The effect of surgical face masks on physiological markers of endurance performance and heart rate recovery in amateur runners

Efecto de las mascarillas quirúrgicas en los marcadores fisiológicos del rendimiento de resistencia y la recuperación de la frecuencia cardíaca en corredores aficionados

Short title: Surgical masks and amateur runners

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Abstract

The use of protective face masks (PFM) has increased significantly since the advent of the COVID-19 pandemic. Their use is growing steadily, not only among healthcare personnel but also the general population. While PFMs are important for protection against airborne contaminants, their effect on physiological and autonomic responses during running has not been fully investigated. This study aimed to assess the impact of wearing a surgical mask on physiological indicators of endurance performance and heart rate recovery following aerobic exercise in amateur runners. Nine young males underwent a cardiopulmonary exercise test (CPET) and progressive square wave test (PSWT) on a treadmill with and without a surgical mask (SM). Cardiorespiratory parameters were evaluated during both CPET and PSWT, and autonomic parameters were measured during the 60-minute post-exercise recovery. The aerobic performance index showed that SM use resulted in lower peak VO_2 (ml/kg/min) ($p < 0.02$). However, no significant differences were found in anaerobic threshold, respiratory compensation point, and running economy with SM use ($p > 0.05$). Similarly, SM use did not affect heart rate recovery (HRR), RR intervals, and rMSSD during recovery compared to no mask (NM) use ($p > 0.05$). In conclusion, using a surgical mask may decrease aerobic performance under maximal conditions. However, its use did not limit physiological indicators of endurance performance or heart rate recovery in amateur runners during submaximal aerobic running.

Keywords: Aerobic fitness; Cardiorespiratory; Recovery; Respiratory.

Resumen

El uso de mascarillas protectoras (MP) ha aumentado significativamente desde el início de la pandemia de COVID-19. Su uso está creciendo de manera constante, no solo entre el personal sanitario, sino también en la población general. Aunque las MP son importantes para la protección contra contaminantes en el aire, su efecto en las respuestas fisiológicas y autonómicas durante la carrera no ha sido investigado completamente. Este estudio tuvo como objetivo evaluar el impacto del uso de una mascarilla quirúrgica en los indicadores fisiológicos del rendimiento de resistencia y la recuperación de la frecuencia cardíaca después del ejercicio aeróbico en corredores aficionados. Nueve hombres jóvenes se sometieron a una prueba de ejercicio cardiopulmonar (PECP) y a una prueba progresiva de onda cuadrada (PPOC) en una cinta de correr con y sin mascarilla quirúrgica (MQ). Se evaluaron los parámetros cardiorrespiratorios durante tanto la PECP como la PPOC, y se midieron los parámetros autonómicos durante los 60 minutos de recuperación post-ejercicio. El índice de rendimiento aeróbico mostró que el uso de la MQ resultó en un VO_2 pico (ml/kg/min) más bajo ($p < 0.02$). Sin embargo, no se encontraron diferencias significativas en el umbral anaeróbico, el punto de compensación respiratoria y la economía de carrera con el uso de la MQ ($p > 0.05$). De manera similar, el uso de la MQ no afectó la recuperación de la frecuencia cardíaca (RFC), los intervalos RR y el rMSSD durante la recuperación en comparación con el no uso de la mascarilla (NM) ($p > 0.05$). El uso de una mascarilla quirúrgica puede disminuir el rendimiento aeróbico bajo condiciones máximas. Sin embargo, su uso no limitó los indicadores fisiológicos del rendimiento de resistencia ni la recuperación de la frecuencia cardíaca en corredores aficionados durante la carrera aeróbica submáxima.

Palabras clave: Aptitud aeróbica; Cardiorrespiratorio; Recuperación; Respiratorio.

Introduction

The COVID-19 pandemic dramatically transformed global health practices, with respiratory protective masks becoming essential for both healthcare workers and the general population, with over 514 million confirmed cases and over 6.8 million deaths globally as of early March 2023 (John Hopkins University, 2023). While surgical masks effectively reduce pathogen transmission, their physiological impact during physical activity remains incompletely understood - a critical gap given the increasing popularity of mask use during exercise. (Vincent & Edwards, 2016).

