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Comparative study of the effect of N95 facemask and Powered Air-purifying Respirator (2 fans, N95 filter) on cardiovascular parameters of healthy individuals during exercise

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Abstract: N95 masks filter 95% of the small particles and respiratory droplets (>0.3 µm diameter). Therefore, they are widely used both by general public and health workers during pandemic. When physical activity or exercise is performed wearing N95 mask, it induces hypercapnic environment. The heat burden is also increased leading to discomfort and reduced compliance. This study was done to compare physiological effects and subjective perceptions while wearing N95 mask and powered air-purifying respirator (PAPR) (2 fans, N95 filter) during incremental exercise. ECG, respiratory movement, SpO_2, temperature inside the mask were recorded and perception of discomfort was also assessed. Heart rate variability (HRV) values during baseline were within normal limits in both the mask conditions signifying that cardiac autonomic tone is comparable. During incremental exercise, fall in SpO_2 was significantly lesser in PAPR as compared to N95 mask at 60–70% and 70–80% of maximum achievable heart rate. The temperatures inside both the mask conditions were significantly higher than ambient temperature. The scores of humid, hot, breath resistance and fatigue were significantly lower in PAPR than N95 mask. In conditions where prolonged use of mask is required with strenuous physical exertion or exercise, PAPR could be preferred over N95 mask.

Key words: Cardiopulmonary exercise test (CPET), COVID-19, HRV, N95 mask, PAPR

Introduction

The novel SARS COV-2 virus can be transmitted through respiratory droplets and physical contact which is highly transmissible[1)]. The WHO declared COVID-19 as a global pandemic on 11th March, 2020[2)]. The cases are still increasing worldwide. It is mandatory to wear the mask in public places to prevent from infection and also to prevent the spread. There are various types of masks available like surgical masks, N95 facepiece respirators, and powered air-purifying respirator (PAPR) etc. Surgical masks reduce the transmission from the wearer to the patient, hand-to-face contact and facial contact with large droplets, while

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N95 facepiece respirators filter the small airborne particles, tightly fit to the face. N95 mask filters 95% of the small particles (>0.3 µm diameter)[3]. Therefore, they are widely used by health care workers for self-protection during this pandemic.

As the N95 mask is tight fitting and having fine pore size it causes increased resistance to airflow. This also increases temperature and humidity which in turn leads to moisture to condense on surface of the mask. This in turn impairs the respiratory heat loss and increases the heat burden[4]. There is also increase in discomfort on prolonged usage of mask and this leads to lack of compliance[5].

When exercise is done with N95 facemask the above problems are aggravated. Previous studies have noted that exercising with N95 mask induces a hypercapnic hypoxic environment due to inadequate oxygen uptake (O_2) and carbon dioxide (CO_2) removal but in healthy individuals without any cardiovascular comorbidities or risk factors the parameters such as heart rate (HR), saturation of peripheral oxygen (SpO_2) and end tidal carbon dioxide (ETCO2) were within physiological limits even during strenuous exercise[6, 7]. However, exercise remains physiological antidote to risk factors for cardiometabolic diseases[8] and it lessen the chances of acute respiratory distress syndrome (ARDS) associated with COVID-19[9].

PAPR has possible features to ameliorate the issues of airways resistance and thermal discomfort. It has a motor that draws air through filter and delivers the filtered air under positive pressure to the mask[10]. It enhances the comfort of wearing mask by solving the heat related issues via cooling effects of air currents which leads to increase the compliance and the duration of work cycles as compared to N95 mask[11]. However, its effect on physiological parameters during exercise remains to be seen.

The present study was undertaken to compare the physiological effects and subjective perceptions while wearing PAPR (2 fans, N95 filter) and N95 mask during incremental exercise in humans.

