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Original article

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"You can leave your mask on": effects on cardiopulmonary parameters of different airway protection masks at rest and during maximal exercise

*Massimo Mapelli[1,2], *Elisabetta Salvioni[1], Fabiana De Martino[1], Irene Mattavelli[1], Paola Gugliandolo[1], Carlo Vignati[1,2], Stefania Farina[1], Pietro Palermo[1], Jeness Campodonico[1], Riccardo Maragna[1,2], Gerardo Lo Russo[1,2], Alice Bonomi[1], Susanna Sciomer[3], Piergiuseppe Agostoni[1,2]

**Shared first author privilege*

1) Centro Cardiologico Monzino IRCCS, Milan, Italy

2) Department of Clinical Sciences and Community Health, Cardiovascular Section, University of Milan, Milan, Italy

3) Dipartimento di Scienze Cardiovascolari, Respiratorie, Nefrologiche, Anestesiologiche e Geriatriche, "Sapienza", Rome University, Rome, Italy

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Corresponding author: Prof. Piergiuseppe Agostoni, MD, PhD

Heart Failure Unit

Centro Cardiologico Monzino, IRCCS

Via Carlo Parea 4, 20137, Milan (Italy)

Phone: +390258002930

Fax: +390258002266

E-mail: piergiuseppe.agostoni@cardiologicomonzino.it

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Abstract

Background

During the COVID-19 pandemic, the use of protection masks is essential to reduce contagions. However, public opinion reports an associated subjective shortness of breath. We evaluated cardiorespiratory parameters at rest and during maximal exertion to highlight any differences with the use of protection masks.

Methods

Twelve healthy subjects underwent three cardiopulmonary exercise tests: without wearing protection mask, with surgical and with FFP2 mask. Dyspnea was assessed by Borg Scale. Standard pulmonary function tests were also performed.

Results

All the subjects (40.8±12.4 years; 6 males) completed the protocol with no adverse event. At spirometry, from no mask to surgical to FFP2, a progressive reduction of FEV_1 and FVC was observed (3.94±0.91l, 3.23±0.81l, 2.94±0.98l and 4.70±1.21l, 3.77±1.02l, 3.52±1.21l, respectively, $p<0.001$). Rest ventilation, O_2 uptake ($\dot{V}O_2$) and CO_2 production (VCO_2) were progressively lower with a reduction of respiratory rate. At peak exercise, subjects revealed a progressively higher Borg scale when wearing surgical and FFP2. Accordingly, at peak exercise, $\dot{V}O_2$ (31.0±23.4, 27.5±6.9, 28.2±8.8ml/kg/min, p=0.001), ventilation (92±26, 76±22, 72±21l, p=0.003), respiratory rate (42±8, 38±5, 37±4, p=0.04) and tidal volume (2.28±0.72, 2.05±0.60, 1.96±0.65l, p=0.001) were gradually lower. We did not observed a significant difference in oxygen saturation.

Conclusions

Protection masks are associated with significant but modest worsening of spirometry and cardiorespiratory parameters at rest and peak exercise. The effect is driven by a ventilation reduction

due to an increased airflow resistance. However, since exercise ventilatory limitation is far from being reached, their use is safe even during maximal exercise, with a slight reduction in performance.

Introduction

In March 2020, the World Health Organization declared a new pandemic by a new coronavirus (COVID-19) which has heavily influenced social life and health organization all over the world [1-5]. Among the different protective procedure introduced, the use of protection masks (both surgical mask and filtering facepiece particles class 2; FFP2) has been indicated as essential to reduce viral transmission and allow to contain the number of patients in order to avoid the overload of the healthcare systems [6-8].

However, despite the absence of definitive data on the respiratory effects related to the use of protection masks, there is a general belief that their use is associated with shortness of breath during exercise and the need of a greater respiratory effort even at rest, leading to the potential risk of reducing the application of an effective measure that contains infection.

In this study, we aimed to evaluate cardiorespiratory parameters, both at rest and during maximal exertion, assessable through cardiopulmonary exercise test (CPET), to highlight any differences with the use of surgical masks and FFP2 masks compared to normal conditions.

Methods.

This study has an interventional, prospective, randomized, double-blind and cross over design.

Twelve healthy subjects, both males and females, were enrolled in July 2020. Inclusion criteria were age≥18 years and signature of the informed consent. Exclusion criteria were the presence of underlying cardiorespiratory diseases, history of COVID-19 infection, presence of any chronic drug treatment, inability or clinical contraindications to perform a maximal exercise. Intense physical efforts were forbidden in the 24 hours preceding each test. All subjects were nonsmokers and none were professional athletes or involved in an intense exercise training program.

All subjects underwent three consecutive CPETs performed at least 24 hours apart but within 2 weeks, in the following conditions: wearing a sham protection mask, with surgical mask (disposable medical mask, Aiminde, China) and with FFP2 mask (KN95 particulate respirator, BYD care, China). In all conditions the masks were worn under the standard CPET silicone mask (Cosmed, Italy) prepared by medical personnel not associated to the study and they were externally indistinguishable from each other (see

Figure 1). The absence of lateral air leakage was carefully verified as a standard used procedure in CPET laboratories before each test. Specifically, after wearing the CPET mask, we performed maximal expiration and inspiration maneuvers while closing the anterior mask valve with the palm of the hand, checking for any air leaks. The execution order of the CPETs was assigned in a randomized fashion to cover all possible combinations (Figure 1). Symptom-limited incremental exercise tests were performed on an electronically braked cycle ergometer (Corival-Lode, The Netherland) using a personalized ramp protocol (the same across the three CPETs in every subject) aimed at achieving peak exercise in ~10 minutes [9]. All subjects had previously performed a CPET at our laboratory. During the execution of the tests, subjects were allowed to see their rpm, but all other variables, including time, workload, heart rate and gas exchange parameters were obscured to them.

