The Effect of Wearing a Powered Air Purifying Respirator Versus an N95 Mask on the Olfactory Function of Healthcare Workers

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Research Article

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Abstract

Background: With the COVID-19 epidemic, wearing a mask has become routine to prevent and control the virus's spread. Wearing masks for long periods can have various adverse effects on the human body, but little attention has been paid to the impact on olfaction. This study aimed to investigate whether wearing a mask affects healthcare workers' olfactory function and provide a reference for clinical olfactory research and mask wear regulations.

Methods: We recruited fifty-six healthcare workers and randomly divided them into two groups, wearing a Powered Air Purifying Respirator (PAPR, experiment group, N=28) and an N95 mask (control group, N=28) for 8h. Olfactory discrimination tests and threshold tests were performed before and after wearing the masks. SPSS 26.0 software was used for the statistical analyses.

Results: Current results suggested no statistical difference in the discrimination test scores between the PAPR Group (Z=-0.707 P =0.480) and N95 Group (Z=-0.828 P =0.408) before and after wearing the masks. The olfactory threshold test revealed a statistical difference in threshold scores before and after wearing the mask in the PAPR Group (Z= -2.595 P = 0.009) and N95 Group (Z= -2.120 P= 0.034). Both PAPRs and N95 masks reduce the sensitivity of healthcare workers to odors, with no significant difference between the two (χ^2= 0.292，p = 0.589).

Conclusion: Wearing a mask affects the healthcare workers’ olfaction, especially odor sensitivity. Healthcare workers wearing masks have a higher olfactory threshold than before，whether wearing PAPRs or N95 masks. More attention needs to be paid to the effect of masks on the olfactory function.

1 Introduction

Since the outbreak of COVID-19, masks have become essential personal protective equipment(PPE) for the community and first-line healthcare workers. Wearing a medical protective mask is one of the most important measures to prevent the transmission of the disease. N95 masks are high-performance filtration masks to protect healthcare workers. Filtration is achieved by combining a web of polypropylene microfibers and electrostatic charge[1]. Nevertheless, some evidence suggests that a Powered Air Purifying Respirator(PAPR) is a good option for exposures to high concentrations of infectious aerosols, especially where the risk is unknown or uncertain. A study has shown that a correctly used PAPR provides an assigned protection factor (APF) of up to 1000 compared to an APF of 10 for the N95 mask[2]. PAPR is a battery-powered blower that provides positive airflow through a filter, cartridge, or canister to a hood or face piece[3]. Compared to other masks, advantages included being cooler, more comfortable, and can be worn for more extended periods [4]. The specific differences between the two types of masks are as followings [5](Table 1):

However, the available scientific evidence questions the safety and efficacy of wearing masks as a preventive intervention for COVID-19. Long-term mask wear has been shown to have significant adverse physiological and psychological effects, such as hypoxia, fatigue, headache, cognitive decline, psychological disorders, and may even lead to hypercapnia and immunosuppression [6]. The effect of wearing a mask on the sense of smell is not yet known. In daily clinical work, we have noticed that wearing N95 masks for a long period seems to cause nasal congestion and diminish the sense of smell. A study from Guangzhou Medical University, China, confirmed this subjective impression. It has been found that wearing a surgical mask reduced odor sensitivity but not odor identification, whereas wearing an N95 mask substantially reduced odor perception[7]. There are few reports on whether masks affect the olfactory deficit. The purpose of this study was to test whether PAPRs and N95 masks have an effect on the sense of smell in healthcare workers by simulating a clinical working environment and provide a reference for clinical olfactory research and mask wear regulations.

Table 1
Comparison of N95 mask and PAPR

Type	Filtration capacity	Duration of use	Fit testing required	Primary intent	Protection from aerosols
N95 mask	95% of 0.3-μm particles	Single Use	Yes	Efficient filtration of airborne particles down to 0.3 mm	Yes
PAPR	99.97% of 0.3-μm particles	Reusable	No	Filters air and creates powered the positive outflow of air from within a hood or mask	Yes

2 Subjects And Methods

Powered Air Purifying respirator (PAPR)

The FreeAir Mask(Furuiaier Technology Ltd, China, FA-R100) with connection to a respiratory blower is a GB/T 18801-2015-certified device that belongs to the category of PAPRs. It consists of a host unit, an air hose, and a mask(Fig. 1). When in use, the external air is driven by a fan through a pre-filter cartridge inside the host unit to filter out hair, particulate impurities and dust, and then the ultra-fine particles carried by the airflow are intercepted by its main filter cartridge twice to eliminate PM2.5, bacteria, viruses and other bio-aerosols from the air.

