The Physiological and Subjective Effects of Exercising with a Face Mask at Different Intensities

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ABSTRACT

Introduction: Face masks are used to reduce the spread of respiratory diseases. Physical exertion increases distance traveled by expelled particles, so masking while exercising is recommended to help prevent disease transmission. However, there is limited literature assessing masking during higher-intensity exercise. **Purpose:** This study aimed to compare the impact of surgical masks on physiological and subjective measures during 45 min of a progressive exercise protocol as compared with unmasked exercise. **Methods:** Each subject completed two random 45-min exercise trials (15 min each at 40%, 60%, and 80% of their oxygen uptake reserve) with and without a surgical mask in random order. Heart rate, oxygen saturation, respiratory rate (RR), ratings of perceived exertion, and dyspnea (Dys) were measured at each intensity. Repeated-measures ANOVA was utilized, and significance was set at $P < 0.05$. **Results:** Thirty subjects (age, 20.4 ± 1.2 yr; peak oxygen uptake, 40.12 ± 11.05 $mL \cdot kg^{-1} \cdot min^{-1}$; 57% female) completed the study. When comparing masked and unmasked trials at each exercise intensity, differences were found only in RR (40%: 17.6 ± 4.9 vs 15.8 ± 4.9, $P < 0.02$, $d = 0.4$; 60%: 23.7 ± 5.5 vs 21.3 ± 6.2, $P < 0.01$, $d = 0.4$; 80%: 35.8 ± 9.0 vs 30.1 ± 8.8, $P < 0.01$, $d = 0.6$). When comparing masked with unmasked trials across all intensities, a difference was found in Dys (3.5 ± 2.4 vs 2.9 ± 2.2, respectively; $P < 0.001$, $d = 0.3$). **Conclusions:** The use of surgical masks seems to impact RR and one's perception of Dys, but has minimal influences on heart rate, oxygen saturation, and rating of perceived exertion. Other than increasing one's RR and perceptions of Dys, it seems that exercising with a mask at moderate and vigorous intensities is acceptable in healthy individuals.

INTRODUCTION

Throughout the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)—the virus that causes coronavirus disease 2019 (COVID-19)—pandemic, face-mask usage has become a common practice to reduce the spread of the virus by limiting the dispersion of infectious respiratory particles. As observed in previous literature, physical exertion produces marked increases in these particles. Mutsch et al. (1) reported a 132-fold average increase in aerosol particle emission from 580 ± 489 particles per minute during rest to 76,200 ± 48,000 particles per minute during maximal exercise. They noted moderate increases in aerosol particle emissions up to a workload of ~2 $W \cdot kg^{-1}$, but beyond that, exponential increases were seen (1). This substantial increase in aerosol particle emissions during exercise has contributed to several COVID-19 "super-spreader" events that have been reported with unmasked exercise at indoor fitness facilities since 2020 (2,3). Face mask use during exercise reduces the transmission of respiratory droplets and has the potential to reduce the spread of COVID-19 and other infectious respiratory diseases. Recommendations for face mask use by the Centers for Disease Control and Prevention in early 2023 depend on levels of SARS-CoV-2 in the local community and face masks are generally recommended in indoor public settings (including fitness facilities) when that level is medium or high (4).

As the COVID-19 pandemic has evolved, the knowledge base regarding the effects of mask use on health, safety, and performance during exercise continues to expand. Although a variety of studies and several meta-analyses have examined the physiological and performance effects of face mask use during exercise (5–20), there are still some remaining gaps in the literature. Much of the literature published examining the effects of face masks on physical performance have used either low-moderate intensity protocols or progressive exercise tests until exhaustion, typically with 2- to 3-min intervals at each work level with a total testing time of ~10–20 min (5–16). Although they reflect standard procedures for cardiopulmonary exercise testing, these exercise-to-exhaustion protocols do not

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evaluate a steady state and are not reflective of the time and submaximal intensity typically spent in conditioning activities performed by athletes and the exercising public.

