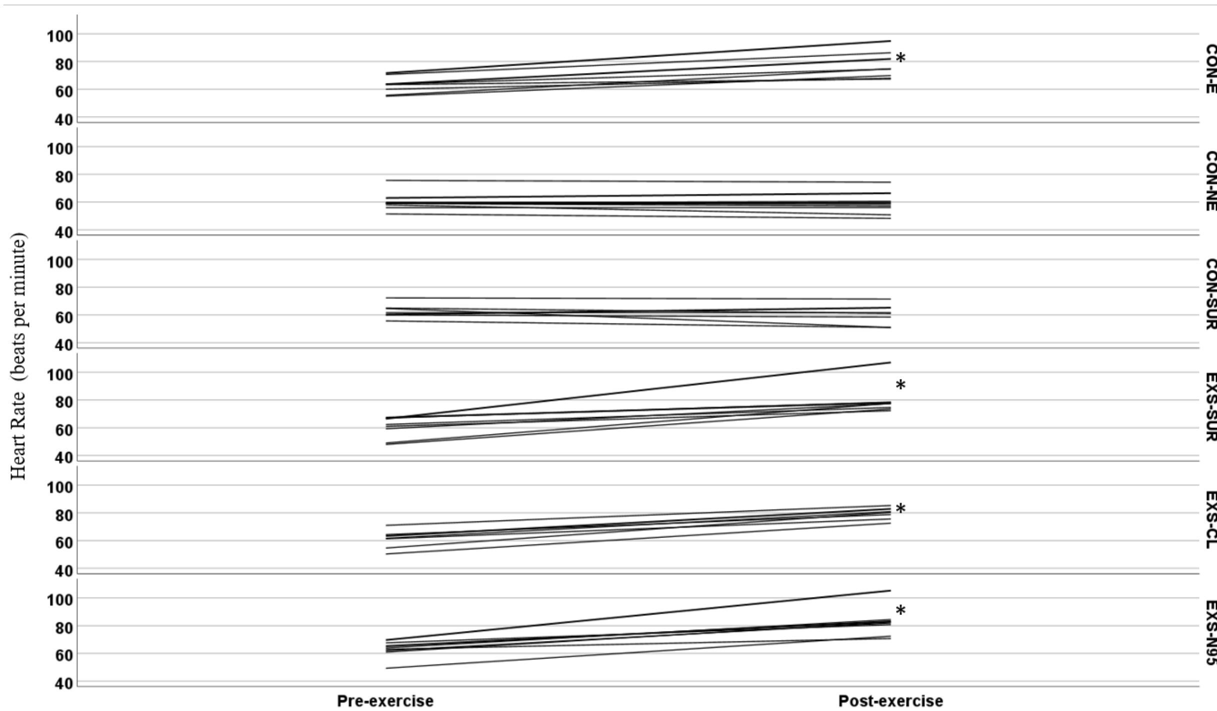
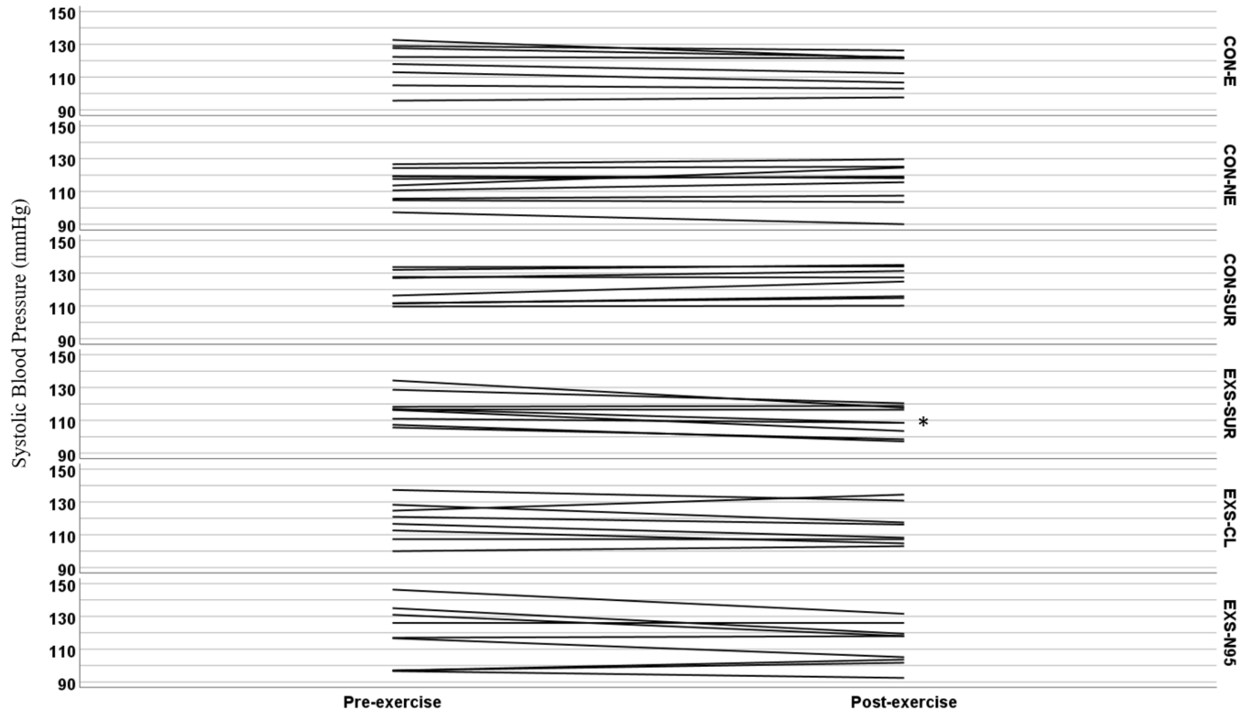