Materials and Methods

This was a cross-over, self-control study conducted in Department of Physiology, All India Institute of Medical Sciences (AIIMS), New Delhi after approval from the institute ethics committee (Ref. No.: IEC-1222/04.12.2020 RP-26/2020). 21 healthy volunteers were recruited for the study. Subjects with recent history of coronary artery disease, chronic smoker, alcoholism and taking vitamin supplements within week of the study were excluded. The subjects were instructed to report to the laboratory after a light breakfast/meal at least 2 hours prior to the study. The subjects were asked to empty the bladder before the recording. All the subjects recruited were health care workers who did not have prior exercise training. Written informed consent was taken from all the healthy volunteers after explanation of the nature, purpose and duration of the study. Each subject performed the test two times: (1) with PAPR (2 fans, N95 filter) and (2) with N95 mask. Randomisation was done while allotting each subject's sequence of intervention. Thereafter, electrodes were placed to record Lead II electrocardiogram by digital data acquisition system (Powerlab™, AD Instruments, Australia). Respiratory Belt Transducer was fixed around the chest at the level of the 4th intercostal space to record respiratory movements. Temperature Probe was put inside the mask to record the temperature of microenvironment of facemask. During the exercise a different ECG configuration was used. Wireless 12 Lead ECG (COSMED, Italy) was placed to record the electrocardiogram and the heart rate was derived from it during exercise. Pulse oximeter was put on index finger of the subject to record the percentage of O_2 saturation of haemoglobin (SpO_2). The bicycle ergometer (Carival, Netherlands) was used to do exercise using 10W/minute incremental exercise protocol using OMNIA 1.4 (CPET) software (COSMED, Italy). The recording setup is shown in Fig. 1. The testing room was air conditioned with ambient temperatures at 22–23°C and relatively low humidity (<50%).

Mask

We used disposable FFP2/N95 protective face masks (Suvayu SV9500, India) and PAPR (2 fans and N95 filter) (Moksha mask, PQR Technologies Pvt. Ltd., India). It uses two small DC fans – one for inhalation and one for exhalation. The first small DC fan pumps in air from outside, after filtering it through the N95/ BFE95 or any such filter, and delivers purified air to the user while the second fan throws out the exhaled CO_2 and moisture laden air. The fan is rotating at 8,000 rpm (Fig. 2).

Baseline recording

A brief medical history was taken to rule out comorbidities and disease states that might affect the exercise capacity of the subject. After giving five minutes of resting period five minutes of ECG recording is selected for computing short term heart rate variability (HRV). Standard procedure was used to record HRV[12] during this period, resting heart rate, SpO_2 and temperature levels in the mask are noted.