Ventilation (V_E) and respiratory gases were measured breath by breath (Quark PFT Cosmed cart, Roma, Italy). Heart rate (HR), 12-lead ECG, and hemoglobin saturation (SaO_2, measured through finger oxymeter) were monitored continuously, while blood pressure was monitored with a cuff sphygmomanometer at rest and every 2 minutes during exercise. Anaerobic threshold was identified using a V-slope analysis of oxygen intake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$), and it was confirmed by specific trends of V_E vs. $\dot{V}O_2$ ($V_E/\dot{V}O_2$) and CO_2 ($V_E/\dot{V}CO_2$), and of end-tidal pressure of O_2 ($PetO_2$) and CO_2 ($PetCO_2$)[10, 11]. Peak exercise was the highest $\dot{V}O_2$ value observed. Respiratory gas exchange ratio (RER) was calculated as $\dot{V}CO_2/\dot{V}O_2$. The $\dot{V}O_2$/work relationship was calculated throughout the exercise test, while the V_E vs. $\dot{V}CO_2$ slope was calculated from the beginning of exercise up to the respiratory compensation point [12]. Y intercept of V_E vs $\dot{V}CO_2$ slope relationship, a value related to dead space V_E, was calculated as previously reported [13]. All tests were analyzed a posteriori by a CPET expert blinded to the steps of the study. Specifically, data during exercise were analyzed as follows: five steps of exercise were considered: rest, peak, 25%, 50% and 75% of maximal workload reached in the test with the sham mask. Consequently, for surgical and FFP2 mask tests, intermediate steps data were reported at the workload (Watt) corresponding to 25, 50 and 75% of maximal workload of the sham mask test. Accordingly, except than at peak exercise, respiratory and gas exchange parameters were analyzed in each patient at iso-Watts.

Subjects' degree of dyspnea was assessed by Borg Scale [14] at rest, after 3 minutes, after 6 minutes and at peak exercise.

Maximal Inspiratory pressure (MIP) and Maximal Expiratory Pressure (MEP) were assessed immediately before and after the end of each exercise as a mean of three consecutive measures (Microrpm respiratory muscle testing, Vyaire).

Standard pulmonary function tests were also performed at rest with a standard mouthpiece and in all three study conditions through the CPET mask (Quark PFT Cosmed, Roma, Italy). Spirometry was performed according to current guidelines [15]. Predicted values are from Quanjer et al. [16].

All participants signed a written informed consent and the protocol was approved by the local Ethics Committee (R1265/20-CCM 1344).

Statistical analysis.

Data are reported as mean ± standard deviation or as frequency and percentage. CPET data were analyzed breath by breath except for peak $\dot{V}O_2$ analysis (averaged over 20 seconds).

Differences between the three protocol conditions were analyzed by repeated measures ANOVA. Trends were assessed by ANCOVA.

For each subject, we calculated the workload corresponding to 25%, 50%, and 75% of the maximal load reached during the test performed without wearing a mask, and we compared the corresponding V_E, $\dot{V}O_2$, and $\dot{V}CO_2$ values between the CPETs in the three conditions at the same workloads. Analyses were carried out with the SAS statistical package v. 9.4 (SAS Institute Inc., Cary, NC, USA), and all tests were 2-sided. $P<0.05$ was considered as statistically significant.

Results.

All the subjects (40.8±12.4 years; 6/6 males/females) completed the study protocol with no adverse event.

*Data at rest.*Spirometry performed with a mouthpiece showed FEV_1 108±19 % predicted and FVC = 104±15 % predicted. Spirometry, cardiorespiratory parameters, and inspiratory/expiratory pressures measured at rest in the 3 experimental conditions are reported in Table 1. At spirometry, from no mask ► surgical ► FFP2 a progressive reduction of FEV_1 and FVC was observed (Figure 2, upper panels). In parallel, inspiratory time (Ti) and expiratory times (Te) increased both at rest and at peak exercise (Figure 2, lower panels). Resting tidal volume (TV) was unaffected by the type of mask, MIP and MEP were also unaffected (Table 1). However, from no mask ► surgical ► FFP2, V_E was progressively lower due to a respiratory rate (RR)reduction, as well as $\dot{V}O_2$, $\dot{V}CO_2$, $PetO_2$ being lower.

Exercise data.