Figure 2. Pre- and post-exercise values for brachial SBP (A), brachial DBP (B), HR (C), SV (D), Q (E), and SVR (F).



Note. * *Represents that the group average is statistically different from average pre-exercise values (p < .05).*

Figure 3. Pre- and post-exercise individual values for HR.



*Note. * Represents that the group average is statistically different from average pre-exercise values (p < .05).*

Figure 4. Pre- and post-exercise individual values for SBP.

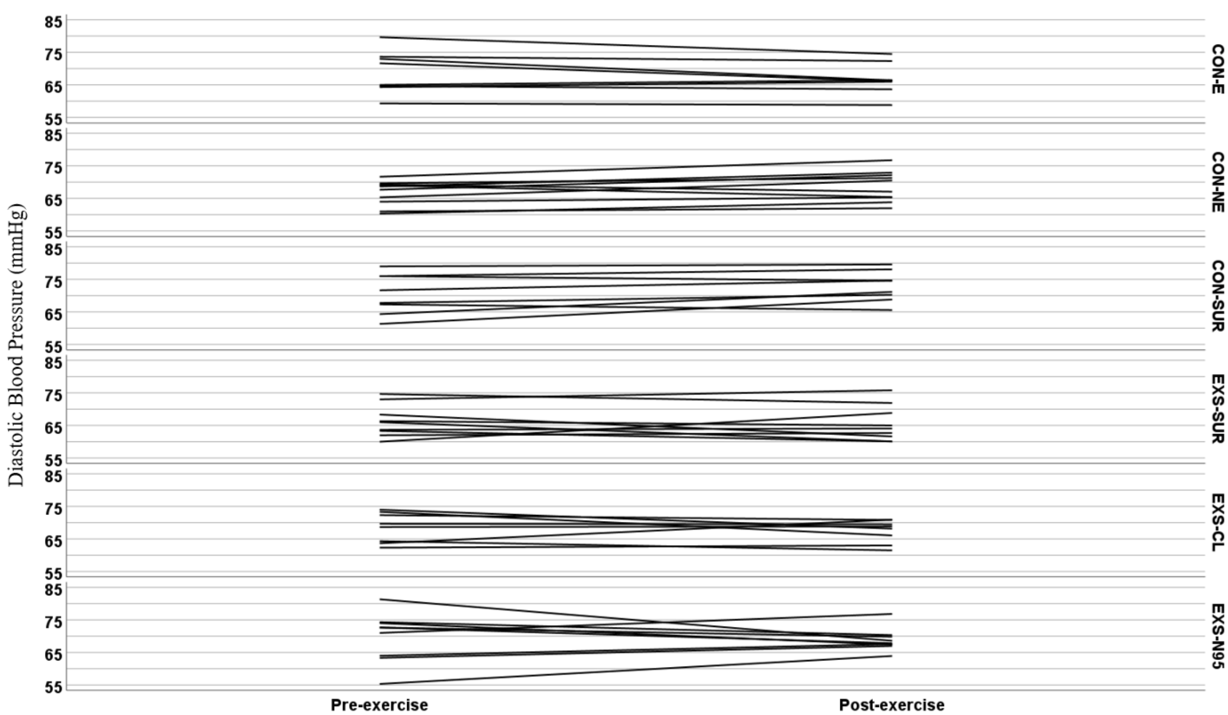


Figure 5. Pre- and post-exercise individual values for DBP.

Figure 5 shows individual DBP responses during each condition. Of the exercise conditions, only EXS-N95 differed from CON-E with an increase of 2.0 ± .88 (SE) mmHg for brachial DBP (p = .02) (Figure 2B) and 2.1 ± .92 (SE) mmHg for central DBP (p = .02). CON-SUR had a statistically higher brachial and central DBP over the entire measurement period than all other conditions (all p < .05). No conditions for brachial and central MAP differed when compared to CON-E (all p < .05). CON-SUR had a higher brachial and central MAP than all other conditions (all p < .05).

When examining the exercise conditions, only EXS-N95 was significantly different from CON-E for SV (-11.8 ± 3.5 (SE) mL.min^{-1}, p < .01) (Figure 2D), Q (-.52 ± .26 (SE) L.min^{-1}, p = .04) (Figure 2E), and SVR (73.7 ± 29.8 (SE) Dyn.s/cm^5, p = .01) (Figure 2F). Within the mask-wearing exercise conditions, EXS-N95 had a significantly lower average post-exercise SV than EXS-SUR (10.0 ± 3.4 (SE) mL.min^{-1}, p < .01) and EXS-CL (7.4 ± 3.6 (SE) mL.min^{-1}, p = .03). Within the mask-wearing exercise conditions, EXS-SUR had significantly higher Q than EXS-CL (.62 ± .25 (SE) L.min^{-1}, p = .01), and EXS-N95 (.82 ± .25 (SE) L.min^{-1}, p < .01). Within the mask-wearing exercise conditions, EXS-N95 has significantly higher SVR than EXS-SUR (126.0 ± 28.8 (SE) Dyn.s/cm^5, p < .01) and EXS-CL (123.5 ± 29.9 (SE) Dyn.s/cm^5, p < .01). There was no post-exercise condition difference on Ap (p = .24) or cfPWV (p = .41). There were condition differences on Aix@HR75 only between the non-exercise (CON-NE and CON-SUR) and exercise conditions. There were no differences between CON-E and EXS-SUR (p = .99), EXS-CL (p = .61), and EXS-N95 (p = .99).

DISCUSSION

The current study found two main conclusions. First, wearing a face mask during HIE did not dramatically change hemodynamic properties during exercise. Although SV was lower in the EXS-N95 condition, no other change was witnessed during exercise. Second, wearing a face covering during HIE did alter the post-exercise hemodynamic response when compared to the CON-E condition. When comparing to CON-E, EXS-N95 produced lower SV, Q, and higher SVR. EXS-N95 also had a higher post-exercise brachial and central DBP when compared to CON-E. EXS-SUR produced a lower brachial SBP response when compared to CON-E, no differences in MAP were seen within the mask-wearing exercise groups. Post-exercise HR was higher in all the mask groups compared to CON-E.