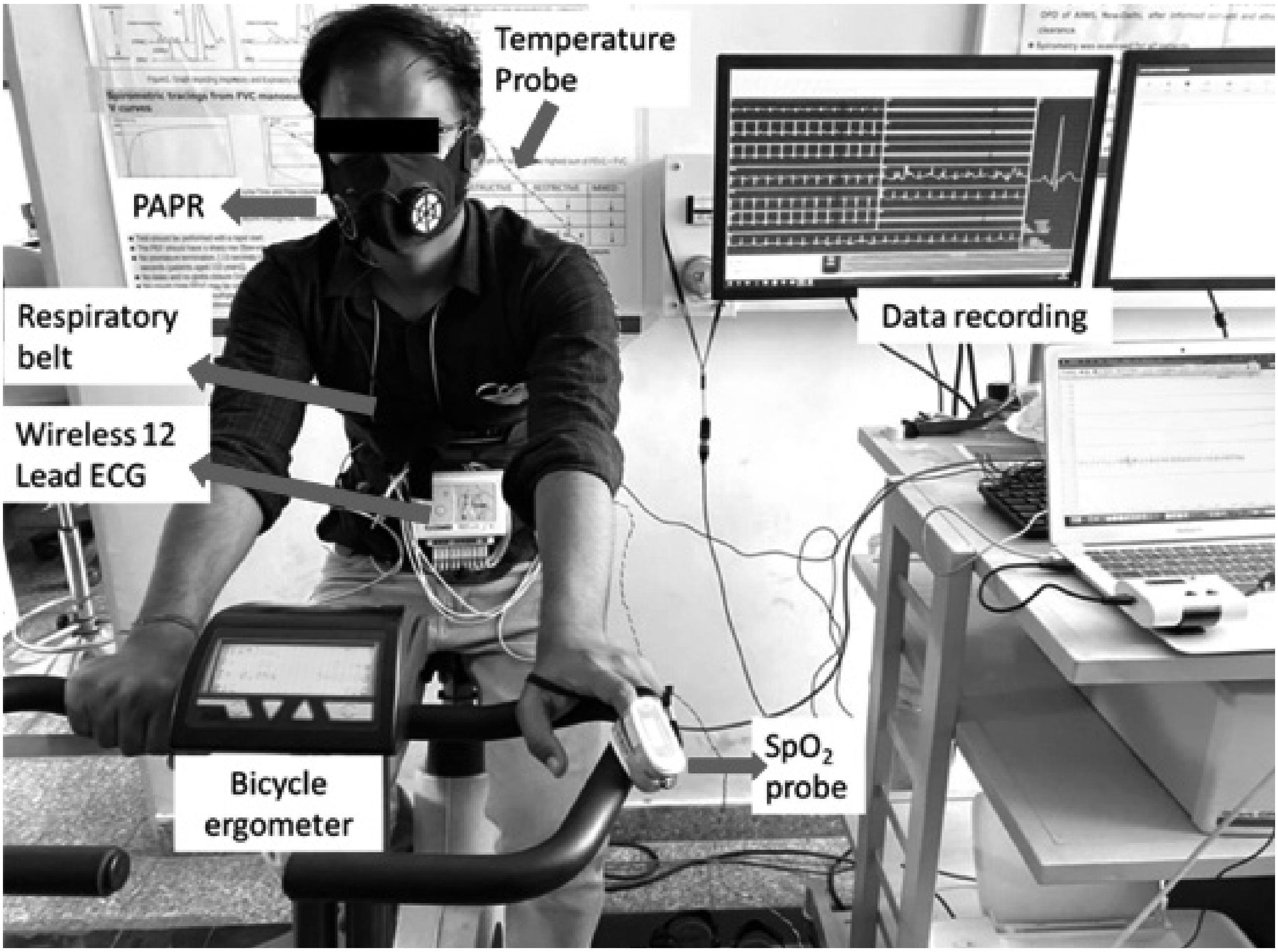

Fig. 1. Recording setup showing the subject performing incremental exercise protocol, wearing PAPR (2 fans and N95 filter). ECG, respiration, SpO_2, and temperature were continuously recorded.

Incremental exertion test (IET)

Each subject performed two incremental exertion tests (IET), one with FFP2/N95 mask and one with PAPR mask. Tests were performed at the same time of day with a minimum of 48 hours between two tests. All the subjects were given a warm up period of 3 minutes to familiarise with the exercise protocol. IET was performed on a (electronically braked) bicycle ergometer (COSMED, Italy) at a constant speed of 60 revolutions per minute (rpm). The test began at a workload of 0 W with an increase of 10W within 1 min (as a ramp) until 80 percent of maximum heart rate was achieved. Maximum heart rate was calculated using the standard formula (220- Age).

Quantification of comfort/discomfort

We used a questionnaire after exercise to quantify the following ten domains of comfort/discomfort of wearing a mask: humidity, heat, breathing resistance, itchiness, tightness, saltiness, feeling unfit, odor, fatigue, and overall discomfort[4]. The perception of discomfort was assessed after 10 minutes of IET.

Statistical analysis

All values are expressed as mean ± standard deviation unless otherwise stated, and the significance level was defined as $p<0.05$. Data were analysed using GraphPad Prism 9 (GraphPad Software Inc., California, USA). The normal distribution of the data was evaluated by the Shapiro–Wilk test. To determine if there was a change following masking, two factor repeated ANOVA with Bonferoni's post hoc test for multiple comparisons was done.

Results

Subject characteristics

Subjects of this study consisted of 21 subjects of whom 9 (43%) were females and 12 (57%) were males (mean age,