Exercise parameters are shown in Table 2. In all conditions, a maximal or nearly maximal effort was reached, as confirmed by RER>1.05 in all cases. At peak exercise, all subjects revealed a progressively higher Borg scale value from no mask ► surgical ► FFP2 (Figure 2), suggestive of a greater dyspnea when wearing surgical and FFP2 masks. In parallel, a reduction of peak exercise workload (Watts) was observed when wearing FFP2 mask, while HR and blood pressure (BP) values did not differ. Anaerobic threshold was identified in all subjects and in all study conditions. At the anaerobic threshold (Table 2), $\dot{V}O_2$ was reduced when wearing a mask without a significant reduction of workload, and with unchanged HR and SaO_2 values. From no mask ► surgical ► FFP2, the $\dot{V}O_2$/work (9.7±1.0, 9.4±0.9, 9.7±1.3, respectively) and V_E/ $\dot{V}CO_2$ slope relationship (27.5±3.7, 28.1±3.7, 26.6±5.0, respectively) did not show any significant change (p = NS, for all). Similarly, the Y-intercept [13] on the V_E/VCO_2 relations did not significantly change (4.9±2.1 L, 3.3±1.4 L, 3.5±1.4 l from no mask ► surgical ► FFP2, respectively, p= NS). At peak exercise (Table 2), $\dot{V}O_2$, CO_2 production ($\dot{V}CO_2$), V_E, RR, and TV were lower while wearing different types of mask. Figure 4 (panel a, b, and c) shows the behavior of $\dot{V}O_2$, $\dot{V}CO_2$, and V_E through exercise. In parallel to the V_E changes during exercise, SaO_2 (as a trend), $PetO_2$ and $PetCO_2$ varied. Specifically, despite a significant trend in oxygen saturation reduction, no significant inter-group difference was observed. This datum was paralleled by increased and reduced $PetCO_2$ and $PetO_2$, respectively, from no mask ► surgical ► FFP2. Ti was significantly longer during exercise wearing the two types of masks then in standard condition. MIP and MEP, collected immediately after the end of exercise, did not differ across the groups.

Discussion

In this experimental study on healthy subjects we demonstrated how the use of protection masks (both surgical mask and FFP2 mask) is associated with a significant worsening of FEV_1 and FVC and of cardiorespiratory parameters both at rest and at peak exercise. At rest, $\dot{V}O_2$, $\dot{V}CO_2$, and V_E decreased, the latter due to a RR reduction which was paralleled by an increase in Ti. At peak exercise, increase in dyspnea and reduction in peak $\dot{V}O_2$ measured during a standardized maximal effort at CPET were observed. The effect is predominantly driven by a reduction in V_E. Specifically, our data suggest that V_E is reduced due to a decrease in both RR and TV along with the three conditions, with a parallel increase in Ti.

During respiratory virus outbreaks, such as the current COVID-19 pandemic, protection masks, together with social distancing, have proven to be essential devices for the containment of the infection, both in everyday life and in hospitals, where health workers most often use FFP2 masks [8, 17, 18]. The presence of breathing discomfort in the general population - not accustomed to their daily use - has been frequently reported by word of mouth and social networks [19], even becoming a potentially dangerous political statement for some [20]. Few previous peer-reviewed publications, , have demonstrated the meaningless clinical impact of wearing protection masks, both in healthy subjects and in patients with respiratory diseases (COPD) although in absence of accurate cardiorespiratory parameters [21-23]. Regardless, in the public opinion, the long-term practicability and tolerability of protection mask are still questioned, and, in spite of their mandatory use, they are frequently worn below nose and mouth, thus becoming useless.

In the present study, we selected 12 healthy subjects who were already familiar with CPET in our laboratory. Subjects were representative of the general population, and indeed, observed peak exercise $\dot{V}O_2$ with no mask was 101% of the predicted value. Masks slightly affected breathing pattern even at rest, as shown by light breathing discomfort referred by some subjects (Figure 2). Notably, a similar observation was reported in two previous reports [24, 25]. We performed spirometry with a commercial

CPET mask as previously demonstrated as adequate by others [26, 27]. In the present study, spirometry with different masks showed a reduction of FEV_1 and FVC which was paralleled by a longer Ti [25]. This datum is consistent with an increased resistance to air flow during inspiration [25, 28]. Of note, some voluntary hyperventilation at rest was present in all conditions as shown by the relatively high RR and $PetO_2$ values. However, from no mask ► surgical ► FFP2 a progressive reduction of V_E, $\dot{V}O_2$, $\dot{V}CO_2$, and $PetO_2$ was observed revealing an involuntary adjustment of V_E to the variable flow resistance. Given the rapidity of this ventilatory adaptation - the masks were worn just before starting the CPET - these changes could be explained by a rapid adaptation of the chemoreceptor to tolerate higher arterial CO_2 and lower O_2 values. Alltogether, these data at rest deserve some summary comments: a) subjects showed the capability to spontaneously adapt to the increased airflow resistance by reducing V_E, $PetO_2$, $\dot{V}O_2$, and $\dot{V}CO_2$ with an unchanged RER, suggesting rapid chemoreceptor response; b) although RER was in the normal range for resting condition and a sufficient resting time was allowed, some voluntary hyperventilation was present in all conditions as shown by RR and $PetO_2$; involuntary altered breathing pattern was hampered by the increased airflow resistance. Indeed, subjects responded to this resistance by self-adjusting Ti and Te, likely to minimize their respiratory effort. In other words, given the increased cost of breathing while wearing protection masks, healthy subjects trigger an innate mechanism by maintaining their V_E to a lower set point.