The current study aligns with what has been published, in that wearing a face covering does not seem to dramatically alter hemodynamic response during high intensity exercise (Hopkins et al., 2021; Shaw et al., 2021; Zheng, Poon, Wan, Dai, & Wong, 2022). Most previous studies examining mask use during high intensity exercise used some sort of progressive test and very few measured exercise BP, Q, and SVR. To the author's knowledge only two studies used interval exercise. The current study adds to the body of evidence that mask use during HIE exercise does not dramatically alter the hemodynamic response. Our study did find however that the N95 condition did have a reduced SV compared to the other conditions. The reduced SV was offset by an increased SVR (not statistically significant, p = .066) such that pressure was similar between all exercise groups. It should be noted that although not statistically significant (p = .055), brachial MAP was highest during exercise while wearing an N95 mask. One meta-analysis was found that during maximal exercise both the N95 and surgical mask slightly reduced oxygen saturation (Shaw et al., 2021). Additionally, data suggests that using an N95, and a surgical mask to a lesser degree, during high intensity exercise may increase arterial and end tidal CO_2 (Litwinowicz, Choroszy, Ornat, Wróbel, & Waszczuk, 2022; Shaw et al., 2021; Zheng et al., 2022). Reduced oxygen saturation and increased arterial and end tidal CO_2 might be why pressure was slightly higher in the N95 group. Cloth masks worn during exercise have not been shown to impact arterial CO_2 (Shein et al., 2021).

Our study found no statistical difference with RPE between groups. Studies looking at submaximal exercise have shown RPE increase with surgical and N95 masks during exercise while studies looking at maximal exercise show that RPE is increased only with N95 (Shaw et al., 2021). Conversely, some studies have found that surgical masks increase RPE with no change while wearing an N95 and cloth mask (Zheng et al., 2022). Our study slightly differed from these past studies in that our subjects performed four intervals of high-intensity exercise opposed to one all-out effort that was conducted in previous studies. Theoretically when a research participant is pushed to maximal exertion the RPE should be high regardless of wearing a face covering or not, possibly leading to no differences in exertion ratings.

Or results are consistent with prior work showing that wearing a surgical or cloth mask does not impact HR during exercise (Shaw et al., 2021; Zheng et al., 2022). The current study showed that N95 mask reduces SV, and this disagrees with prior work that found wearing an N95 mask during an incremental exertion test did not impact SV (Fikenzer et al., 2020). An incremental exertion test is different than interval training in that during the current exercise protocol participants were asked to exercise four times at 85% of VO_2 max. The different exercise protocol may explain these differences in SV.

Our data suggest that mask wearing *does* increase recovery HR. Indeed, it was found that all mask exercise conditions had higher post-exercise HR values when compared to the exercise non mask wearing condition. The possible mechanisms behind increased recovery HR are unknown. Wearing a cloth or surgical mask at rest has shown to not increase HR (Amput & Wongphon, 2022). Data on wearing a face mask on recovery HR is sparse. A group of researchers measured HR during maximal exertion and for 10-min following exercise while subjects wore either a cloth or surgical mask and found that HR did not differ in the recovery period (Fukushi, Nakamura, & Kuwana, 2021). The current study used a longer exercise duration and longer recovery period, possibly explaining differences in results. It could be that HR was increased during recover due to increased respiratory resistance and thus mechanical work of breathing while mask wearing (Fukushi et al., 2021).

