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Physiological impact of different types of mask at rest

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Abstract
Introduction: Due to the mandatory use of a mask in the context of the Covid-19 pandemic, we set out to evaluate the physiological impact of hypoxia and hypercapnia generated by different masks at rest.
Methods: Thirty-two competitive adolescent athletes (40% female) were evaluated. Room air and intra-mask measurements were taken at rest while sitting in a chair. A spirometric study was performed and the intra-mask concentration of O2 and CO2 was evaluated, comparing 3 situations: a) Home (H): mask that the subject was wearing from home. b) Surgical (S): surgical mask. c) KN95 mask (KN95).
Results: The ambient air in the laboratory was: O2: 20.9% and CO2: 544 $\pm$ 67 ppm (0.05%); Intra-mask O2: H: 17.8 $\pm$ 0.72 %; S: 17.08 $\pm$ 0.62 %; KN95: 16.8 $\pm$ 0.56 %; (H vs S: ns; H vs NK95: p <0.001; S vs KN95: p <0.002). Intra-mask CO2: H: 1.81 $\pm$ 0.52 %; S 1.92 $\pm$ 0.35 %; KN95: 2.07 $\pm$ 0.36%; (H vs S: ns; H vs NK95: p <0.001; S vs KN95: p <0.012). CO2 levels with KN95 were lower in men 1.97 $\pm$ 0.37 % vs 2.2 $\pm$ 0.29 % than in women (p<0.04), with a significant correlation between gender and weight (r: 0.98, p: 0.01) and height (r: 0.78, p: 0.01).
Conclusions: The KN95 mask presented a lower concentration of O2, and a higher concentration of CO2 compared to the baseline situation with the surgical masks and those home-made. There is a difference in CO2 between the sexes when the KN95 mask was used, in relation to weight and height.

Introduction

In the context of the Covid-19 pandemic, this study aims to add knowledge to the studies that we have previously carried out with a low number of individuals due to the strict confinement that existed in the first months of the pandemic[1] and from a later study carried out in the exercise physiology laboratory to control and confirm the previous data.[2] The aims of our study were: a) estimate the respiratory profile of the subjects under study; b) determination of

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the different mixtures of O2 and CO2 within the dead space of the mask in the three types of mask studied; c) determination of the impact of the different types of mask (H, S, KN95) at the level of cardiac demand and arterial O2 saturation; d) establish the physiological impact of the morphological characteristics and also at the sex level of the subjects under study; e) estimate the respiratory effort in the different types of masks.

The experience acquired in our previous studies carried out in the underground environment in a situation of extreme hypoxia hypercapnia has been useful to us,[3] in a situation of slight contamination,[4] and in a situation of hypoxia hypercapnic recreated in the laboratory,[5] made in confined spaces, with rarefied air, in these last four decades.

Material and method

A sports aptitude assessment was previously carried out, with physical examination, spirometry, and baseline electrocardiogram. The test was performed at rest, with the subjects sitting on a chair, in a meditative attitude. The Home mask (H) is the one that the subjects were wearing when they arrived from home. A surgical mask (S) and an identical KN95 were provided for all subjects, new and dry. The surgical mask (S) was adjusted using a posterior tightener. The atmospheres of the space confined by the mask are compared.

Materials: MultiRae® Rae Systems model gas analyzer (portable chemical detector) with analysis of oxygen, carbon dioxide and carbon monoxide. O2 and CO2 were adjusted with the laboratory control gas: Abelló—Linde mixture with 6.6% CO2 and 12% O2. The intra-mask breathed air sample was taken using a suction probe connected to the gas analyzer. Spirometry was performed with the Datapir touch-Sibelmed® equipment with turbine transducer and bacterial/viral filter.

The current study was carried out in the Metropolitan Area of Barcelona, in the physiology laboratory of the Unitat d'Esport i Salut of the Secretaria General de l'Esport (Government of Catalonia) during the second wave of COVID-19 (October-November 2020).

RaeSystem® detector observations are compared with the gases of the Effort Physiology Laboratory, of the Sports and Health Unit. The corresponding corrections are made. We calculated the anatomical dead space (VDana) from the formula: VDana = 2.4783 x height + 1.1895, a formula obtained from data published;[6] respiratory deficits are determined by the formula: ((VDana + Air mort mask) x 100)/TV; VDana is anatomical dead space and TV is tidal volume.