Emerging evidence suggests COVID-19 itself significantly impairs athletic performance, with infected runners showing reduced VO_2max, slower running speeds, and prolonged recovery (Jafarnezhadgero et al., 2022; Śliż et al., 2022). These findings raise important questions about how protective equipment might further influence exercise physiology, particularly in amateur runners whose participation in endurance events has grown substantially in recent years (Lee et al., 2017).

In this context, for endurance athletes, optimal performance depends on precise cardiorespiratory coordination to meet oxygen demands and waste removal (Poole & Richardson, 1997; Prado et al., 2016). Key physiological markers, including anaerobic threshold (AT), running economy, and VO_2max, interact with autonomic regulation to determine exercise capacity (McArdle. D William et al., 2019). Of particular interest is heart rate recovery (HRV), a sensitive indicator of cardiovascular fitness that reflects the balance between sympathetic and parasympathetic activity (Boullosa et al., 2020; Hautala et al., 2009). The autonomic nervous system's responsiveness, measurable through HRV, becomes especially relevant when considering how facemasks may alter respiratory patterns and perceived exertion (Martín-Montero et al., 2023; Prado et al., 2022).

Current literature presents conflicting perspectives on mask use during exercise. While some studies report increased respiratory discomfort, others suggest minimal impact on aerobic performance (Prado et al., 2022). However, few investigations have specifically examined how surgical masks affect the integrated physiological response during running, particularly in amateur athletes. This represents a significant oversight, as even subtle alterations in ventilatory efficiency or autonomic regulation could influence training adaptations and competitive performance.

Therefore, this study aims to to evaluate the acute effect of wearing a surgical mask on physiological markers of endurance performance and heart rate recovery after aerobic exercise in amateur runners.

Methods

Subjects

The figure presents a CONSORT flow diagram detailing the enrollment, allocation, follow-up, and analysis of participants in the study (Figure 1). This study involved nine male amateur runners (26.7 ± 3.5 years, 65.2 ± 7.1 kg, 170.3 ± 5.9 cm, 48.7 ± 4.5 $mL\cdot kg^{-1}\cdot min^{-1}$). All participants had been running half-marathons for at least two years and had been running 23.1 ± 5.9 kilometers per week for the past three months, with a frequency of 3-4 weekly sessions. The participants were familiarized with running while wearing face masks, as they had previous experience using various types of face masks during training due to the COVID-19 pandemic, including the surgical masks used in this study. They self-reported that they had not been diagnosed with COVID-19 before or during the study, which was conducted in June 2020, during the most critical phase of the COVID-19 pandemic. The volunteers engaged exclusively in endurance training, without incorporating other forms of physical training or exercise modalities, and did not have any chronic diseases or injuries that could affect their performance during the study. No smokers were included in this investigation. Written informed consent was obtained from all participants before beginning the experiment, which was conducted according to the principles of the Declaration of Helsinki. The study was approved by the Research Ethics Committee of the Federal University of Piauí, Teresina, Brazil, under protocol number 4.429.909.

[please insert Figure 1 around here]

Study design

The volunteers who participated in the study were randomly assigned to perform running tests while wearing a surgical mask (SM) and without a mask (NM) in two different visits. Participants were randomly allocated to either the surgical mask (SM) or no mask (NM) group using a computer-generated randomization sequence. The allocation sequence was concealed until interventions were assigned to prevent selection bias. An independent researcher (not involved in data collection) handled group assignments to ensure blinding where possible. Tests were conducted from 9 am to 11 am, with a minimum interval of 48 hours between conditions. All testing occurred in a climate-controlled laboratory maintained at 22-24°C with 40-50% relative humidity. Each runner underwent three different tests: a pulmonary function test (PFT) to measure lung volume, capacity, and flow rates; a cardiorespiratory exercise test (CPET) to assess functional cardiorespiratory capacity; and a progressive square wave test (PSWT) to evaluate running economy (Herdy et al., 2016). The PFTs involve a series of non-invasive tests that evaluate lung function, including capacity, airflow, and gas exchange. Gas exchange and ventilatory variables during the PFT, CPET, and PSWT were measured continuously breath-by-breath using a metabolic analyzer system (Ergoestik Geratherm®, Germany). The running tests were conducted on a programmable treadmill (Inbramed model ATL, Brazil).