For the most part, PEH values did not dramatically differ between mask wearing groups. The only change found with reference to mask wearing on post-exercise BP values was that wearing a surgical mask produced on average a ~3 mmHg reduced brachial SBP compared to the CON-E. Interestingly EXS-N95 increase brachial and central DBP by roughly 2.0 ± .88 (SE) mmHg when compared to CON-E. It appears that wearing a mask during exercise may provoke changes on the mechanisms of post-exercise BP. The EXS-N95 produced lower SV and Q while increasing SVR. On the other hand, EXS-SUR produced higher SV and Q while lowering SVR. There is a dearth of studies examining the impact of face covering on BP and its components making it difficult to precisely state the mechanisms of these changes. In a study of healthcare workers, HR, respiratory rate, and SPO_2 were measured after an hour of wearing a N95 mask (Sultanoğlu, Boğan, Erdem Sultanoğlu, & Altınsoy, 2021). SPO_2 decreased over the hour (97.2 to 96.05 %, $p = .001$) and respiratory rate increased as a countermeasure ($p = .001$). No difference in HR was seen. Additionally, both surgical, and to a greater degree, N95 masks, have been shown to increase respiratory distress or shortness of breath (Kunstler et al., 2022). It is plausible that changes in SPO_2, arterial CO_2, or respiratory changes could have provoked the hemodynamic differences witnessed between groups following exercise.

The finding that the longer the surgical mask was worn the higher BP increased is of interest. A group of treated hypertensive patients wore a surgical mask for 10-min and found no difference between wearing and not wearing a surgical mask on outcomes of BP or HR (Konstantinidis et al., 2022). The current study did show that Q, driven solely by increased SV, was the driving factor for the increased pressure. The specific mechanism for this is unknown. Wearing a surgical mask has been shown in some to reduce SPO_2 which could in turn increase BP (Kishimoto, Tochikubo, & Ohshige, 2007). Additionally higher CO_2 increases vasoconstriction, potentially leading to elevated BP (Burnum, Hickam, & McIntosh, 1954).

This study is not without its limitations. The confounding of habituation in wearing masks for a long period of time before the conduction of the study cannot be excluded. Indeed, the physiological adaptations may be lessened as one becomes accustomed to mask wearing (Johansson, 2020). Additionally, all participants in the current study were young and relatively healthy, limiting the ability to generalize results to older or clinical populations. Those with cardiopulmonary disease may have exaggerated dyspnoea from mask wearing during exercise and this may negatively impact hemodynamic outcomes. Also, the CON-E group did not have a PEH response. Although controversial, HIE is just as good, if not superior to MIE on the outcome of PEH (Marcal et al., 2021). Thus, the current results of no PEH are more than likely due to the relatively low resting BP in the participants, and not the exercise protocol used. Indeed, a higher pre-exercise BP value is a predictor of a greater BP reduction following exercise (Eicher, Maresh, Tsongalis, Thompson, & Pescatello, 2010).

CONCLUSIONS

In conclusion, during the COVID pandemic, the Centres for Disease Control and Prevention in the United States endorsed face masks while exercising in fitness facilities to reduce virus spread (Lendacki et al., 2021) that may be higher in enclosed exercise facilities (Jang, Han, & Rhee, 2020). Some have expressed concern that face coverings during exercise may be harmful to one's health. The current study shows that in healthy populations, wearing a face covering of any type during HIE does not impactfully change the hemodynamic respond during exercise or the recovery period.

AUTHOR CONTRIBUTIONS

Zachary Zeigler: Study design, data analysis, manuscript preparation. Payton Price: Data collection, manuscript preparation. Malia Nowlen: Data collection, manuscript preparation. Luke Heikka: Data collection, manuscript preparation. Ruthie Larson: Data collection, manuscript preparation. Sara Thomasson: Data collection, manuscript preparation. Anthony Acevedo: Data collection, manuscript preparation.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ETHICS STATEMENT

The experiments completed in this study comply with the current laws of the country in which they were performed.