The cavity air index (CAI) is determined inside the mask. It is the CO2 difference above the ambient (0.05) divided by the oxygen difference with respect to the ambient (20.9%). It indicates, in the present study, that the sum of oxygen and carbon dioxide does not add up to 20.9%, as in the usual atmospheric composition.[5]

The excess respiratory effort generated by the three types of mask is calculated using the formula: ((VDana+ air mask volume) x 100) / TV, where VDana is the anatomical dead space and TV is the tidal volume. The dead space in the mask, is estimated at 15 cc for Home, 25 cc for Surgical and 75 cc for KN95.

Continuous variables were expressed as means and standard deviations. The two-tailed t-test with paired data was used to check if the differences were significant. Since the sample is <50 cases, the cut-off value p<0.005 was used. Statistical correlations of different parameters were studied to relate them, using Pearson's r coefficient (r).

The study has been favorably reported by the ethics committee of the sports Government of Catalonia (certificate: 018 / CEICGC / 2021).

Results

32 individuals (13 women and 19 men) were included. Mean age = 17.8 ± 6 years; height = 172.1± 10.1 cm; BMI: 20.4 ± 2.5. The sports were cycling, volleyball, pentathlon, speed skating, sport climbing, crossfit and running (Table 1).

The respiratory profile of the subjects under study are: Forced vital capacity (FVC): 4.30±0.95 L FEV1: Forced expiratory volume in the first second (FEV1): 3.75 ± 0.83 L. FEV/FVC: 87.4 ± 6.2% Peak expiratory flow (PEF): 7.8 ± 1 .78 L/s (Table 2).

The different mixtures of O_2 and CO_2 within the intra-mask dead space were determined in the three types studied, presenting different levels of cavitary hypoxia and hypercapnia with statistically significant differences (Table 3).

At the sex level, we found statistically significant differences in CO_2 levels: (men) 1.97 ± 0.37 vs (women) 2.2 ± 0.29; p<0.04, in the KN95 mask (Table 4).

The respiratory deficit generated by each type of mask compared to ambient air without a mask was: Home 4.3 ± 0.87%, Surgical 7.2 ± 1.45% and KN95 21.4 ± 4.34%, with a significance greater than p< 0.0001 between them.

Table 1 Physiological profile. N= 32.

Woman average	Sd		Man average	Sd	p<
16.4	2.46	Age (y)	18.7	7.1	0.185
51.7	7.56	Weigth (Kg)	66.3	9.1	0.000
1.63	0.05	Heigt (m)	1.78	0.08	0.000
19.59	2.10	BMI	20.9	2.48	0.185

BMI: Body mass index.

Table 2 Spirometric profile by gender.

Woman average	Sd		Man average	Sd	$p<$
3.64	0.41	FVC (L)	5.02	0.85	0.000
3.14	0.30	FEV1 (L)	4.13	0.68	0.000
86.5	7.62	FEV1/FVC (%)	88.2	4.30	0.50
6.67	1.02	PEF (L/s)	9.16	1.46	0.000
185	0.02	VDana (ml)	233	0.02	0.000
310	45.4	TV (ml)	398	54.5	0.000

FVC: forced vital capacity. FVC1: forced vital capacity in the first second. PEF: Peak espiratory flow. VDana: is anatomical dead space. TV: is tidal volume.

Anatomical dead air (VDA) was calculated to be 214 ± 33 ml. Flowing air (VTIDAL) under the study conditions was calculated at 363.5 ± 67 ml.

Discussion

The results of our study show that there are differences between different models of masks such that the more dead space there is in the mask, the more unfavorable the mixture of oxygen and carbon dioxide available to be breathed.

There are very few studies on the composition of the air inside the masks in common use. Studies with Snorkel masks adapted for the assistance of patients with COVID syndrome, Germonpre P, (2020) observed a small initial increase in CO_2,[7] Kechli et al. estimated the physiological dead space in the system at 60 ml Modified snorkel, using a modified Snorkel mask shows a slight decrease in heart rate after 20 minutes of rest.[8]

The main contribution of our study consists in verifying that the dead air of the mask influences the quality of the breathed air sample. In the case of the Home mask, the main characteristic is its humidity and its imperfect fit to the subject's face. The KN95 mask adjusts spontaneously to the subject's face and in the case of the surgical mask (S) a tensioner has been required for a perfect fit, without air leaks.