In this study, we used a disposable non-woven COVID-19 type II surgical mask. Its structure comprises a non-woven fabric layer, filter material (melt-blown fabric), nose clip, and mask belt. The mask is rectangular and contains three layers (World Health Organization, 2020). The spirometry mask was placed over the surgical mask and secured with head straps to ensure it was leak-proof. Both the investigators and the volunteer checked the mask's fit to ensure there was no leakage. The correct fitting and leak tightness were confirmed before each test to ensure accurate results.

The PFT was conducted before the CPET as per the recommendations of the American Thoracic Society (Graham et al., 2019). The CPET was conducted in order to determine maximal oxygen consumption (VO_2max), AT, and respiratory compensation point (RCP) (Herdy et al., 2016). The exercise workload (speed) was increased every minute during the incremental part of the exercise test, which lasted between 11 to 17 minutes (Brito et al., 2023). The starting speed was 7 km/h. The following criteria were used to define maximal effort: 1) the participant should demonstrate subjective evidence of exhaustion (perceived exertion) with a Borg scale above 17 (Borg, 1982) and either 2) peak HR ≥90% age-predicted maximum, or 3) maximal respiratory exchange ratio (RER) ≥1.10 (Howley et al., 1995). 24 hours after the CPET, the participants underwent a PSWT to determine running economy (RE) and cardiorespiratory response in steady-state conditions at 80% AT, AT, and RCP exercise intensity domains (Barner & Kilding, 2015). Each intensity domain lasted five minutes. The RE was calculated in terms of oxygen cost for a given distance using the following equation (di Prampero, 1986):

$$RE\ (mlO^2.kg^{-1}.km^{-1} = VO_2(ml.kg^{-1}.h^{-1}) \times 60 \div speed\ (km.h^{-1})$$

Heart rate was measured during the CPET via electrocardiography using a diagnostic-quality 10-lead system (Ergoestik Geratherm®, Germany). Heart rate decrease during the recovery phase was quantified during the PSWT as the absolute difference (Δ) between heart rate at RCP and heart rate determined at 5, 15, 30, 45, and 60 minutes during the recovery period. Heart rate variability (HRV) was assessed before (at rest) and every five minutes during the 60-minute post-exercise recovery period using an Android® smartphone with the Camera Heart Rate Variability app (Bentinckstraat 43h 1051 GE, Amsterdam, Netherlands) (Plews et al., 2017). The indices of HRV were: 1) the square root of the sum of the squared differences between RR intervals divided by the number of RR intervals minus one (rMSSD); and 2) the RR intervals. Data analysis was based on RR intervals in a 5-minute recording window. The raw data recorded by the app was exported as a text file and analyzed using Kubios HRV Standard software (version 3.2.0; Biosignal Analysis and Medical Imaging Group, Kuopio, Finland).

Statistical analysis

Data normality was assessed using the Shapiro-Wilk test. Parametric data were presented as mean ± standard deviation, while non-parametric data were presented as median with interquartile range. Mauchly's W test was used to verify sphericity, and the Greenhouse-Geisser correction was applied when necessary. For post-exercise heart rate and HRV analysis (RR, rMSSD, and SDNN), a two-way ANOVA with repeated measures and Bonferroni post-hoc tests were conducted to compare conditions (SM vs NM) across five post-exercise time points. Student's t-test was used to compare cardiopulmonary parameters between conditions. HRV at rest was compared using dependent t-tests for parametric data and Wilcoxon signed-rank tests for non-parametric data. Statistical analyses were conducted using IBM SPSS version 21 for Windows (IBM Corp., Armonk, NY, USA).