Participants and Mask Wearing

Fifty-six healthy healthcare workers from Guang’anmen Hospital, China Academy of Chinese Medical Sciences, aged 22–28 years old, were randomized to an experiment group (PAPR Group, N = 28) or a control group (N95 Group, N = 28). The basic information collected from the subjects included age, gender, heart rate, and oxygen saturation (Table 2). All the participants had no history of olfactory disorders, nasal polyps, nasal trauma, chronic sinusitis, or other diseases that significantly affect the reduced olfactory function, and no acute respiratory infections or allergies at the beginning of the study. Our Clinical Research Ethics Committee approved the study. The volunteers filled out an informed consent form.

The PAPR Group had no previous routine experience in the use of PAPRs and received detailed instruction in the handling and use of this mask(Fig. 2). The N95 Group was instructed to correctly wear the N95 masks (Winner Medical, China, 604–008783). We simulated general clinical working hours and work intensity. Both masks were worn continuously for 4 hours, with a break and lunch for 1 hour, and again continued to be worn continuously for 4 hours, for a total of 8 hours. All subjects were provided with the same diet and allowed to drink or defecate as required during the experiment. The mask was removed and worn in strict accordance with precautions. We simulated common scenarios in clinical work, such as walking (5km/h), deep squatting, and reading aloud during the observation period.

Table 2
Characteristics of the Groups

Parameters	PAPR Group (N = 28)	N95 Group (N = 28)	P
Age(yr)	23.5(23, 24)	24(23, 25)	0.280
Male: Female ratio	10:18	9:19	0.778
HR(/min)	78 ± 9	75 ± 9	0.690
SpO2(%)	98(98, 99)	98(98, 99)	0.602

Measurements of the olfactory test

The olfactory tests were carried out in a ventilated environment. All subjects underwent an odor discrimination test and a threshold test before and after wearing the mask for 8 hours, with a 5-minute break between trials to prevent olfactory fatigue.

The odor discrimination test: we used identical opaque vials with daily items to produce odors: ethanol, vinegar, soy sauce, lemon juice, camphor, and identical vials of water as controls. Each correct answer was scored 1 point out of 6, with a minimum of 0. The subject had to try again after a 5s interval after one incorrect answer.

The olfactory threshold test: 99% anhydrous ethanol was used as the olfaction, and water was used to test the olfactory threshold. The solution was prepared ready to use and diluted 11 times in succession according to the ratio of anhydrous ethanol:water = 1:2. The test is carried out by having the subject sniff the vial, starting at a low concentration (usually at a dilution of 9). If the subject can correctly identify the ethanol at the same attention three times in a row, the concentration is reduced; if the subject is unable to identify it 1 out of 3 times, increase the engagement until it is correctly identified three times in a row, at which point the value is the threshold.

3 Statistical Analyses

All statistical analyses were performed using the SPSS version 26.0 (SPSS Inc., Chicago, Illinois, USA). Normally distributed data were expressed as mean ± standard deviation, and non-normally distributed data were expressed using interquartile spacing. Count data were expressed as composition ratios and percentages. Non-parametric statistical tests were applied using the Mann-Whitney U-test and chi-squared test. Statistical significance was set at $P < 0.05$.

4 Results

For the odor discrimination test (Table 3), in the PAPR Group, the discrimination test scores were 6 (6,6) before and after wearing the mask, of which 2 (7.1%) subjects were less able to distinguish odor after wearing the mask than before. In the N95 Group, the discrimination test scores were 6 (6,6) before and after wearing the mask, of which 4 (14.2%) subjects were less able to distinguish odor after wearing the mask. There was no statistical difference between the two groups in the before-mask discrimination test scores (Z=-0.428 P = 0.669) and after-mask discrimination test scores (Z=-0.40 P = 0.459). There was no statistical difference between the PAPR Group in the before- and after-mask discrimination test scores (Z=-0.707 P = 0.480) and no statistical difference in discrimination test scores before and after wearing the mask in the N95 Group (Z = -0.828 P = 0.408). The proportion of diminished olfactory discrimination was not significantly different in the two groups ($\chi^2 = 0.187$, p = 0.666).