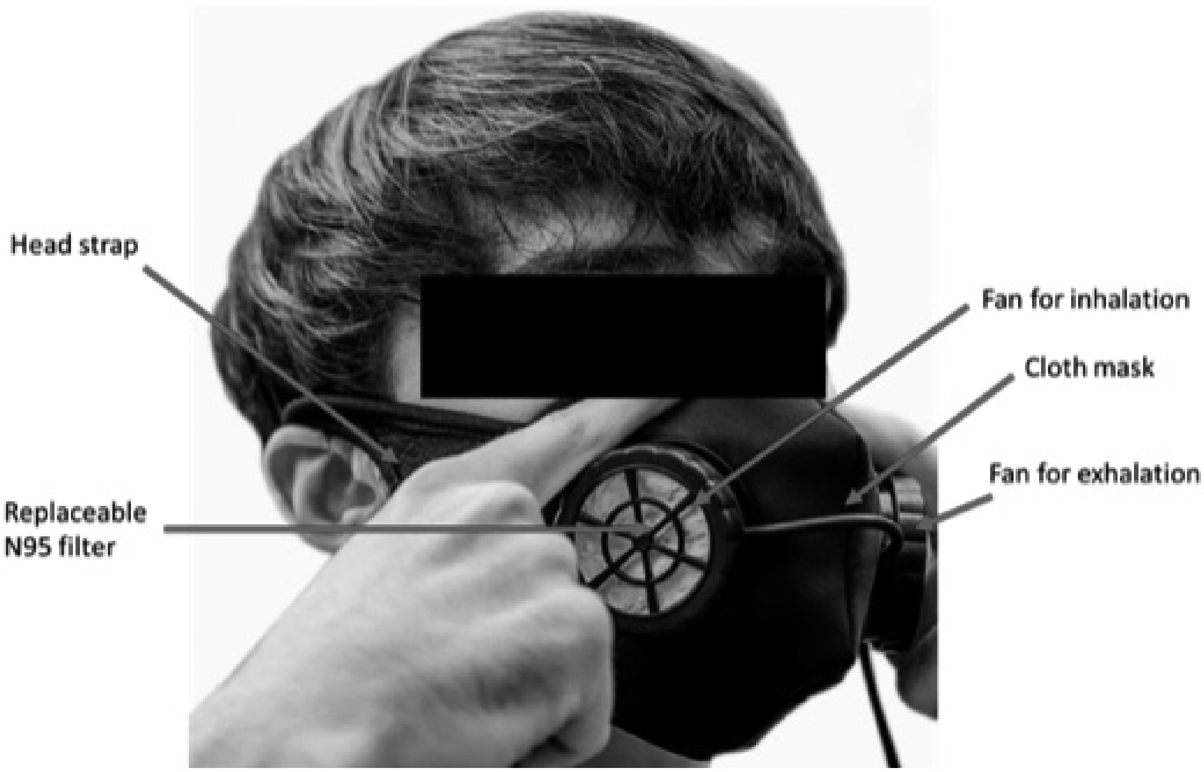

Fig. 2. Components of PAPR (2 fans, N95 filter).

Table 1. Overall characteristics of subjects (n=21)

S.N.	Parameters	Mean
1	Age (years)	28 ± 4
2	Height (cm)	164 ± 6
3	Weight (kg)	65 ± 10
4	BMI (kg/m^2)	24 ± 3
5	Male: Female Ratio	12 : 9
6	Average HR (N95) (beats/min)	86 ± 14
7	Average HR (PAPR 2 fans, N95 filter) (beats/min)	83 ± 11

28 ± 4 years, range 22–35). Resting average heart rate was not significantly different between the two conditions i.e., N95 mask group and PAPR (2 fans, N95 filter) condition (Table 1).

Heart rate variability during baseline

The parameters of time domain - SDSD, RMSSD, frequency domain - LF, HF, Total Power & LF/HF Ratio and non-linear analysis – SD1/SD2 Ratio were within normal range and showed no significant difference between N95 mask and PAPR (2fans, N95 filter) (Table 2).

Parameters studied during incremental exercise test

a) Change of SpO_2:

During the incremental exercise, fall in SpO_2 was noted in both N95 mask and PAPR (2 fans, N95 filter) at various percentages of maximum achievable heart rate. But this fall was significantly lesser in PAPR (2 fans, N95 filter) as compared to N95 mask at 60–70 and 70–80 percentage of maximum achievable heart rate. While at 30–40, 40–50 and 50–60 percentage of maximum achievable heart rate, the mean values showed no significant difference (Fig. 3).