Although tests to exhaustion do not replicate common patterns of training and conditioning, results from studies using these protocols can delineate the potential impacts of mask use during high-intensity activity. The physiological foundation for many potential effects of mask usage may be due to the changes in partial pressure of carbon dioxide that has been shown to accrue over time with high-intensity exercise while wearing face masks (20). Epstein et al. (14) examined the effects of masked versus unmasked exercise on end tidal carbon dioxide ($EtCO_2$) during a progressive time-to-exhaustion trial. Higher-intensity exercise while wearing a surgical mask resulted in increased $EtCO_2$ as compared with unmasked exercise, which reached statistical significance (40 ± 4 vs 35 ± 6 mm Hg, $P < 0.04$) at the study endpoint (14). Partial pressure of carbon dioxide closely correlates with $EtCO_2$, and this difference is sufficient to increase respiratory drive and sympathetic neural activation, which may result in significant changes in a variety of cardiopulmonary measures. Studies examining other effects of mask use during maximal exercise testing report conflicting findings regarding the influence of masks on heart rate (HR), oxygen saturation (SpO_2), ratings of perceived exertion (RPE), and exercise duration (11,12,15,16).

Several recent studies have looked at the effects of masking during bouts of submaximal activity at moderate-high levels of intensity. Poon et al. (19) compared the effects of exercise with and without surgical masks during an incremental treadmill protocol consisting of three 6-min stages at 25%, 50%, and 75% of maximal oxygen uptake ($\dot{V}O_{2max}$). They found no significant differences between HR and SpO_2 in the masked and unmasked trials at any intensity (19). RPE was higher when wearing a mask at 75% intensity, but no difference was found during low-moderate intensities at 25% and 50% (19). In contrast, Lässing et al. (18) examined the effects of surgical masks during a 30-min exercise bout at maximal lactate steady state and found no differences in RPE, but higher HR and lower ventilation and oxygen uptake during masked compared with unmasked exercise.

Throughout the COVID-19 pandemic, local mask mandates, Centers for Disease Control and Prevention guidelines, and individual personal preference influenced the use of a variety of cloth masks, surgical masks, and N95 respirators to help prevent transmission of the disease. In our observations, surgical masks were one of the most widely available and commonly used face masks, especially in fitness centers and exercise facilities. For these reasons, surgical masks were selected for use in the present study.

The inconsistencies in the literature regarding the impact of face mask use on physical performance and physiological parameters are of particular concern to physically active individuals. Particularly given the potential cumulative effects of increased carbon dioxide (CO_2) with higher intensity and longer bouts of activity, further studies examining the effects of mask use on select physiological and perceptual measures are needed. The purpose of our study was to assess the effects of surgical mask use with sustained higher-intensity exercise to better assess the impacts of mask use during real-life training and conditioning sessions.

METHODS

Ethics

Ethical approval for this study was obtained from the Institutional Review Board at the University of New England (072020-11). All participants provided voluntary, written informed consent for participation in this study. The study was performed in accordance with the Declaration of Helsinki (2013).

Participants

Because of the SARS-CoV-2 outbreak, recruiting off-campus participants was restricted during this period; therefore, participants consisted of healthy students recruited from the University of New England. Participants were required to be between the ages of 18 and 25 yr and engaged in a minimum of 30 min of exercise on average at least three times per week for at least 3 months. Participants were also required to be vaccinated against COVID-19. Exclusion criteria included testing positive for COVID-19 within the previous 6 months; active cardiovascular, metabolic (diabetes), or kidney disease; or other active medical condition or injury that would limit strenuous exercise testing.

Sample Size Determination

There is a paucity of data regarding exercise testing and training with all face masks. However, based on limited studies that utilized exercise training versus maximal exercise testing when assessing HR, SpO_2, and RPE, a sample size was determined. A power analysis was completed (G*Power, Kiel, Germany) with 80% power and 5% significance level, which indicated that a sample size of 28 subjects was needed to detect differences at this level (21).