Protection masks did not affect gas exchange kinetics pattern, since V_E/ $\dot{V}CO_2$ slope and $\dot{V}O_2$/work relationships were unchanged. However, a slight anticipation of the threshold metabolism was observed$\dot{V}O$ with protection masks. It must be underlined that, as well as others [24, 25, 28], we studied the effects on respiration of various types of surgical masks worn under the standard CPET silicon mask both during spirometry and CPET. This was necessary to allow respiratory gases measurements. It is possible, but unknown, that the silicone mask *per se* influence the respiratory function, albeit minimally.

The reported index of dyspnea at peak exercise showed a clear worsening with masks (Figure 2). At peak exercise, with the different types of masks V_E decreased for a greater extent compared to $\dot{V}O_2$ and $\dot{V}CO_2$, a datum accompanied by an increased Ti and again suggestive of increased resistance to air flow. Of note, a proper ventilatory limitation, assessed applying the standards for exercise limitation during CPET, was not observed [29]. Indeed, peak exercise breathing reserve, as measured by [(FEV1 x 35) – observed V_E][30] was always >20l/m, being 45.5 ± 25.9, 61.6 ± 19.5, and 66.1 ± 22.9 with no mask ► surgical ► FFP2. Indeed, an increased resistance of the masks has been shown also by spirometry data. Accordingly, it is possible to hypothetized that the reduced V_E at peak exercise is due to an increased airway opening resistance reducing ventilatory capacity, then leading to dyspnoea and reduced performance.$\dot{V}O$ Regardless of the reduction of SaO_2, V_E, TV and the increase in Ti, all speak in favor of a V_E mediated effect of masks on exercise performance, which was clearly reduced as shown by the lower peak $\dot{V}O_2$ and workload achieved. Of note, we observed neither signs of respiratory fatigue, as shown by an unchanged peak exercise MIP and MEP, nor ventilatory limitation to exercise. Unfortunately, flow/volume curves during exercise were not performed, to avoid any possible interference of these respiratory maneuvers with peak exercise performance. Since our results were obtained in a population of middle-aged healthy subjects, more studies are needed to assess the cardiorespiratory effects of various protection masks on exercise performance in elderly subjects or in patients with proven exercise limitation. Finally, we analyzed the effects of masks using a maximal workload incremental protocol aimed at achieving peak exercise in ≈10 minutes performed in a temperature and humidity controlled laboratory located at sea level. This is the gold standard for maximal exercise performance evaluation [12, 31]. However, efforts performed with different exercise protocols as for instance during daily life activities [32], or in different ambient conditions (i.e. temperature, humidity or at altitude) may produce different results. Indeed, in these conditions the effects of protection masks are unknown. protection

In conclusion, the use of protection masks in healthy middleaged subjects: a) slightly influences cardiorespiratory variables at rest and during exercise, b) reduces peak $\dot{V}O_2$ by ~ 10% due to an increase in airflow resistance, but V_E limitation was far from being reached. Accordingly, the population should be aware that the use of protection masks in healthy subjects is associated with a modest respiratory discomfort but their use is safe even during maximal exercise, albeit with a slight reduction in performance.

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Figure Legend

Figure 1

Schematic representation of the protocol procedures. The 12 subjects were randomized to perform the tests wearing the masks in a different sequence: 1) The mask was cut to mimic the “no mask” condition in a blinded manner 2) Surgical mask 3) FFP2 mask.

Figure 2

Upper panel: FEV_1 (left) and FVC (right) results obtained with no mask (green), with surgical mask (red) and with FFP2 (blue) at standard spirometry.

Lower panel: Relationship between FEV_1 and inspiratory time (Ti) with sham mask (green), with surgical mask (red) and with FFP2 (blue) at rest (left) and at peak exercise (right). * = $p < 0.05$ vs. sham mask.

Figure 3

Box plot of Borg scale values declared by the subjects before the effort (rest), after 3 minutes of exercise, after 6 minutes and at peak with sham mask (green), with surgical mask (red) and with FFP2 (blue) at rest (left) and at peak exercise (right). * = $p < 0.05$ between gropus.

Figure 4

Trend of cardiopulmonary variables during ramp exercise compared to the percentage of exercise performed. The exercise percentage has been calculated with respect to the peak workload reached by each subject during the basal test (with sham mask). Upper panel: Oxygen uptake expressed as $\dot{V}O_2$/kg, Middle panel: Ventilation (V_E), Lower panel (CO_2 production ($\dot{V}CO_2$).

*: $p<0.05$ among the three conditions.

Data sharing:

• All raw data collected for the study will be made available to others after request. Data will be stored in anonymized form at www.zenodo.org when the paper will be published.

Take home message:

Protection masks use in healthy subjects is associated with a modest respiratory discomfort, a slight reduction in exercise performance mainly due to due to an increase in airflow resistance.

Table 1: Rest values at cardiopulmonary exercise test in the three protocol conditions.