Results

The participants presented similar pulmonary function values for SM and NM (Table 1). Additionally, Figure 2 shows no differences in oxygen consumption (Panel A) or running economy (Panel B) between conditions at 80%AT, AT, and RCP ($p > 0.15$). However, the volunteers exhibited lower values for VO_2max ($mL \cdot kg^{-1} \cdot min^{-1}$ and $L \cdot min^{-1}$) ($p < 0.016$), VE max ($p = 0.001$), BF ($p = 0.002$), VT ($p = 0.039$), and exercise time ($p = 0.008$) while wearing the SM (Table 1).

[please insert Table 1 around here]

[please insert Figure 2 around here]

Table 2 shows the autonomic response of the participants during the 1-hour post-exercise recovery period. The participants showed no significant differences in HR between conditions ($F = 0.29$; $p = 0.86$) or between condition and time ($F = 0.59$; $p = 0.56$). However, a significant difference was found over the course of the recovery time ($F = 97.3$; $p < 0.01$). Similarly, the volunteers did not show significant differences in ΔHRR at any time point ($p > 0.05$) when comparing SM with NM conditions (Figure 3, Panel A). rMSSD did not differ between conditions (Figure 3, Panel B) and there was no interaction between condition and time ($F = 1.30$; $p > 0.13$). However, significant differences were found between time points ($F = 15.69$; $p < 0.01$). As seen in Figure 3, Panel C, RR did not differ between conditions ($F = 0.07$; $p = 0.79$). Additionally, there was no interaction between condition and time ($F = 1.08$; $p = 0.38$), but significant differences were found between time points ($F = 115.72$; $p < 0.01$).

[please insert Table 2 around here]

[please insert Figure 3 around here]

Discussion

To our knowledge, this represents one of the few prospective randomized cross-over trials examining the effect of surgical face masks on physiological markers of endurance performance and heart rate recovery following aerobic exercise in amateur runners. Within the context of our experimental conditions and sample characteristics, the principal observations suggest that wearing a surgical mask during submaximal aerobic running at various intensity domains may not substantially alter 1) key physiological markers of endurance performance, 2) heart rate recovery patterns, or 3) cardiac autonomic modulation during recovery. However, our data indicate a potential reduction in VO_2max with mask use. These findings should be interpreted considering several factors, including the relatively small sample size and the specific population of trained amateur runners, which may limit generalizability. Additionally, while the observed VO_2max reduction could suggest impaired maximal aerobic capacity, the absence of concurrent changes in related physiological parameters warrants further investigation with larger, more diverse cohorts and additional outcome measures.

As previously mentioned, during long-distance races, self-pacing is dependent on physiological markers of endurance performance (i.e., VO_2max, ventilatory thresholds, and running economy) (Poole & Richardson, 1997; Prado et al., 2016). In this context, our results suggest that the use of a SM reduces both VO2max and exercise tolerance. However, we observed that the runners showed no differences in both VO2 and speed at the ventilatory thresholds (i.e., AT and RCP) when wearing a SM. Similarly, our data did not show alterations in running economy at different exercise intensity domains with the use of a SM. Collectively, these findings suggest that the runners did not demonstrate alterations in either aerobic capacity or mechanical efficiency during submaximal running, despite the reduction in exercise tolerance at peak exercise with the use of a SM.

Another interesting point is how the HRR adapts to the use of a SM after the PSWT. Briefly, HRR is considered an important marker of cardiorespiraory fitness (Boullosa et al., 2020; Hautala et al., 2009). In this context, it is well known that fast recovery may be associated with better aerobic performance. The intensity of HRR is heavily influenced by several factors, including the characteristics of the population, the type, duration, and intensity of the exercise, and the recovery characteristics (Peçanha et al., 2014). Greater HRR has been reported in younger individuals compared to middle-aged participants and in physically active people compared to sedentary individuals (Trevizani et al., 2012), as well as after cycle ergometer compared to a treadmill exercise (Maeder et al., 2009). Interestingly, the autonomic nervous system modulation plays a key role in promoting an adequate hemodynamic response, such as an increase in heart rate and cardiac output.