REFERENCES

Amput, P., & Wongphon, S. (2022). Effects of wearing face masks on cardiorespiratory parameters at rest and after performing the six-minute walk test in older adults. Geriatrics, 7(3), 62. https://doi.org/10.3390/geriatrics7030062

Blocken, B., Malizia, F., van Druenen, T., & Marchal, T. (2020). Towards aerodynamically equivalent COVID19 1.5 m social distancing for walking and running. Questions and Answers.Website Bert Blocken, Eindhoven University of Technology (the Netherlands) and KU Leuven (Belgium).

Brito, L. C., Fecchio, R. Y., Pecanha, T., Andrade-Lima, A., Halliwill, J. R., & Forjaz, C. L. (2018). Postexercise hypotension as a clinical tool: A "single brick" in the wall. Journal of the American Society of Hypertension, 12(12), e59-e64. https://doi.org/10.1016/j.jash.2018.10.006

Burnum, J. F., Hickam, J. B., & McIntosh, H. D. (1954). The effect of hypocapnia on arterial blood pressure. Circulation, 9(1), 89-95. https://doi.org/10.1161/01.CIR.9.1.89

Chandrasekaran, B., & Fernandes, S. (2020). "Exercise with facemask; are we handling a devil's sword?"-A physiological hypothesis. Medical Hypotheses, 144, 110002. https://doi.org/10.1016/j.mehy.2020.110002

Charloux, A., Lonsdorfer-Wolf, E., Richard, R., Lampert, E., Oswald-Mammosser, M., Mettauer, B., . . . Lonsdorfer, J. (2000). A new impedance cardiograph device for the non-invasive evaluation of cardiac output at rest and during exercise: Comparison with the "direct" fick method. European Journal of Applied Physiology, 82(4), 313-320. https://doi.org/10.1007/s004210000226

de Brito, L. C., Fecchio, R. Y., Peçanha, T., Lima, A., Halliwill, J., & de Moraes Forjaz, Claudia Lucia. (2019). Recommendations in post-exercise hypotension: Concerns, best practices and interpretation. International Journal of Sports Medicine, 40(08), 487-497. https://doi.org/10.1055/a-0938-4415

Eicher, J. D., Maresh, C. M., Tsongalis, G. J., Thompson, P. D., & Pescatello, L. S. (2010). The additive blood pressure lowering effects of exercise intensity on post-exercise hypotension. American Heart Journal, 160(3), 513-520. https://doi.org/10.1016/j.ahj.2010.06.005

Epstein, D., Korytny, A., Isenberg, Y., Marcusohn, E., Zukermann, R., Bishop, B., . . . Miller, A. (2020). Return to training in the COVID-19 era: The physiological effects of face masks during exercise. Scandinavian Journal of Medicine & Science in Sports. https://doi.org/10.1111/sms.13832

Fields, D. A., Hunter, G. R., & Goran, M. I. (2000). Validation of the BOD POD with hydrostatic weighing: Influence of body clothingin. International Journal of Obesity, 24(2), 200-205. https://doi.org/10.1038/sj.ijo.0801113

Fikenzer, S., Uhe, T., Lavall, D., Rudolph, U., Falz, R., Busse, M., . . . Laufs, U. (2020). Effects of surgical and FFP2/N95 face masks on cardiopulmonary exercise capacity. Clinical Research in Cardiology, 1-9. https://doi.org/10.1007/s00392-020-01704-y

Fink, S. (2020). Worst-case estimates for US coronavirus deaths. New York Times.Published March, 13.

Fukushi, I., Nakamura, M., & Kuwana, S. (2021). Effects of wearing facemasks on the sensation of exertional dyspnea and exercise capacity in healthy subjects. PloS One, 16(9), e0258104. https://doi.org/10.1371/journal.pone.0258104

Gentil, P., de Lira, Claudio Andre Barbosa, Souza, D., Jimenez, A., Mayo, X., de Fátima Pinho Lins Gryschek, Anna, . . . Paoli, A. (2020). Resistance training safety during and after the SARS-cov-2 outbreak: Practical recommendations. BioMed Research International, 2020. https://doi.org/10.1155/2020/3292916