Significantly lesser percentage fall of SpO_2 was noted in PAPR (2 fans, N95 filter) as compared to N95 mask. In PAPR (2 fans, N95 filter) group, 3 out of 21 subjects showed > 5% SpO_2 fall compared to 9 out of 21 subjects in N95 mask group above 60% of maximum achievable heart rate (Fig. 4).

b) Change in temperature inside the mask:

The temperatures inside both the masks (N95 mask and PAPR) were significantly higher than the ambient temperature (22.31 ± 0.06) both at rest and during incremental exer-

Table 2. HRV parameters in the both mask group (N95 mask and PAPR)

Variables	N95 mask	PAPR (2 fans, N95 filter)
Time domain analysis		
SDSD (ms)	35.73 ± 6.08	32.19 ± 3.77
RMSSD (ms)	35.75 ± 6.07	32.15 ± 3.77
Frequency domain analysis		
LF (ms^2)	873.89 ± 112.60	999.52 ± 195.79
HF (ms^2)	908.41 ± 249.29	612.77 ± 96.31
LF/HF Ratio	1.54 ± 0.22	1.69 ± 0.21
Total power (ms^2)	2,999.48 ± 452.19	2,270.15 ± 315.25
Non-linear analysis		
SD1 (ms)	25.27 ± 4.30	22.76 ± 2.67
SD2 (ms)	65.08 ± 6.38	60.57 ± 4.25

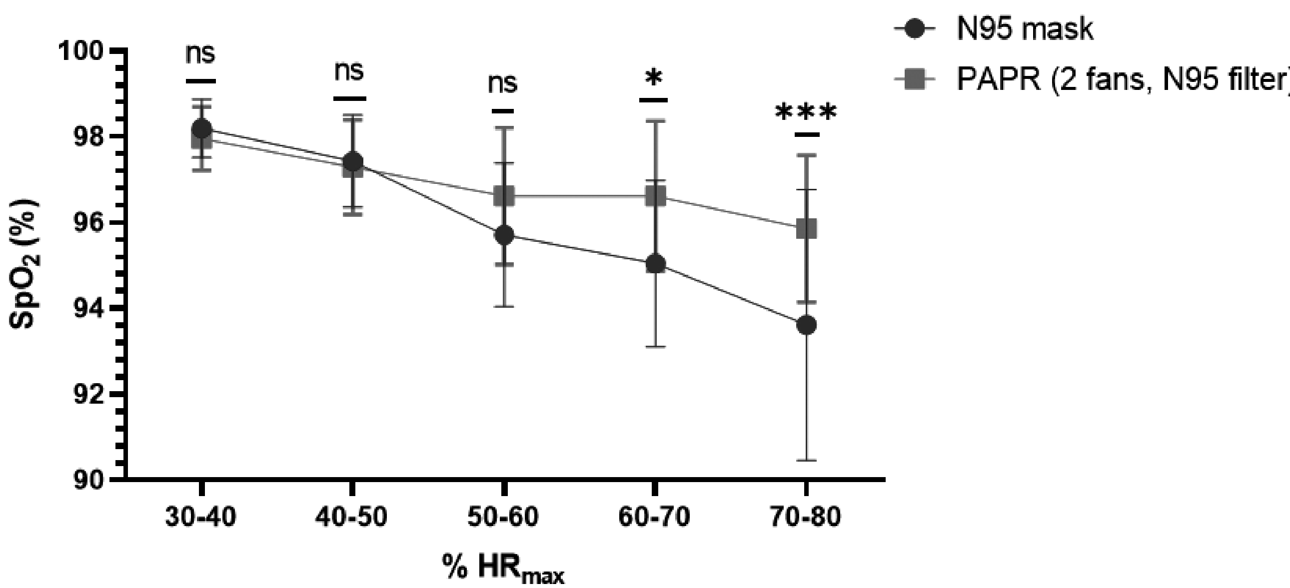

Fig. 3. Changes in SpO_2 during incremental exercise.
(%HRmax, percentage of maximum achievable heart rate, * represents *p*-value < 0.05, ****p*<0.001, ns not significant)

cise (32.93 ± 0.93, 32.72 ± 1.07). But there was no significant difference between both N95 mask and PAPR (2 fans, N95 filter) (Fig. 5).

Perception of discomfort after wearing N95 mask and PAPR (2 fans, N95 filter):

The scores of humid, hot, breath resistance and fatigue were significantly higher in N95 mask than PAPR (2 fans, N95 filter) (Fig. 6).

Discussion

The results from the study demonstrate that percentage oxygen saturation, microclimate inside the mask and subjective ratings were significantly and equally influenced by the wearing of N95 mask and PAPR (2 fans, N95 filter) at rest.