It is worth mentioning that the runners showed a similar decline in heart rate recovery during the one-hour recovery period with SM use. In fact, our data reinforce previous findings that wearing a PFM during submaximal aerobic exercise does not lead to alterations in physiological function (Steinhilber et al., 2022). This is probably due to the fact that, while the use of face masks may lead to heightened dyspnea and changes in perceived effort, the impact on parameters such as the work of breathing, blood gases, and other physiological factors during physical activity is typically minimal and often falls below detectable levels (Hopkins et al., 2021). Furthermore, regarding heart rate variability, we did not find differences in autonomic modulation during the recovery period with SM compared to NM. Therefore, these findings imply that wearing an SM is safe and tolerable for amateur runners during aerobic exercise. Our results provide evidence that wearing a surgical face mask during running does not cause disturbances in cardiorespiratory response during moderate (i.e., 80% AT) and heavy (i.e., AT and RCP) submaximal exercise domains. This is in accordance with other recent investigations that observed little to no impact of face masks on cardiopulmonary response, especially during low-intensity exercise (Doherty et al., 2021; Fukushi et al., 2021; K. A. Shaw, Butcher, et al., 2021; Zhang et al., 2021).

On the other hand, our results show a decrease in ventilatory response at the peak of the maximal cardiorespiratory exercise test with SM use, considering parameters such as pulmonary ventilation, breathing frequency, and tidal volume. In fact, our data are in accordance with other studies, which found that the use of protective face masks leads to a decrease in both peak aerobic performance and ventilatory response, with increased breathing distress (Fikenzer et al., 2020; Morris et al., 2020; Prado et al., 2021; Ramos-Campo et al., 2021; Rosa et al., 2021; Shein et al., 2021). It should be noted that this finding may be due to a methodological limitation caused by the fitting of the CPET mask for data collection over the surgical face mask. This seals the protective face mask to the face, therefore not reflecting a real-life situation when wearing a protective face mask. Additionally, the protective face mask prevents the data-collection mask (i.e., the rubber/silicon mask) from forming a proper seal with the skin of the face, most likely resulting in air leakage from the data-collection mask (K. A. Shaw, Zello, et al., 2021).

Lastly, contrary to our results, several studies did not find any influence of SM, N95 (Epstein et al., 2020; K. Shaw et al., 2020), and cloth mask (K. Shaw et al., 2020) on maximum power, time to exhaustion, HR, and SpO2 after a maximal exercise test on a cycle ergometer. It is important to emphasize that future intervention studies with larger samples should be conducted to evaluate the effects of different types of protective face masks in other populations (i.e., untrained individuals, women, children, older adults, and professional athletes) on cardiorespiratory response during aerobic exercise.

This study has several important limitations that warrant consideration. First, the double-mask system (surgical mask + spirometry mask) used during testing may have compounded respiratory discomfort and influenced outcomes, particularly for VO_2max and ventilation measures. Without participant feedback on termination criteria, we cannot definitively separate physiological effects from potential discomfort-related influences. Second, the small sample size (n=12 from an initial pool of 20 volunteers) limits statistical power and generalizability, a constraint imposed by COVID-19 lockdown conditions. Third, the absence of blood lactate measurements precluded a more comprehensive analysis of metabolic stress, which could have clarified the dissociation between the observed VO_2max reduction and unchanged secondary markers (e.g., heart rate, AT). Future studies should employ larger cohorts, longitudinal designs, single-mask protocols where feasible, and multimodal assessments (e.g., lactate, perceived exertion) to isolate the true physiological impact of mask use during exercise.