Procedures

All exercise testing was performed at the Applied Exercise Science Laboratory at the University of New England. During their first visit, participants were fitted to the cycle ergometer (Monark Bike Ergometer LC&TT; Monark Exercise and Medical, Vansbro, Sweden) and to the silicone mask used for metabolic testing (7450 V2 Series; Hans Rudolph Inc., Shawnee, KS). Participants then exercised for 15 min (5 min at fairly light (RPE = 11), somewhat hard (RPE = 13), and hard (RPE = 15)) based on the 6–20 Borg RPE, to become familiar with the equipment and the Borg scale. During their second laboratory visit, participants completed a $\dot{V}O_{2peak}$ test. The test was conducted using a Parvomedics 2400 TrueOne metabolic cart (Parvo Medics, Salt Lake City, UT). Participants completed a 5-min warm-up immediately before the exercise test, with women performing the warm-up at 25 W and men at 50 W. Women began the exercise test at 50 W, and men began at 100 W. The differences in starting wattage between sexes were based on adjusting for increased body and muscle mass in males. The test consisted of 2-min stages with the intensity progressing by 25 W at each stage. At the completion of each stage, HR (Polar T31 and FT1; Polar Electro, Bethpage, NY) and RPE (Borg 6–20 scale) were collected. Participants were instructed to reach their maximal effort during the test. Each participant's $\dot{V}O_{2peak}$ was determined by averaging the two highest consecutive $\dot{V}O_2$ (mL·kg^{-1}·min^{-1}) values. From the averaged $\dot{V}O_{2peak}$ value, each participant's 40%, 60%, and 80% oxygen uptake reserve ($\dot{V}O_2R$) was calculated and converted to a specific wattage.

One week after the $\dot{V}O_{2peak}$ test, participants completed two exercise trials (1 wk apart)—one with a surgical-grade face mask and one with no face mask—on their third and fourth visits. A randomized table was used to assign the order of masked trials and nonmasked trials to each participant (n = 15 starting in both exercise trials). The masks were appropriately fitted to each subject, and the ear loops were crossed over the ears to maintain a snug fit to the participants' faces.

Participants were asked to rest for 24 h without exercising before each exercise trial. A dietary log for the day of the first trial was submitted before the session, and participants were asked to maintain a similar diet on the second trial day. Both exercise trials were completed a week apart at the same time of day (±2 h).

Before each trial, resting measurements for HR, SpO_2 (8500 handheld pulse oximeter; Nonin Medical, Inc., Plymouth, MN), and respiratory rate (RR; Cardionics, Inc. E-Scope, Webster, TX) were obtained. When subjects began cycling, workload was adjusted to meet 40% of their $\dot{V}O_2R$ for 15 min. The trials were identical and consisted of 15-min stages at 40%, 60%, and 80% of $\dot{V}O_2R$. HR, SpO_2, RR, RPE (Borg 6–20 scale), and dyspnea (Dys; Modified Borg 0–10 scale) were collected at the midpoint and endpoint during each 15-min exercise stage. Total exercise time was recorded if the subject could not complete all 45 min.

Statistical Analyses

Statistical analyses consisted of comparing the difference between wearing a mask and no mask at each exercise intensity with the variables of interest (HR, SpO_2, RR, RPE, and Dys). A repeated-measures ANOVA and Bonferroni *post-hoc* test for multiple comparisons were done using SPSS Version 27 (Statistical Package for the Social Sciences Inc., Chicago, IL), and $P < 0.05$ was used to determine significance.

RESULTS

A total of 31 subjects were recruited for the present study. One subject withdrew because of injury unrelated to our study; therefore, 30 participants completed the study (mean age, 20.4 ± 1.2 yr; height, 67.19 ± 3.80 inches; weight, 154.4 ± 21.1 lb; $\dot{V}O_{2peak}$, 40.12 ± 11.05 $mL \cdot kg^{-1} \cdot min^{-1}$; 57% female). The total exercise times of masked and unmasked trials showed no difference (43.2 ± 2.7 min vs 43.9 ± 2.6 min, $P > 0.05$).

Midpoint and endpoint values of the dependent variables of interest (HR, SpO_2, RR, RPE, and Dys) were averaged together. With respect to all dependent variables, when combining mask conditions, all three intensities (40%, 60%, and 80% of $\dot{V}O_2R$) were significantly different from each other ($P < 0.001$). Regarding differences between masked and unmasked conditions across the three intensities, Dys and RR were greater when masked (Dys: 3.5 ± 2.4 for masked and 2.9 ± 2.2 for unmasked, $P < 0.001$, $d = 0.3$; RR: 25.5 ± 10.2 for masked and 22.2 ± 9.0 for unmasked, $P < 0.05$, $d = 0.3$). With respect to the interaction between masked conditions and intensity, RR was greater with a mask at each intensity (40%: 17.6 ± 4.9 vs 15.8 ± 4.9, $P < 0.04$, $d = 0.4$; 60%: 23.7 ± 5.5 vs 21.3 ± 6.2, $P < 0.01$, $d = 0.4$; 80%: 35.8 ± 9.0 vs 30.1 ± 8.8, $P < 0.01$, $d = 0.6$), respectively (Table 1). We observed that the use of a surgical mask while exercising had no influence on HR, SpO_2, and RPE compared with unmasked exercise. However, we did see an overall influence on Dys when combining all three intensities and an increase in RR at all three intensities when wearing a surgical mask.