Heart rate variability during baseline recording were comparable to the normative values from our lab[12] and those provided by HRV Task Force 1996[13] in both the masks, signifying that cardiac autonomic tone remains normal and there is no abnormal alteration in parasympathetic and sympathetic tone using either mask. To our knowledge, this is the first study to report this finding.

In our study, during incremental exercise there was no significant difference in fall of SpO_2 till 60% of HR_{max} after that there was significant difference in fall of SpO_2 noted between both the mask conditions. 9 out of 21 subjects wearing N95 mask had SpO_2 fall of more than 5%, signifying that there could be a subset of the population who are more susceptible to SpO_2 fall. While using PAPR (2 fans,

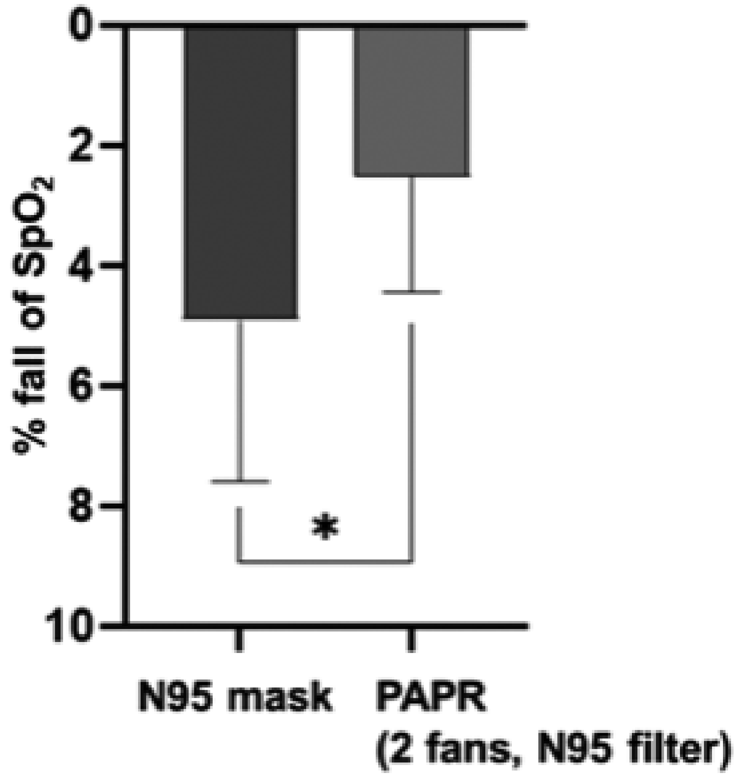

Fig. 4. Percentage fall of SpO_2 in N95 mask and PAPR (2 fans, N95 filter) during incremental exercise (> 60% of maximum achievable heart rate).
(* represents *p*-value < 0.05)