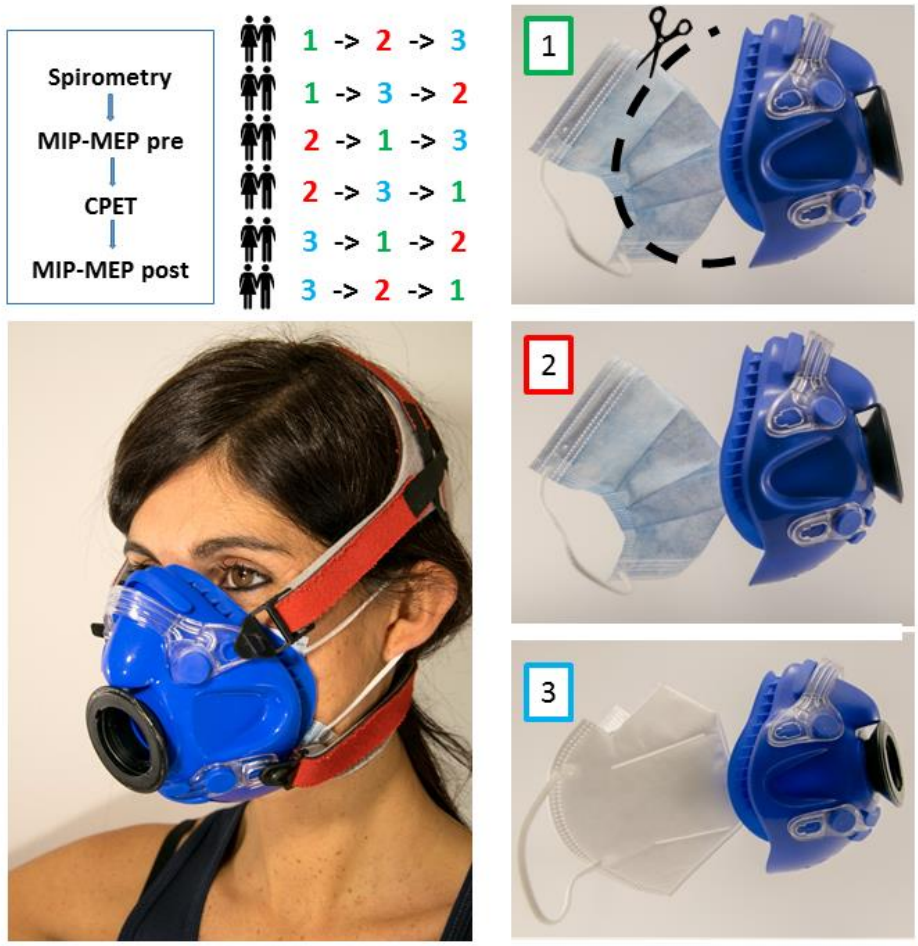
	Sham Mask			**Surgical Mask**			**FFP2**			**p for trend**	**P ANOVA**	**No mask Vs Surgical Mask**	**No mask Vs FFP2**	**FFP2 Vs Surgical Mask**
SBP (mmHg)	113	±	14	116	±	10	114	±	14	0.809	0.801	1.000	1.000	1.000
DBP (mmHg)	70	±	8	70	±	8	72	±	9	0.449	0.741	1.000	1.000	1.000
HR (bpm)	73	±	19	77	±	13	75	±	18	0.755	0.670	1.000	1.000	1.000
$\dot{V}O_2$ (ml/min)	355	±	56	321	±	78	276	±	90	0.014	0.023	0.223	0.023	0.373
$\dot{V}CO_2$ (mmHg)	299	±	52	256	±	72	220	±	68	0.005	0.018	0.290	0.010	0.804
VE (l/min)	12.9	±	1.6	10.4	±	1.8	9.3	±	2.4	<0.001	0.001	0.001	0.002	0.452
RR (acts/min)	18.5	±	3.2	15.2	±	3.1	14.3	±	3.6	0.004	0.008	0.006	0.008	0.706
TV (l)	0.71	±	0.13	0.71	±	0.18	0.69	±	0.24	0.756	0.918	1.000	1.000	1.000
$PetO_2$ (mmHg)	109	±	6	107	±	6	107	±	8	0.069	0.000	0.002	0.003	1.000
$PetCO_2$ (mmHg)	35.60	±	5.74	36.50	±	4.88	36.85	±	6.14	0.223	0.053	0.132	0.121	1.000
SaO_2 (%)	97.2	±	0.942	96.8	±	0.8	96.9	±	1.2	0.548	0.678	1.000	1.000	1.000
Ti (s)	1.14	±	0.38	1.30	±	0.43	1.41	±	0.59	0.002	0.000	0.003	0.000	0.029
Te (s)	1.41	±	0.68	1.52	±	0.64	1.78	±	1.02	0.012	0.038	0.585	0.031	0.157
Ttot (s)	2.55	±	1.04	2.82	±	1.04	3.19	±	1.38	0.003	0.002	0.085	0.001	0.043
Ti/Ttot	0.45	±	0.04	0.47	±	0.05	0.46	±	0.08	0.688	0.082	0.080	1.000	0.959
MIP (cmH_2O)	81.83	±	18.20	83.28	±	16.63	85.17	±	16.18	0.630	0.223	1.000	0.281	1.000
MEP (cmH_2O)	82.56	±	26.26	83.00	±	23.83	80.75	±	24.17	0.857	0.915	1.000	1.000	1.000
FEV1 (l/s)	3.94	±	0.91	3.23	±	0.81	2.94	±	0.89	0.008	0.000	0.000	0.000	0.156
FVC (l)	4.70	±	1.21	3.77	±	1.02	3.52	±	1.21	0.017	0.000	0.000	0.000	0.286