Greenhalgh, T., Dijkstra, P., Jones, N., & Bowley, J. (2020). Exercising and face masks: An important hypothesis buried in a selective review. Medical Hypotheses. https://doi.org/10.1016/j.mehy.2020.110255

Halliwill JR, Buck TW, Lacewell AN, Romero SA. (2012). Postexercise hypotension and sustained postexercise vasodilatation: What happens after we exercise. Exp Physiol, 00(00), 1-12. https://doi.org/10.1113/expphysiol.2011.058065

Hopkins, S. R., Dominelli, P. B., Davis, C. K., Guenette, J. A., Luks, A. M., Molgat-Seon, Y., . . . Stickland, M. K. (2021). Face masks and the cardiorespiratory response to physical activity in health and disease. Annals of the American Thoracic Society, 18(3), 399-407. https://doi.org/10.1513/AnnalsATS.202008-990CME

Howley, E. T., Bassett, D. R., & Welch, H. G. (1995). Criteria for maximal oxygen uptake: Review and commentary. Medicine and Science in Sports and Exercise, 27, 1292. https://doi.org/10.1249/00005768-199509000-00009

Hwang, M. H., Yoo, J. K., Kim, H. K., Hwang, C. L., Mackay, K., Hemstreet, O., . . . Christou, D. D. (2014). Validity and reliability of aortic pulse wave velocity and augmentation index determined by the new cuff-based SphygmoCor xcel. Journal of Human Hypertension, 28(8), 475. https://doi.org/10.1038/jhh.2013.144

Jang, S., Han, S. H., & Rhee, J. (2020). Cluster of coronavirus disease associated with fitness dance classes, south korea. Emerging Infectious Diseases, 26(8), 1917. https://doi.org/10.3201/eid2608.200633

Johansson, B. (2020). Masking the general population might attenuate COVID-19 outbreaks. arXiv Preprint arXiv:2006.15626.

Kenney, M. J., & Seals, D. R. (1993). Postexercise hypotension. key features, mechanisms, and clinical significance. Hypertension, 22(5), 653-664. https://doi.org/10.1161/01.HYP.22.5.653

Kessler, H. S., Sisson, S. B., & Short, K. R. (2012). The potential for high-intensity interval training to reduce cardiometabolic disease risk. Sports Medicine, 42(6), 489-509. https://doi.org/10.2165/11630910-000000000-00000

Kishimoto, A., Tochikubo, O., & Ohshige, K. (2007). Relation between nocturnal arterial oxygen desaturation and morning blood pressure. Clinical and Experimental Hypertension, 29(1), 51-60. https://doi.org/10.1080/10641960601096786

Konstantinidis, D., Polyzos, D., Drogkaris, S., Tatakis, F., Manta, E., Kariori, M., . . . Thomopoulos, C. (2022). Common surgical masks and unattended blood pressure changes in treated hypertensive patients. Hypertension Research, 45(5), 911-914. https://doi.org/10.1038/s41440-022-00886-4

Kunstler, B., Newton, S., Hill, H., Ferguson, J., Hore, P., Mitchell, B. G., . . . Cole, K. (2022). P2/N95 respirators & surgical masks to prevent SARS-CoV-2 infection: Effectiveness & adverse effects. Infection, Disease & Health, 27(2), 81-95. https://doi.org/10.1016/j.idh.2022.01.001

Lendacki, F. R., Teran, R. A., Gretsch, S., Fricchione, M. J., & Kerins, J. L. (2021). COVID-19 outbreak among attendees of an exercise facility-Chicago, illinois, August-September 2020. Morbidity and Mortality Weekly Report, 70(9), 321. https://doi.org/10.15585/mmwr.mm7009e2

Litwinowicz, K., Choroszy, M., Ornat, M., Wróbel, A., & Waszczuk, E. (2022). Bayesian network meta-analysis of face masks' impact on human physiology. Scientific Reports, 12(1), 1-11. https://doi.org/10.1038/s41598-022-09747-z