For the olfactory threshold test (Table 4), in the PAPR Group, the before-mask threshold test score was 8.5 (8, 10). The after-mask threshold test score was 8 (7, 8.75), of which 17 (60%) subjects had a higher concentration of detectable odor than before the mask. In the N95 Group, the before-mask threshold test score was 8 (7, 9), and the after-mask threshold test score was 8 (6.25, 8), of which 15 (54%) subjects had a higher concentration of detectable odor than before the mask. There was no statistical difference between the two groups in the before-mask threshold scores (Z=-1.218 P = 0.223) and after-mask threshold scores (Z=-0.998 P = 0.318). But there was a statistical difference in threshold scores before and after wearing the mask in the PAPR Group (Z= -2.595 P = 0.009) and N95 Group (Z= -2.120 P = 0.034) (Fig. 3). The proportion of elevated olfactory thresholds was not significantly different in the two groups ($\chi^2 = 0.292$, p = 0.589).

Table.3 odor discrimination test

Groups	N	Less odor discrimination(n %)	Before mask	After mask	Z	P	χ^2	P
PAPR Group	28	2(7.1)	6(6, 6)	6(6, 6)	-0.707	0.480	0.187	0.666
N95 Group	28	4(14.2)	6(6, 6)	6(6, 6)	-0.828	0.408		

Table.4 olfactory threshold test

Groups	N	higher detectable odor (n %)	Before mask	After mask	Z	P	χ^2	P
PAPR Group	28	17(60)	8.5(8, 10)	8(7, 8.75)	-2.595	0.009	0.292	0.589
N95 Group	28	15(54)	8(7, 9)	8(6.25, 8)	-2.120	0.034		

5 Discussion

In the context of COVID-19, wearing a mask is essential for outbreak prevention and control. Healthcare workers are required to wear masks for prolonged periods. Previous studies have shown that prolonged mask-wearing can have various adverse effects, including headaches and skin damage [8, 9]. Still, there are fewer reports on whether mask-wearing affects olfactory.

This study shows that wearing a mask reduces odor sensitivity but does not significantly affect odor recognition. Also, there was no significant difference in the impact of the PAPRs compared to the N95 mask on the olfactory threshold test. Both masks increased the olfactory threshold. The reasons for this result were not exactly the same between the two masks, which need to be explored further.

Of all the human sensory systems, the sense of smell is the most difficult to understand. The human olfactory system consists of millions of olfactory neurons arranged in sensory epithelial cells located in the nasal cavity and is closely related to neurological and psychological aspects. A variety of reasons can cause olfactory impairment, upper respiratory tract infections, head trauma, and nasal-sinus disease being the most common causes. Recent studies have found that reduced olfactory function is also associated with a range of neurodegenerative diseases, such as Alzheimer's disease[10]. It has been established that breathing is an integral part of the olfactory system. It plays a crucial role in detecting and perceiving odors in the olfactory system [11, 12]. Nwosu et al.[13] noted that the discomfort of the mask on breathing might be due to the increased resistance to breathing, increased temperature, humidity, and carbon dioxide in the dead space of the mask, or the pressure of the straps. Cardiopulmonary exercise capacity and lung function parameters are significantly reduced in healthy volunteers, whether wearing surgical masks or N95 masks. Therefore, we speculate that the effect of masks on reduced olfactory function may be related to restricted respiratory physiology.

Some scholars refer to the physical and psychological deterioration and multiple symptoms after wearing masks as Mask-Induced Exhaustion Syndrome (MIES). It is accompanied by typical changes and symptoms, such as an increase in breathing dead space volume, increase in breathing resistance, increase in blood carbon dioxide, decrease in blood oxygen saturation, etc. [14]. These changes in respiratory physiology have a significant impact on olfactory function. Hypoxia, excessive CO2, and low nasal airflow may have an effect on the sense of smell[15]. It has been demonstrated that chronic intermittent hypoxia induces olfactory impairment while altering the activity of the main olfactory bulb neural network and its response to odor[16]. Huppertz et al. Found a decrease in olfactory sensitivity under normobaric hypoxia. In contrast, the ability to discriminate odors was not impaired, which is very similar to the results of our study. He suggested that hypoxia can be considered a stressful situation for the human body, which leads to an increased activity of the hypothalamic-pituitary-adrenocortical axis (HPA) [17]. The N95 mask consists of four layers. A significant decrease in PaO2 and an increase in respiratory rate occurs after 4 hours of wearing the N95 mask, which may be related to the shortness of fresh air for inhalation. The combination of low oxygen and high CO2 contributed to the effect of the N95 mask on the sense of smell.