DISCUSSION

Of the dependent variables assessed in the present study, only Dys and RR were observed to be altered when wearing a surgical mask. Dys was greater when wearing a mask when combining all three intensities together, and RR was greater when wearing a mask at each intensity (40%, 60%, and 80% $\dot{V}O_2R$). No differences were observed with HR, SpO_2, or RPE when comparing masking conditions. In addition, no differences were observed in total exercise duration between masked and unmasked conditions.

The observed differences in Dys and RR may be due to the changes in $EtCO_2$ seen with mask use (20). Epstein et al. (14) reported a 5-mm-Hg increase in $EtCO_2$ in subjects exercising with a surgical mask compared with those exercising without a mask after a mean total exercise duration of 18.3 ± 3.7 min. The total exercise time in our study was far longer at 45 min, including the final stage in our study, which required 15 min of exercise at 80% $\dot{V}O_2R$. Although our study did not measure $EtCO_2$, this intensity is likely above the lactate threshold for our recreationally active subjects and may be expected to further augment the $EtCO_2$ changes seen with mask use in the study by Epstein et al. (14).

The increase in Dys when wearing a mask in our study is consistent with a 2022 meta-analysis that found a moderate effect of surgical masks on subjective Dys with physical exertion (22). A recent review proposed several potential mechanisms for this effect, including possible CO_2 rebreathing with mask use, as well as influences related to changes in temperature and/or moisture of the face and mask (23). In contrast to our Dys findings, the increased RR with mask use in this study is not consistent with previous literature, including a meta-analysis that did not show increased RR while exercising with a surgical mask (20). One factor that may account for the difference between our findings and those of others includes the longer time spent at each level of intensity in this study. Subjects in this study spent 15 min at each level of intensity, as compared with 6 min in a prior study (19), potentially increasing moisture retention and temperature within the mask as described previously. In addition, our protocol specifically enhanced surgical mask fit by crossing the ear loops in front of each ear, which has not been specifically described in most other studies to date. Improving the fit of the surgical mask potentially produced large changes in air filtration (23), which may have further increased rebreathing of exhaled CO_2 and subsequently influenced respiratory drive.

Our study found no differences in RPE between masking conditions. The meta-analysis by Shaw et al. (20), looking at the effects of mask use during exercise, reported that surgical masks were generally associated with small increases in RPE; however, this difference dissipated after elimination of studies at high risk for bias or those studies looking at maximal-intensity exercise.

Our study did not find differences in HR between masked and unmasked conditions, which is consistent with previous studies (6,12,14,19). Our findings differed from those of Lässing et al. (18), who reported greater increases in HR and other cardiac and pulmonary measurements when wearing a surgical mask over a 30-min constant-load exercise trial at a maximum lactate steady state. Because our subjects exercised for a total of 45 min (up to 80% of $\dot{V}O_2R$), it would seem reasonable that if the mask inhibited exercise performance, we would have observed an increase in HR when masked. However, it should be

TABLE 1.
Effects of Face Mask Use on Objective and Subjective Measures during Submaximal Progressive Cycling Exercise Protocol.