Practical applications

The findings of this study suggest that wearing a surgical mask during submaximal aerobic running may not significantly alter physiological markers of endurance performance or heart rate recovery in amateur runners, though a reduction in VO_2max was observed under maximal effort. However, these results should be interpreted with caution due to several limitations. First, the small sample size may limit the generalizability of the findings. Second, the use of a double-masked setup (surgical mask + spirometry mask) during testing could have introduced additional respiratory discomfort, potentially confounding the physiological measurements. Without subjective feedback from participants regarding termination criteria, it remains unclear whether the observed VO_2max reduction stems from true physiological limitations or mask-related discomfort.

Declarations

Abbreviations

BF, breathing frequency; bpm, beats per minute; CPET, cardiopulmonary exercise test; FEV1, forced expiratory volume in 1 second; FEV1/FVC, forced expiratory volume in 1 second to functional vital capacity ratio; FVC, functional vital capacity; HR, heart rate; HR, heart rate; HRR, heart rate variability; HRV, heart rate variability; km/h, kilometres per hour; L, litres; L/s, litres per seconds; AT, anaerobic threshold; ms, milliseconds; NM, no mask; PEFR, peak expiratory flow rate; PFM, protective face mask; PFT, pulmonary function test; PSWT, progressive square wave test; RCP, respiratory compensation point; RE, running economy; RER, respiratory exchange ratio; RER, respiratory exchange ratio; rMSSD, root mean square of successive normal-to-normal interval differences; RR, R-R intervals; SDNN, standard deviation of normal-to-normal intervals; SM, surgical mask; VE, pulmonary ventilation; VO_2max, maximal oxygen consumption; VT, tidal volume; VVO_2, the speed at maximal oxygen consumption.

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Ethics approval and consent to participate: This study was approved by the ethics committee of the Federal University of Piauí, under protocol 4.429.909. All participants signed the informed consent form and all procedures were carried out in accordance with the guidelines proposed by the resolution 466/12 of the National Health Council.

Consent for publication: Not applicable.

Competing interests: The authors declare that they have no competing interests.

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Tables and Figure legends

Table 1. Physical and cardiorespiratory parameters

Anthropometry	
Age (Years)	26.67 ± 3.48
Body mass (kg)	65.22 ± 7.14
Stature (cm)	170.33 ± 5.93
Skeletal muscle mass (kg)	32.77 ± 4.80
Body fat (%)	15.15 ± 3.25

Pulmonary Function	**SM**	**NM**	**p**
FVC (L)	4.11 ± 0.56	4.25 ± 0.56	0.278
FEV_1 (L)	3.32 ± 0.35	3.25 ± 0.75	0.790
FEV_1/FVC (%)	80.76 ± 10.66	76.00 ± 14.58	0.485
PEPR (L/s)	6.07 ± 2.15	5.87 ± 1.19	0.793
CPET			
Peak of Exercise			
VO_2max ($mL.kg^{-1}.min^{-1}$)	44.82 ± 4.93	48.69 ± 4.52	0.013*
VO_2max ($L.min^{-1}$)	2.91 ± 0.33	3.15 ± 0.28	0.016*
VVO_2max (km/h)	16.78 ± 1.14	17.56 ± 0.69	0.065
Exercise time (mm:ss)	13:39 ± 1:51	15:28 ± 0:56	0.008*
Peak RER (Units)	1.14 ± 0.05	1.2 ± 0.05	0.115
Peak HR (bpm)	175.13 ± 14.88	184.44 ± 5.70	0.119
Peak O_2 pulse (mL/bpm)	17.08 ± 3.45	16.97 ± 2.37	0.992
VE max ($L.min^{-1}$)	86.11 ± 13.88	113.00 ± 16.22	0.001*
BF ($b.min^{-1}$)	44.33 ± 5.26	54.56 ± 7.16	0.002*
VT ($L.min^{-1}$)	1.95 ± 0.20	2.13 ± 0.32	0.039*
Anaerobic Threshold			
VO_2 ($mL.kg^{-1}.min^{-1}$)	30.72 ± 3.62	30.00 ± 3.31	0.716
VO_2 ($L.min^{-1}$)	1.95 ± 0.18	1.94 ± 0.22	0.771
Speed (km/h)	10.78 ± 1.58	10.58 ± 1.50	0.519
HR (bpm)	146.89 ± 13.48	140.11 ± 14.32	0.241
Respiratory compensation point			
VO_2 ($mL.kg^{-1}.min^{-1}$)	41.41 ± 6.55	39.17 ± 4.87	0.266
VO_2 ($L.min^{-1}$)	2.66 ± 0.30	2.53 ± 0.17	0.330
Speed (km/h)	14.89 ± 2.32	14.02 ± 1.78	0.247
HR (bpm)	174.57 ± 21.90	169.29 ± 14.27	0.637