The results of Salati et al. demonstrated that an N95 mask caused excessive CO2 inhalation by approximately 7x greater per breath compared with normal breathing[18]. Several studies on marine organisms have found that high CO2 seawater reduces the olfactory sensitivity of fish and macroinvertebrates. It is related to the interference of high CO2 with brain neurotransmitter function and the reduced affinity of odorants for their receptors at high CO2[19, 20]. Some studies showed that End-tidal CO2 increased significantly after wearing an N95 mask alone, but it was significantly mitigated when used in combination with a PAPR and the rise in CO2 was consistently lower when wearing the PAPR compared to the N95[21, 22]. This may be due to the positive pressure generated by PAPR through increased oxygen concentration in the hood and positive pressure assisted expiration. But the mechanism of how hypercapnia affects the olfactory function in humans remains to be investigated.

In addition, when wearing an N95 mask, heat exchange between the mucosal wall and the inhaled air were reduced, influencing the perception of nasal patency[18]. The main mechanism that produces the sensation of nasal patency is a thermal receptor activated by cooling the nasal mucosa. Both ambient air temperature and humidity significantly modulate an individual's perception of patency through heat loss in the nasal mucosa and trigeminal sensory input[23, 24]. While wearing a mask, the humidity and temperature inside the mask increase compared to the air, which impacts the nasal patency, further affecting the perception of a smell. Airflow also plays a role in the human olfactory. Yao et al. indicated that nasal flow spontaneously engages central olfactory processing and is an integral part of the olfactory percept in humans[25]. Fu et al. reported that alteration of nasal airflow affected odor thresholds distinctly[26]. Oka et al. found that the nasal airflow rate significantly affected the responses of glomeruli in the mouse olfactory bulb[27]. Lee et al. demonstrated an average increment in inspiratory and expiratory airflow resistance of 126% and 122%, respectively, and an average reduction in air exchange of 37% when using the N95 mask. This is objective evidence that wearing a mask can cause substantial damage to nasal airflow[28]. PAPRs have a greater advantage in mitigating increased temperatures and humidity, which is associated with the respirator circulating fresh air into the mask[29]. However, at the same time, 9 (32%) subjects experienced nasal congestion and dryness after wearing the PAPR compared to 2 (7%) in the N95 group($P<0.05$). This may be the main reason for the olfactory changes caused by the PAPR. Most of the existing studies have focused on PAPRs induced eye dryness[29, 30], and we suspected that adding a humidification device to the PAPR may improve these symptoms.

Furthermore, the sense of smell is adaptive. Same as vision, when our eyes are exposed to very intense light, our visual threshold rises considerably, and it takes tens of minutes to return to entirely normal. This phenomenon, known as “dark adaptation," has been studied for decades[31]. Olfactory adaptation leads to a temporary inability to perceive a specific odor after prolonged exposure to the sense of smell. It reduces the sensitivity to perceive odors and raises the detection threshold[32]. Therefore, we guess there is also an olfactory adaptation process before and after wearing the mask. It may take some time for people to regain their original threshold of olfactory recognition after removing the mask, but how long this time is and how different types of masks affect the length of time is not yet known.

6 Limitations Of The Study

There were some limitations in this study. First, a small sample size of 56 subjects was included, resulting in the poor extrapolation of the findings. Second, due to the limitation of the test, we only conducted the smell test before and after 8h of wearing the mask and found that masks did not affect the ability to discriminate smell. However, it is not clear whether the long-term wearing of the mask will affect this index, so we expect a more prolonged study to clarify this effect further. Third, olfactory tests need further refinement. There are two main clinical tests for smell internationally: subjective and objective tests. The Sniffin sticks test is the most established personal test and can assess the subject's odor perception threshold, odor discrimination, and odor identification. The most representative objective test is the olfactory event-related potentials (OERP). In contrast, structural imaging of the olfactory system (CT, MRI, DWI) and functional imaging of the olfactory system (fMRI, PET, SPECT) have also started to get noticed [10, 33]. Only subjective tests were performed in our study, and further research is needed for an objective evaluation of olfaction. Fourth, long-term mask-wearing under the influence of COVID-19 is not limited to healthcare workers, so we need more extensive scale and larger sample size studies to clarify the effect of mask-wearing on olfaction.