	$\dot{V}O_2R$								
	40%			60%			80%		
	WM	NM	*P*	WM	NM	*P*	WM	NM	*P*
HR (bpm)	124.3 ± 12.6 (119.5, 129.0)	123 ± 12.7 (118.3, 127.7) [0.1]	$P > 0.05$	155.8 ± 13.5 (150.8, 160.9)	153.7 ± 13.1 (148.8, 158.5) [0.2]	$P > 0.05$	179.3 ± 11.1 (175.1, 183.5)	176.8 ± 11.8 (172.3, 181.2) [0.2]	$P > 0.05$
SpO_2 (%)	96.3 ± 1.0 (95.9, 96.6)	96.3 ± 1.1 (95.8, 96.7) [0.0]	$P > 0.05$	95.1 ± 1.2 (94.6, 95.6)	95.5 ± 1.3 (95.0, 96.0) [0.3]	$P > 0.05$	94.5 ± 1.5 (93.9, 95.1)	95.0 ± 1.4 (94.5, 95.5) [0.3]	$P > 0.05$
RR (breaths per minute)	17.6 ± 4.9 (15.7, 19.4)	15.8 ± 4.9 (14.0, 17.6) [0.4]	$P < 0.05$*	23.7 ± 5.5 (21.6, 25.7)	21.3 ± 6.2 (19.0, 23.6) [0.4]	$P < 0.01$**	35.8 ± 9.0 (32.4, 39.1)	30.1 ± 8.8 (26.8, 33.4) [0.6]	$P < 0.001$***
RPE (6–20 Borg scale)	9.2 ± 1.6 (8.6, 9.8)	8.7 ± 1.8 (8.1, 9.4) [0.3]	$P > 0.05$	13.2 ± 1.2 (12.7, 13.6)	12.9 ± 1.7 (12.3, 13.5) [0.2]	$P > 0.05$	17.3 ± 1.4 (16.8, 17.8)	16.7 ± 1.6 (16.1, 17.3) [0.4]	$P > 0.05$
Dys (0–10 Borg scale)	1.2 ± 0.6 (1.0, 1.4)	0.9 ± 0.6 (0.7, 1.1) [0.5]	$P > 0.05$	3.1 ± 0.9 (2.7, 3.4)	2.6 ± 1.0 (2.3, 3.0) [0.5]	$P > 0.05$	6.1 ± 1.8 (5.4, 6.7)	5.2 ± 1.7 (4.5, 5.8) [0.5]	$P > 0.05$

Data presented as mean ± SD (95% confidence interval) [Cohen's effect size].
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.
NM, no mask; WM, with mask.

noted that Lässing et al. (18) placed the surgical mask under a spirometry mask when assessing their subjects, which could have greatly changed the resistance, most likely due to greater moisture being trapped within the mask, and could have been responsible for an upregulation of HR.

No difference in SpO_2 was observed between masked and unmasked conditions in the current study, which is supported by previous studies (12,16,19). However, the meta-analysis by Shaw et al. (20) did find small reductions in SpO_2 in studies looking at maximal exercise testing, but no SpO_2 reduction when submaximal exercise tests were used.

The present study is unique in that our 45-min exercise protocol is longer than many other prior studies in this area, and more reflective of time spent in sport and conditioning activities by athletes and the exercising public. In addition, although our subjects did not push into complete exhaustion, the 80% $\dot{V}O_2R$ in our protocol is higher than most other submaximal test protocols, and also more reflective of the intensities achieved by athletes during training and competition. With both greater duration and exercise intensity as observed by RPE (17.0 ± 1.5 at 80% $\dot{V}O_2R$), the only differences we observed between masked and unmasked conditions were reflective in Dys and RR. These findings are not likely to be of clinical consequence in young healthy adults and did not produce significant changes in our subjects' ability to complete a demanding exercise protocol. Although individuals partaking in high-intensity exercise should be aware that wearing a mask may lead to small increases in respiratory strain (RR and Dys) at a similar workload, our study suggests that surgical mask use with exercise in young, healthy adults does not interfere with their ability to perform and complete high-intensity conditioning/performance activity.

The main limitation of this study was that the study population consisted of young, healthy, physically active individuals. Therefore, these results should not be generalized to older populations or individuals with cardiac, metabolic, or pulmonary disease. Our results are also specific to surgical (also known as "procedural") masks and cannot be generalized to other mask types or respirators. In addition, our exercise trials were conducted in a controlled environment for 45 min, with participants only exercising at each intensity level for 15 min. Different results may be found if exercise is performed under conditions that may increase moisture retention in the mask, including longer exercise duration or exercising in warmer or more humid environments.