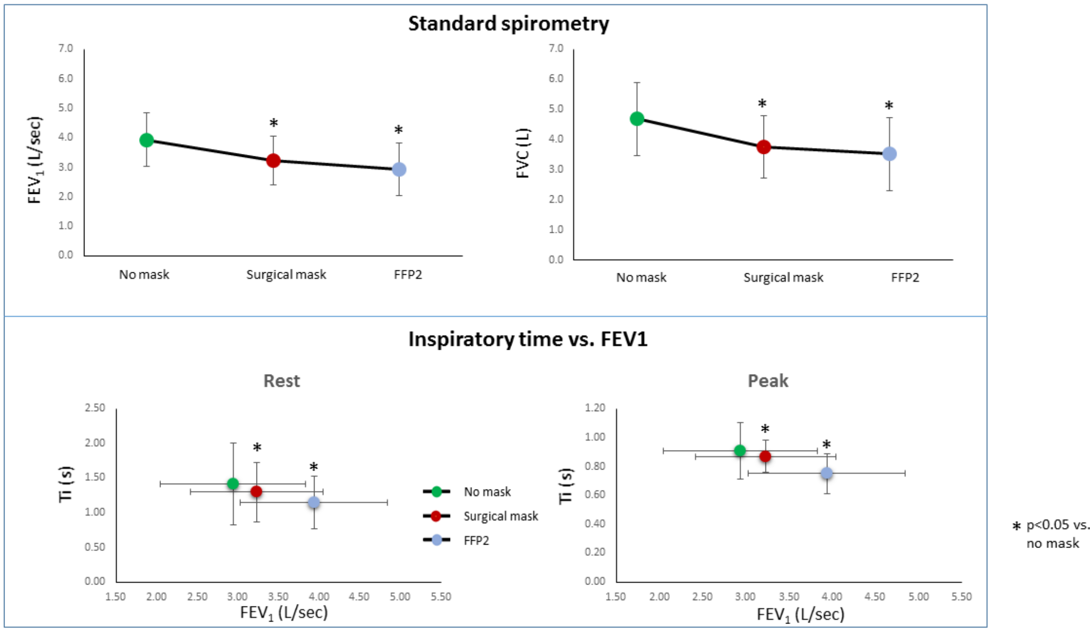
SBP: Systolic blood pressure; DBP: Diastolic blood pressure; HR: Heart rate; $\dot{V}O_2$: Oxygen uptake; $\dot{V}CO_2$: Carbon dioxide production; V_E: ventilation; RR: Respiratory rate; TV: Tidal volume; $PetO_2$: end-tidal oxygen pressure $PetCO_2$: end-tidal carbon dioxide pressure; SaO_2:hemoglobin oxygen saturation; Ti: Inspiratory time; Te= Expiratory time; Ttot: Inspiratory + expiratory time; MIP: Maximal inspiratory pressure; MEP: Maximal expiratory pressure; FEV1: Forced expiratory volume in 1 second; FVC: Forced vital capacity.

Table 2: Values at anaerobic threshold (AT) and at peak exercise, obtained at cardiopulmonary exercise test in the three protocol conditions.