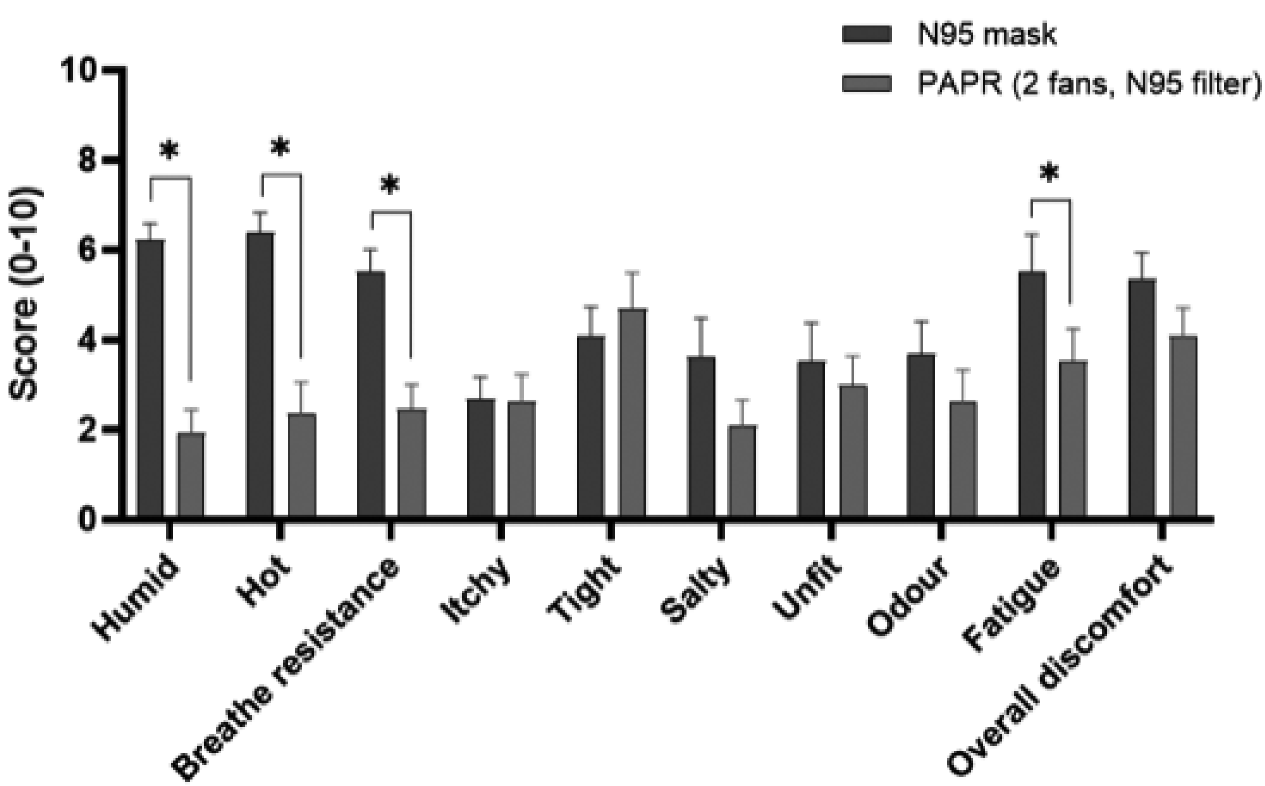

Fig. 5. Comparative chart of scoring for various subjective parameters of perception of discomfort after wearing N95 mask and PAPR (2 fans, N95 filter).
(* represents *p*-value < 0.05)