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The data sets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

REFERENCES

1. Mutsch B, Heiber M, Grätz F, et al. Aerosol particle emission increases exponentially above moderate exercise intensity resulting in superemission during maximal exercise. *Proc Natl Acad Sci U S A*. 2022;119(22):e2202521119.
2. Chu DKW, Gu H, Chang LDJ, et al. SARS-CoV-2 superspread in fitness center, Hong Kong, China, March 2021. *Emerg Infect Dis*. 2021;27(8):2230–2.
3. Jang S, Han SH, Rhee JY. Cluster of coronavirus disease associated with fitness dance classes, South Korea. *Emerg Infect Dis*. 2020;26(8):1917–20.
4. Centers for Disease Control and Prevention [Internet]. *When to Wear a Mask or Respirator*. Atlanta (GA): US Department of Health and Human Services [Updated 2022 Sept 9; cited 2022 Oct 3] Available from: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/about-face-coverings.html.
5. Kim JH, Benson SM, Roberge RJ. Pulmonary and heart rate responses to wearing N95 filtering facepiece respirators. *Am J Infect Control*. 2013;41(1):24–7.
6. Kim JH, Wu T, Powell JB, et al. Physiologic and fit factor profiles of N95 and P100 filtering facepiece respirators for use in hot, humid environments. *Am J Infect Control*. 2016;44(2):194–8.
7. Shein SL, Whitticar S, Mascho KK, et al. The effects of wearing facemasks on oxygenation and ventilation at rest and during physical activity. *PloS One*. 2021;16(2):e0247414.
8. Wong AY, Ling SK, Louie LH, et al. Impact of the COVID-19 pandemic on sports and exercise. *Asia Pac J Sports Med Arthrosc Rehabil Technol*. 2020; 22:39–44.
9. Roberge R, Benson S, Kim JH. Thermal burden of N95 filtering facepiece respirators. *Ann Occup Hyg*. 2012;56(7):808–14.
10. Roberge RJ, Kim JH, Benson SM. Absence of consequential changes in physiological, thermal and subjective responses from wearing a surgical mask. *Respir Physiol Neurobiol*. 2012;181(1):29–35.
11. Mapelli M, Salvioni E, De Martino F, et al. "You can leave your mask on": effects on cardiopulmonary parameters of different airway protective masks at rest and during maximal exercise. *Eur Respir J*. 2021;58(3):2004473.
12. Shaw K, Butcher S, Ko J, et al. Wearing of cloth or disposable surgical face masks has no effect on vigorous exercise performance in healthy individuals. *Int J Environ Res Public Health*. 2020;17(21):8110.
13. Fikenzer S, Uhe T, Lavall D, et al. Effects of surgical and FFP2/N95 face masks on cardiopulmonary exercise capacity. *Clin Res Cardiol*. 2020; 109(12):1522–30.
14. Epstein D, Korytny A, Isenberg Y, et al. Return to training in the COVID-19 era: the physiological effects of face masks during exercise. *Scand J Med Sci Sports*. 2021;31(1):70–5.
15. Driver S, Reynolds M, Brown K, et al. Effects of wearing a cloth face mask on performance, physiological and perceptual responses during a graded treadmill running exercise test. *Br J Sports Med*. 2022;56(2):107–13.
16. Fukushi I, Nakamura M, Kuwana S. Effects of wearing facemasks on the sensation of exertional dyspnea and exercise capacity in healthy subjects. *PloS One*. 2021;16(9):e0258104.
17. Jones JG. The physiological cost of wearing a disposable respirator. *Am Ind Hyg Assoc J*. 1991;52(6):219–25.
18. Lässing J, Falz R, Pökel C, et al. Effects of surgical face masks on cardiopulmonary parameters during steady state exercise. *Sci Rep*. 2020;10(1):22363.
19. Poon ET, Zheng C, Wong SH. Effect of wearing surgical face masks during exercise: does intensity matter? *Front Physiol*. 2021;12:775750.
20. Shaw KA, Zello GA, Butcher SJ, et al. The impact of face masks on performance and physiological outcomes during exercise: a systematic review and meta-analysis. *Appl Physiol Nutr Metab*. 2021;46(7):693–703.
21. Faul F, Erdfelder E, Lang AG, et al. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods*. 2007;39(2):175–91.
22. Glänzel MH, Barbosa IM, Machado E, et al. Facial mask acute effects on affective/psychological and exercise performance responses during exercise: a meta-analytical review. *Front Physiol*. 2022;13:994454.
23. Hopkins SR, Dominelli PB, Davis CK, et al. Face masks and the cardiorespiratory response to physical activity in health and disease. *Ann Am Thorac Soc*. 2021;18(3):399–407.