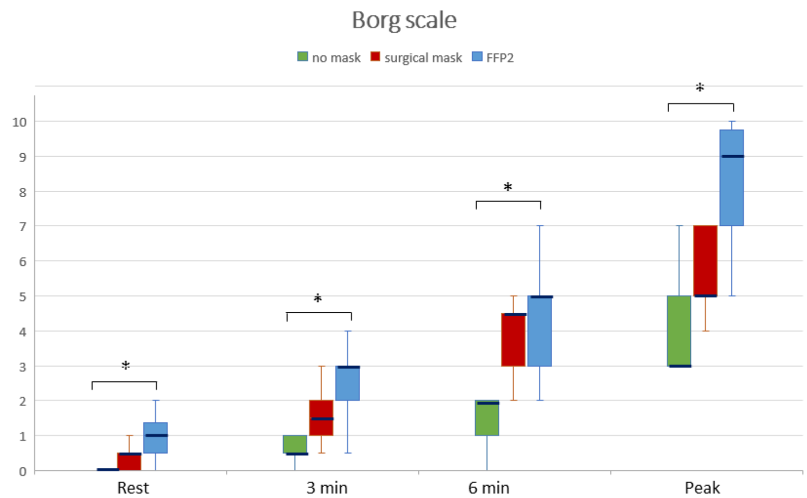
	Sham Mask	Surgical Mask	FFP2	p for trend	P ANOVA	No mask Vs Surgical Mask	No mask Vs FFP2	FFP2 Vs Surgical Mask
$\dot{V}O_2$ AT (ml/min)	1346 ± 345	1163 ± 329	1204 ± 403	0.341	0.020	0.013	0.113	1.000
$\dot{V}O_2$ AT/kg (ml/min/kg)	19.18 ± 4.77	16.41 ± 4.00	17.02 ± 5.34	0.273	0.028	0.019	0.110	1.000
HRAT	125 ± 22	120 ± 16	119 ± 12	0.402	0.531	0.805	0.803	1.000
VE AT (l/min)	39.5 ± 8.5	31.4 ± 7.0	31.1 ± 9.0	0.016	0.007	0.006	0.007	1.000
$\dot{V}CO_2$ AT (l/min)	1288 ± 361	1053 ± 291	1086 ± 382	0.164	0.007	0.009	0.014	1.000
Workload AT (Watt)	110 ± 34	101 ± 29	101 ± 32	0.494	0.173	0.341	0.192	1.000
SBP peak (mmHg)	164 ± 27	173 ± 30	155 ± 19	0.397	0.053	0.343	0.287	0.039
DBP peak (mmHg)	88 ± 9	89 ± 8	86 ± 8	0.627	0.716	1.000	1.000	1.000
HR peak (beat/min)	170 ± 14	168 ± 16	167 ± 16.1	0.621	0.349	0.613	0.468	1.000
$\dot{V}O_2$ peak (ml/min)	2190 ± 586	1928 ± 498	1994 ± 643	0.410	0.006	0.003	0.080	1.000
$\dot{V}O_2$ peak/kg (mL/min/kg)	30.96 ± 6.71	27.50 ± 6.92	28.24 ± 8.79	0.380	0.001	0.001	0.093	1.000
$\dot{V}O_2$ peak % (%predicted)	102 ± 23	91 ± 20	93 ± 31	0.389	0.020	0.017	0.111	1.000
$\dot{V}CO_2$ peak (ml/min)	2578 ± 763	2217 ± 691	2268 ± 794	0.317	0.017	0.012	0.028	1.000
V_E peak l/min)	92.3 ± 26.0	76.2 ± 21.6	71.6 ± 21.2	0.034	0.003	0.002	0.007	0.946
RR peak (acts/min)	41.5 ± 8.0	37.7 ± 5.5	37.1 ± 4.5	0.089	0.041	0.028	0.197	1.000
RER	1.16 ± 0.07	1.15 ± 0.08	1.15 ± 0.08	0.668	0.665	1.000	1.000	1.000
TV peak (l/min)	2.28 ± 0.72	2.05 ± 0.60	1.96 ± 0.65	0.235	0.001	0.044	0.001	0.660
SaO_2 peak (%)	97.3 ± 1.2	96.5 ± 1.2	95.1 ± 3.1	0.017	0.132	0.362	0.252	0.520
$PetO_2$ peak (mmHg)	118 ± 3.0	115 ± 3	114 ± 3	0.021	0.013	0.053	0.020	1.000
$PetCO_2$ peak (mmHg)	33.04 ± 4.28	35.13 ± 3.09	36.26 ± 3.94	0.043	0.012	0.022	0.011	0.455
Workload peak (Watt)	194 ± 57	187 ± 52	184 ± 54	0.656	0.002	0.120	0.001	1.000
Ti_peak (s)	0.75 ± 0.14	0.87 ± 0.11	0.91 ± 0.20	0.010	0.004	0.009	0.017	0.369
Te_peak (s)	0.87 ± 0.24	0.89 ± 0.24	0.89 ± 0.28	0.871	0.975	0.822	0.881	0.957
Ttot_peak (s)	1.48 ± 0.43	1.62 ± 0.39	1.64 ± 0.41	0.343	0.476	0.274	0.163	0.735
Ti/Ttot_peak	0.46 ± 0.05	0.50 ± 0.08	0.53 ± 0.09	0.170	0.315	0.329	0.267	0.899
MIPpost (cmH_2O)	80.64 ± 26.34	82.47 ± 23.00	84.86 ± 24.69	0.674	0.457	1.000	0.927	1.000
MEPpost (cmH_2O)	75.94 ± 18.19	80.97 ± 29.07	77.97 ± 24.34	0.837	0.614	0.958	1.000	1.000

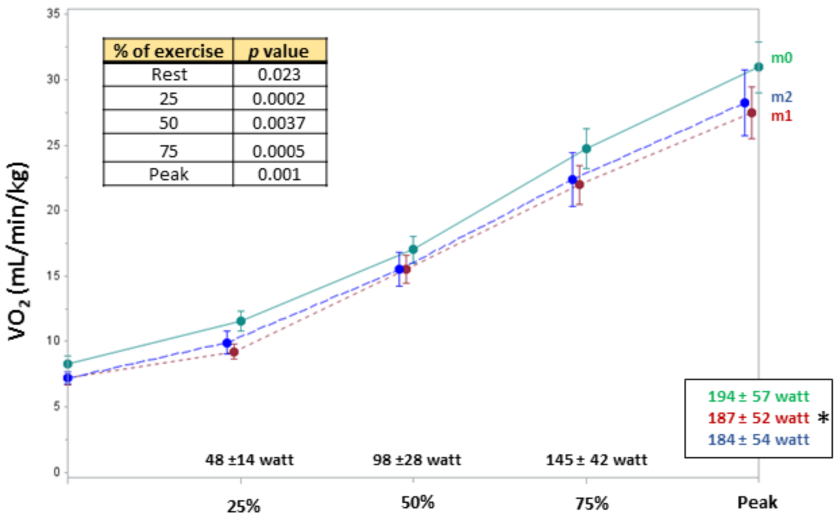
SBP: Systolic blood pressure; DBP: Diastolic blood pressure; HR: Heart rate; $\dot{V}O_2$: Oxygen uptake; $\dot{V}CO_2$: Carbon dioxide production; V_E: Ventilation; RR: Respiratory rate; RER: Respiratory exchange ratio; TV: Tidal volume; $PetO_2$: end-tidal oxygen pressure ; $PetCO_2$: end-tidal carbon dioxide pressure; SaO_2:hemoglobin oxygen saturation; Ti: Inspiratory time; Te= Expiratory time; Ttot: Inspiratory + expiratory time; MIP: Maximal inspiratory pressure; MEP: Maximal expiratory pressure