Data are presented as mean and standard deviation. Symbols and abbreviations: SM: surgical mask; NM: no mask; *: significant difference between NM and SM; FVC: functional vital capacity; FEV_1: forced expiratory volume in 1 second; FEV_1/FVC: forced expiratory volume in 1 second to functional vital capacity ratio; PEFR: peak expiratory flow rate; VO_2max: maximal oxygen consumption; VVO_2: the speed at maximal oxygen consumption; RER: respiratory exchange ratio; HR: heart rate; VE: pulmonary ventilation; BF: breathing frequency; VT: tidal volume; L: litres; L/s: litres per seconds; km/h: kilometres per hour; bpm: beats per minute.

Table 2. Heart rate variability parameters during the post-exercise 60-min recovery period with SM and NM.

Time	Condition	HR (bpm)	RR (ms)	rMSSD (ms)
5 min	NM	96.3 ± 7.9	615.7 ± 44.9	29.2 ± 38.1
	SM	94.0 ± 11.2	627.3 ± 62.0	13.9 ± 11.9
15 min	NM	87.7 ± 6.9[a]	671.9 ± 39.9[a]	23.2 ± 19.7
	SM	87.3 ± 11.4	661.3 ± 46.4	21.0 ± 15.9
30 min	NM	80.7 ± 8.3[ab]	729.7 ± 54.5[ab]	32.6 ± 14.3
	SM	80.1 ± 8.5[ab]	733.6 ± 56.1[ab]	35.4 ± 22.1[b]
45 min	NM	76.1 ± 5.3[abc]	790.7 ± 53.5[abc]	60.3 ± 16.8
	SM	77.1 ± 7.5[ab]	785.0 ± 75.8[ab]	59.5 ± 23.9[ab]
60 min	NM	70.8 ± 6.2[abcd]	851.8 ± 73.8[abcd]	59.1 ± 24.2[c]
	SM	72.75 ± 9.2[ab]	822.3 ± 87.3	50.9 ± 26.0[a]

Data are presented as mean and standard deviation. Symbols and abbreviations: a: significant difference compared to 5 minutes; b: significant difference compared to 15 minutes; c: significant difference compared to 30 minutes; d: significant difference compared to 45 minutes; NM: no mask; SM: surgical mask; HR: heart rate; RR, R-R intervals; rMSSD: root mean square of successive normal-to-normal interval differences; ms: milliseconds; bpm: beats per minute.

Figure 1. CONSORT flow diagram.

Figure 2. Aerobic endurance parameters of the participants during a PSWT with and without the use of a surgical mask at different exercise intensities domains. Panel A= Oxygen consumption (VO_2); Panel B= running economy (RE); Abbreviations: AT= anaerobic threshold; PSWT= progressive square wave test; RCP= respiratory compensation point

Figure 3. Autonomic response of the participants during the recovery after a CPET with and without the use of a surgical mask at different exercise intensities. Panel A= Delta of the heart rate recovery (HRR); Panel B= square root of the mean squared differences between adjacent R-R intervals (rMSSD); Panel C= RR intervals. Abbreviations: CPET= cardiopulmonary exercise test; bpm= beats per minute; ms = millisecond