7 Conclusion

In summary, wearing a mask affects the healthcare workers’ olfaction, especially odor sensitivity. Healthcare workers wearing masks have a higher olfactory threshold than before. The reduced sense of smell caused by wearing a mask is the result of a combination of factors such as hypoxia, excessive CO2, changes in temperature, humidity, and nasal airflow. PAPRs appear to be more advantageous in several ways. Further research is needed on how wearing a mask affects olfaction and how long it takes for people's olfactory thresholds to return to their original levels after wearing a mask. Our findings will also be relevant to future pandemics and the use of personal protective equipment.

Abbreviations

COVID-19: Coronavirus disease 2019; PAPR: Powered Air Purifying respirator; PPE: Personal protective equipment; MIES: Mask-Induced Exhaustion Syndrome; HPA: hypothalamic -pituitary-adrenocortical axis; OERP: Olfactory Event-Related Potentials; CT: Computed Tomography; MRI: Magnetic Resonance Imaging; DWI: Diffusion Weighted Imaging; fMRI: functional Magnetic Resonance Imaging; PET: Positron Emission Computed Tomography; SPECT: Single Photon Emission Computed Tomography.

Declarations

Author Contributions

XX and GL conceived and designed the study. XX, JZ, and YL collected the data. XK and YY re-examined the data. SL and XL analyzed the data. XX wrote the first draft of the manuscript. XK and SL wrote sections of the manuscript. GL reviewed and revised the manuscript. All authors contributed to the article and approved the submitted version.

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Ethics approval and consent to participate

The Ethics Committee of Guang’anmen Hospital, China Academy of Chinese Medical Sciences reviewed and approved this study (No. 4110701). Written informed consent was obtained from all subjects (healthcare workers) who volunteered to participate in this study.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Written informed consent for publication of study data was obtained from all participants.

Conflict of interest

The authors have no conflicts of interest to declare.