Spirometry
MIP-MEP pre
CPET
MIP-MEP post
1 -> 2 -> 3
1 -> 3 -> 2
2 -> 1 -> 3
2 -> 3 -> 1
3 -> 1 -> 2
3 -> 2 -> 1
1
2
3

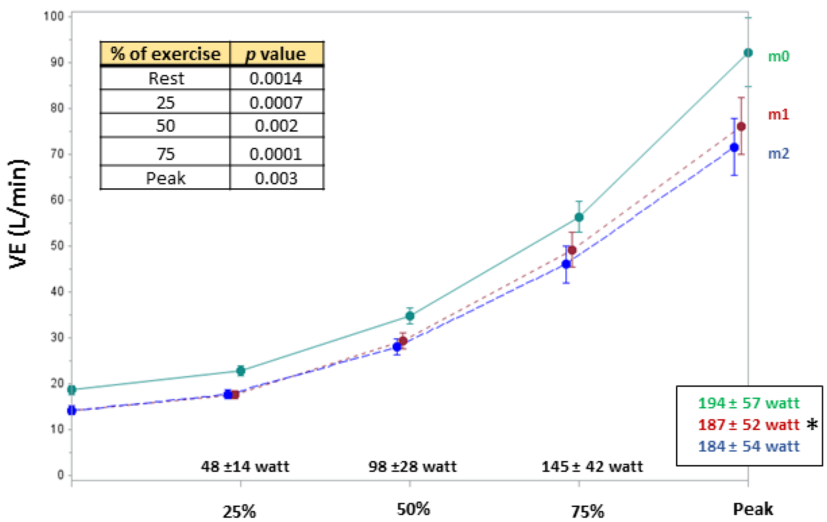


Standard spirometry
FEV1 (L/sec)
FVC (L)
No mask
Surgical mask
FFP2
Inspiratory time vs. FEV1
Rest
Peak
Ti (s)
FEV1 (L/sec)
No mask
Surgical mask
FFP2
* p<0.05 vs. no mask

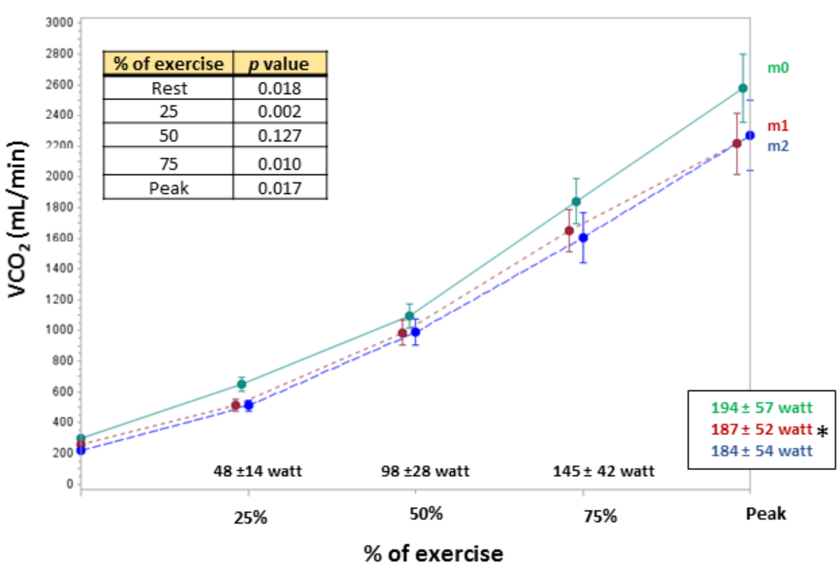

Borg scale
no mask
surgical mask
FFP2
10
9
8
7
6
5
4
3
2
1
0
*
*
*
*
Rest
3 min
6 min
Peak



VO$_2$ (mL/min/kg)
% of exercise | p value
Rest | 0.023
25 | 0.0002
50 | 0.0037
75 | 0.0005
Peak | 0.001
m0
m2
m1
194 ± 57 watt
187 ± 52 watt *
184 ± 54 watt
48 ±14 watt
98 ±28 watt
145 ± 42 watt
25%
50%
75%
Peak



VE (L/min)
% of exercise | p value
Rest | 0.0014
25 | 0.0007
50 | 0.002
75 | 0.0001
Peak | 0.003
m0
m1
m2
194 ± 57 watt
187 ± 52 watt *
184 ± 54 watt
48 ±14 watt
98 ±28 watt
145 ± 42 watt
25%
50%
75%
Peak



VCO$_2$ (mL/min)
% of exercise | p value
Rest | 0.018
25 | 0.002
50 | 0.127
75 | 0.010
Peak | 0.017
m0
m1
m2
194 ± 57 watt
187 ± 52 watt *
184 ± 54 watt
48 ±14 watt
98 ±28 watt
145 ± 42 watt
25%
50%
75%
Peak
% of exercise