Luttrell, M. J., & Halliwill, J. R. (2015). Recovery from exercise: Vulnerable state, window of opportunity, or crystal ball? Frontiers in Physiology, 6, 204. https://doi.org/10.3389/fphys.2015.00204

Marcal, I. R., Goessler, K. F., Buys, R., Casonatto, J., Ciolac, E. G., & Cornelissen, V. A. (2021). Post-exercise hypotension following a single bout of high intensity interval exercise vs. a single bout of moderate intensity continuous exercise in adults with or without hypertension: A systematic review and meta-analysis of randomized clinical trials. Frontiers in Physiology, 12, 675289. https://doi.org/10.3389/fphys.2021.675289

Roberge, R. J., Bayer, E., Powell, J. B., Coca, A., Roberge, M. R., & Benson, S. M. (2010). Effect of exhaled moisture on breathing resistance of N95 filtering facepiece respirators. Annals of Occupational Hygiene, 54(6), 671-677.

Roberge, R. J., Coca, A., Williams, W. J., Powell, J. B., & Palmiero, A. J. (2010). Physiological impact of the N95 filtering facepiece respirator on healthcare workers. Respiratory Care, 55(5), 569-577.

Scheid, J. L., Lupien, S. P., Ford, G. S., & West, S. L. (2020). Commentary: Physiological and psychological impact of face mask usage during the COVID-19 pandemic. International Journal of Environmental Research and Public Health, 17(18), 6655. https://doi.org/10.3390/ijerph17186655

Shaw, K. A., Zello, G. A., Butcher, S. J., Ko, J. B., Bertrand, L., & Chilibeck, P. D. (2021). The impact of face masks on performance and physiological outcomes during exercise: A systematic review and meta-analysis. Applied Physiology, Nutrition, and Metabolism, 46(7), 693-703. https://doi.org/10.1139/apnm-2021-0143

Shein, S. L., Whitticar, S., Mascho, K. K., Pace, E., Speicher, R., & Deakins, K. (2021). The effects of wearing facemasks on oxygenation and ventilation at rest and during physical activity. PLoS One, 16(2), e0247414. https://doi.org/10.1371/journal.pone.0247414

Sultanoğlu, H., Boğan, M., Erdem Sultanoğlu, T., & Altınsoy, H. B. (2021). Examination of physiological changes seen in workers using breathing masks during COVID-19 pandemic. Hospital Practices and Research, 6(3), 93-97. https://doi.org/10.34172/hpr.2021.18

Van Bortel, L. M., Laurent, S., Boutouyrie, P., Chowienczyk, P., Cruickshank, J. K., De Backer, T., . . . Protogerou, A. D. (2012). Expert consensus document on the measurement of aortic stiffness in daily practice using carotid-femoral pulse wave velocity. Journal of Hypertension, 30(3), 445-448. https://doi.org/10.1097/HJH.0b013e32834fa8b0

Zachary, Z., Brianna, F., Brianna, L., Garrett, P., Jade, W., Alyssa, D., & Mikayla, K. (2020). Self-quarantine and weight gain related risk factors during the COVID-19 pandemic. Obesity Research & Clinical Practice. https://doi.org/10.1016/j.orcp.2020.05.004

Zeigler, Z. S., Swan, P. D., Buman, M. P., Mookadam, F., Gaesser, G. A., & Angadi, S. S. (2018). Postexercise hemodynamic responses in lean and obese men. Med Sci Sports Exerc, 50(11), 2292-2300. https://doi.org/10.1249/MSS.0000000000001684

Zheng, C., Poon, E. T., Wan, K., Dai, Z., & Wong, S. H. (2022). Effects of wearing a mask during exercise on physiological and psychological outcomes in healthy individuals: A systematic review and meta-analysis. Sports Medicine, 1-26. https://doi.org/10.1007/s40279-022-01746-4