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Figures

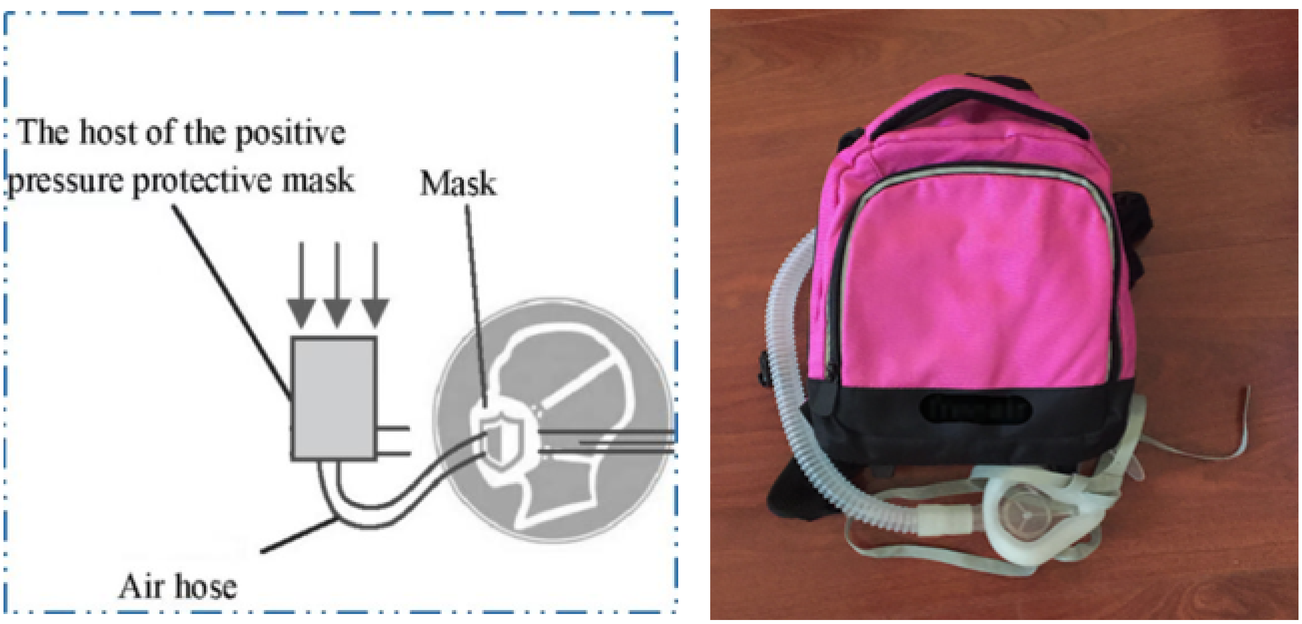

Figure 1

A Powered Air Purifying Respirator

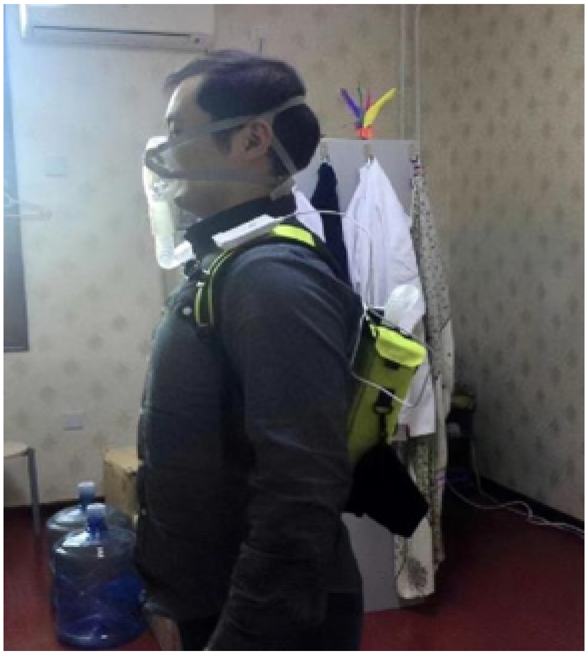

Figure 2

PAPR for PPE in healthcare workers

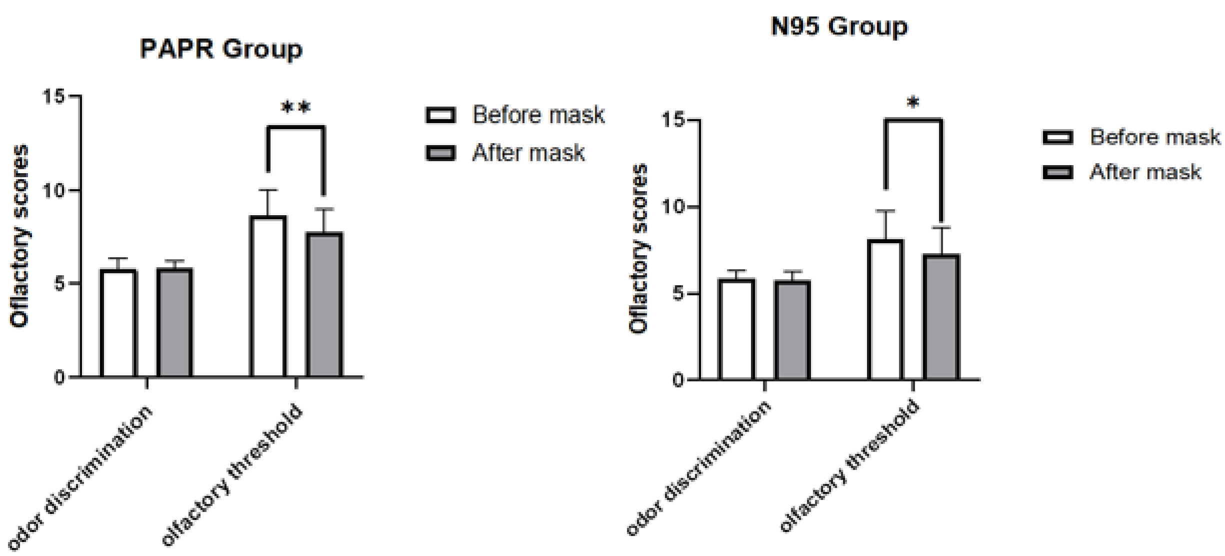

Figure 3

Change of olfaction before and after Powered Air Purifying Respirators (PAPRs) and N95 mask in subjects