The masks are an element interposed between the airway and the free atmosphere. They are an enlargement of the anatomical dead space and therefore modify breathing. Secondly, they are an element for filtering the air, therefore, they increase the demand of the respiratory muscles to breathe. To consider, as a third element, the facial adjustment of the mask, which allows leaks and air circulation outside the mask. Mask cavity air: ranges from 20 ml (surgical mask) to 75 ml for KN95 models based on our own observations. Anatomical dead air: it goes from the alveoli to the teeth and nostrils. The manuals estimate it at 150 ml on average, but we calculated it for each subject under study, based on the formula VDANAT = 2.4783 x height + 1.1895.[6]

We calculated respiratory tidal air (Vtidal) from Chula's formula[9] and the multiplication of 6 ml per kg of body mass. The 13 women in the study had worse figures for respiratory gases inside the mask, but their age was lower than the male group and their weight and height were significantly smaller. We attribute this different adaptation to the size of the subjects under study. Generally, taller subjects will have a greater anatomical dead space and the dead space of the mask will be smaller in proportion to their height, and therefore the respiratory effort of tall subjects will be lower than that of subjects with less height.

Regarding the cardiorespiratory repercussion, the differences between the three levels of $SATO_2$, in the three types of masks, are not statistically significant. Therefore, it must be concluded that compensatory mechanisms work to guarantee the supply of oxygen necessary for the economy, as well as for the elimination of CO_2.

Table 3 Total results. N = 32.

	Home	Surgical	KN95
CO_2 %	1.81 ± 0.52	1.92 ± 0.35	2.07 ± 0.36*,#
O_2%	17.8 ± 0.72	17.0 ± 0.62	16.8±0.56*,#
CAI	0.48 ± 0.08	0.49 ± 0.09	0.49 ± 0.10
O_2 saturation	98.6 ± 0.87	98.3 ± 1.05	98.4 ± 1.00
HR	64.1 ± 10.8	64.8 ± 11.5	64.6 ± 11.1

All three mask types create an environment with a similar Cavity Air Index (CAI).
* $p<0.0001$ vs Home.
\# $p<0.01$ vs Surgical.

Table 4 Results by gender.

	Male	Female	P
HomeO_2	17.3 ± 0.81	17 ± 0.56	n/s
HomeCO_2	1.75 ± 0.56	1.89 ± 0.45	n/s
Surgical O_2	17.4 ± 0.67	17 ± 0.55	n/s
Surgical CO_2	1.86 ± 0.37	2.01 ± 0.33	n/s
KN95 O_2	16.9 ± 0.57	16.6 ± 0.48	n/s
KN95 CO_2	1.97 ± 0.37	2.2 ± 0.29	<0.04
age (y)	18.8±7.1	16.4±2.5	n/s
Weight (kg)	66.3±9.1	51.7±7.6	< 0.0001
Height (m)	1.78±0.1	1.63±0.1	<0.0001
BMI	20.9±2.5	19.6±2.1	n/s

The intra-mask CO_2 difference presented a significant correlation between sex and weight (r: 0.98, p: 0.01) and height (r: 0.78, p: 0.01).

In subsequent studies, it is important that we pay attention to the contributions of Florian Egger et al., who present data that could indicate that the air rarefied by face masks can affect the neuro-vegetative balance of subjects during exercise.[10]

As a limitation of the study, the study lacks power to clarify whether there are sex differences in the use of masks. The cause of this is the differences in the physical and morphological profile presented by the group of young men and women in our study, which does not allow us to compare both groups. Another limitation is they belong to a sample of ages, reduced to adolescence.

Conclusions

The KN95 mask presented a lower concentration of O2 and a higher concentration of CO2 compared to the baseline situation with the surgical masks and those home-made. There is a difference in CO2 between the sexes when the KN95 mask was used, in relation to weight and height.

Conflicts of interest

None of the authors present a conflict of interest that may affect the present study.

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