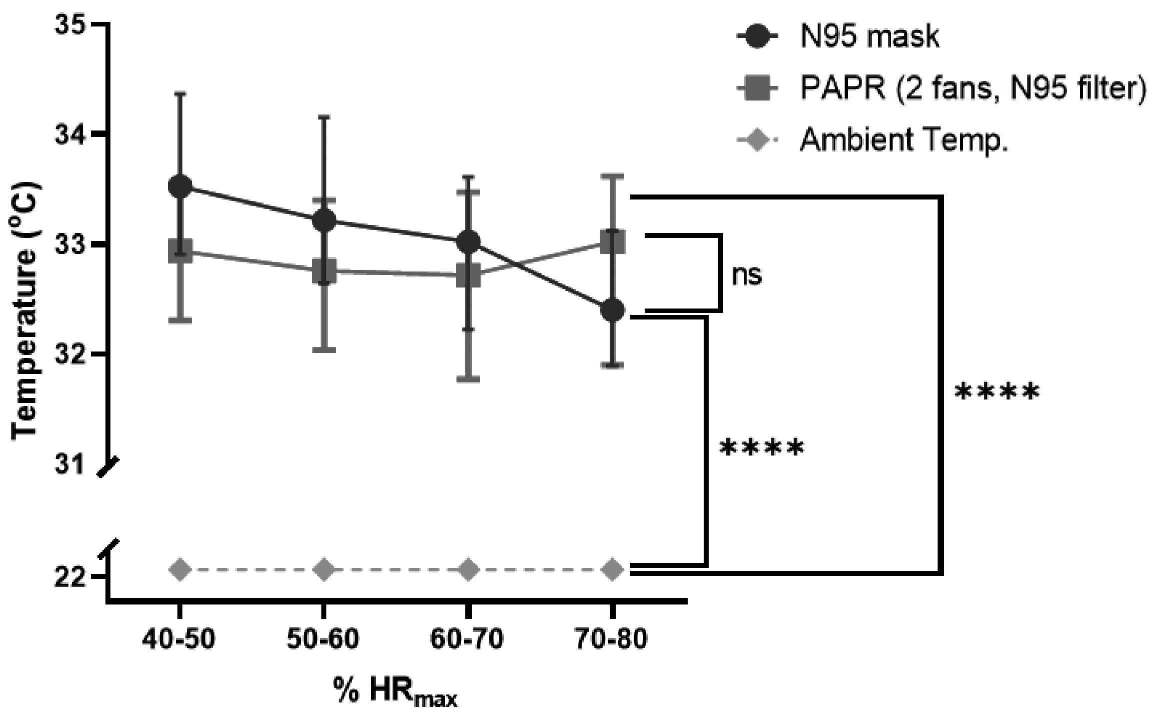

Fig. 6. Changes in temperature inside the N95 mask and PAPR (2 fans, N95 filter) during incremental exercise. (%HRmax, percentage of maximum achievable heart rate, ** represents *p*-value < 0.0001, ns not significant)**

N95 filter), fall in SpO_2 during all intensities of exercise was minimal, only 3 out 21 subjects had a fall of more than 5%. Powell *et al.* found that during low-to-moderate exercise there was no significant difference in cardiopulmonary variables such as SpO_2, transcutaneous carbon dioxide ($tcPCO_2$), heart rate (HR), respiratory rate (RR) during wearing of N95 mask and PAPRs. This was attributed to the fact that cardiovascular parameters are more impacted by the intensity of exercise rather than the types of masks (N95 and PAPR)[14]. Similar findings were observed with N95 mask during low intensity physical activity in the treadmill studies done by Roberge *et al*[6]. However, they also found that there was a 3% increase in inhalation and exhalation resistance when exhaled moisture was retained by the N95 mask[15]. Epstein *et al.* noted that exercising with N95 mask was associated with significant but mild increase in end tidal carbon dioxide ($EtCO_2$) levels and the differences were more prominent when the intensity of exercise was increased[7]. In the N95 mask we found that sweating, humidity, heat perception and fatigue were significantly higher than PAPR (2 fans, N95 filter) during strenuous exercise (> 60% of HR_{max}) and this in turn increased the breath resistance. When breath resistance increases during strenuous exercise, work of respiratory muscles is increased and prolonged inspiratory activity would lead to more negative intrathoracic pressure and finally increase the preload[16]. And the after load also increases due to the raised transmural left ventricular pressures[17]. These findings could be more pronounced in subjects with obstructive lung diseases and cardiovascular disorders with low cardiac output.

In current study, the temperatures inside both the masks were significantly higher than those of ambient temperature but the differences between the two microenvironments were negligible during incremental exercise. Slight decrease in temperatures (at 60–70% HR_{max}) inside the N95 mask during the course of exercise could be attributed to the cooling effect of sweating[18]. But in PAPR (2 fans, N95 filter), there is an air current which is maintained, which reduces the sweating, humidity and heat accumulation inside the mask. In individuals sensitive to thermal stress, sweating might be increased and fall in SpO_2 might be exaggerated.

Use of PAPR (2 fans, N95 filter) could be preferred over N95 mask for high intensity workouts, athletic or sports training, factory workers, health care workers, work spaces without air conditioning, spectators in stadiums and music concerts, military training etc. But for universal acceptability of PAPR (2 fans, N95 filter), there is a need to develop lighter, less bulky, more accessible and cost-effective models.

Limitations of the present study include the relatively low number of subjects (12 males, 9 females). Due to COVID pandemic restrictions, study without wearing the mask could not be done and spirometry parameters could not be assessed. The study was performed in a laboratory where ambient temperature was maintained, so that we can't comment on the impact of these masks in hot, humid environments.

In future studies, the other cardiopulmonary parameters such as $EtCO_2$, lung volumes changes, VO_2 max, arterial blood gas parameters at different stages of exercise could be assessed in real time. The effect of different fan speeds and pressures changes inside the masks could be assessed to further elucidate the mechanisms involved. And further these findings could help us to create an automated mask that would eliminate the increase in breath resistance.

Conclusion

During resting conditions and mild physical activity, the use of both N95 and PAPR (2 fans, N95 filter) did not affect autonomic and cardiovascular parameters. But during heavy exercise (at 60–70% and 70–80% of HR_{max}) fall in SpO_2 was significantly lesser in PAPR (2 fans, N95 filter) as compared to N95 mask. In conditions where prolonged use of mask is required with high intensity of work or exercise and strenuous physical exertion, PAPR (2 fans, N95 filter) could be preferred over N95 mask.

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