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# The impact of wearing powered air purifying respirators or N95 masks on the olfactory function in healthcare workers

## A randomized controlled trial

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**Abstract**

**Background:** With the Coronavirus disease 2019 epidemic, wearing a mask has become routine to prevent and control the virus's spread, especially for healthcare workers. However, the impact of long-term mask wear on the human body has not been adequately investigated. This study aimed to investigate whether Powered Air Purifying Respirators and N95 masks impact the olfaction in healthcare workers.

**Methods:** We recruited fifty-six healthcare workers and randomly divided them into 2 groups, wearing a powered air purifying respirator (PAPR) (experiment group, N = 28) and an N95 mask (control group, N = 28). Olfactory discrimination and threshold tests were performed before and after wearing the masks. SPSS 26.0 (SPSS Inc., Chicago, Illinois) software was used for the statistical analyses.

**Results:** There was a statistical difference in the olfactory threshold test after wearing the mask in both PAPR Group ($Z = -2.595$, $P = .009$) and N95 Group ($Z = -2.120$, $P = .034$), with no significant difference between the 2 ($\chi^2 = 0.29$, $P = .589$). There was no statistical difference in the discrimination test scores in both 2 groups after wearing the masks.

**Conclusion:** Wearing a mask affects the healthcare workers' olfaction, especially odor sensitivity. Healthcare workers have a higher olfactory threshold after long-term mask wear, whether wearing PAPRs or N95 masks.

**Abbreviations:** PAPR = powered air purifying respirator.

**Keywords:** COVID-19, healthcare, masks, olfaction, trial

## 1. Introduction

Since the outbreak of Coronavirus disease 2019, masks have become essential personal protective equipment for the community and first-line healthcare workers. Wearing a medical protective mask is one of the most important measures to prevent disease transmission. N95 masks are high-performance filtration masks to protect healthcare workers, which are recommended by the World Health Organization. Compared with surgical masks, N95 masks have a filtration efficiency of more than 95% for particles with a diameter of 0.3 $\mu$m or more and can protect the wearer from aerosols.[1] Filtration is achieved by combining a web of polypropylene microfibers and electrostatic charge.[2] However, the impact of long-term mask wear on the human body has not been adequately investigated. Long-term mask wear has been shown to have several adverse physiological and psychological effects, such as hypoxia, fatigue, headache, cognitive decline, and psychological disorders.[3] The impact 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 an extended period seems to cause nasal congestion and diminish the sense of smell. A study from Guangzhou Medical University, China, confirmed this subjective impression.[4] It has been found that wearing a surgical mask reduced odor sensitivity, whereas an N95 mask substantially reduced odor perception.

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

*The authors have no conflicts of interest to disclose.*

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

*The Ethics Committee of Guang'anmen Hospital, China Academy of Chinese Medical Sciences, reviewed and approved this study (No. 4110701). All subjects (healthcare workers) who volunteered to participate in this study obtained written informed consent and consented to the publication of identifying images in an online open-access publication.*

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Powered air purifying respirator (PAPR), a battery-powered blower that provides positive airflow through a filter, cartridge, or canister to a hood or face piece, is a new and suitable option for exposures to high concentrations of infectious aerosols, especially where the risk is unknown or uncertain.[5] Compared to other masks, advantages included being cooler, more comfortable, and can be worn for more extended periods.[6] The specific differences between the 2 types of masks are as followings[1] (Table 1). However, the impact of PAPR on the human body has not been adequately examined.

## 2. Objectives

The aim of this study is to investigate whether PAPRs and N95 masks impact 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. Our hospital Ethics Committee approved the study (*Research Ethics No.4110701*) and strictly adhered to the research ethics specifications in the Declaration of Helsinki.

## 3. Subjects and methods

### 3.1. PAPR

The free air 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.

**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 |

PAPR = powered air purifying respirator.

## 4. Participants

All enrolled participants were healthcare workers from Guang'anmen Hospital, China Academy of Chinese Medical Sciences. Participants were enrolled if they met all of the following criteria: Aged ≥ 18 years; Had no history of olfactory disorders, nasal polyps, nasal trauma, and chronic sinusitis, and; Had no other diseases that significantly affect the reduced olfactory function; Had no acute respiratory infections or allergies at the beginning of the study. Informed consent was obtained from all participants.

## 5. Study design

This was a randomized, controlled trial with open allocation but masked scoring of end points. The study was approved by the Guang'anmen Hospital Ethics Committee (*Research Ethics No.4110701*) and strictly adhered to the research ethics specifications in the Declaration of Helsinki.

All enrolled participants were randomized to an experiment group (PAPR Group) or a control group (N95 Group) through a random number allocation in blocks of 5 by the principal investigator. The PAPR Group received detailed instructions on handling and using this mask. 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 shows 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 (5 km/hours), deep squatting, and reading aloud during observation. The outcomes were the odor discrimination test and the olfactory threshold test. The treatment allocation was concealed from the scorer, but not from the principal investigator.

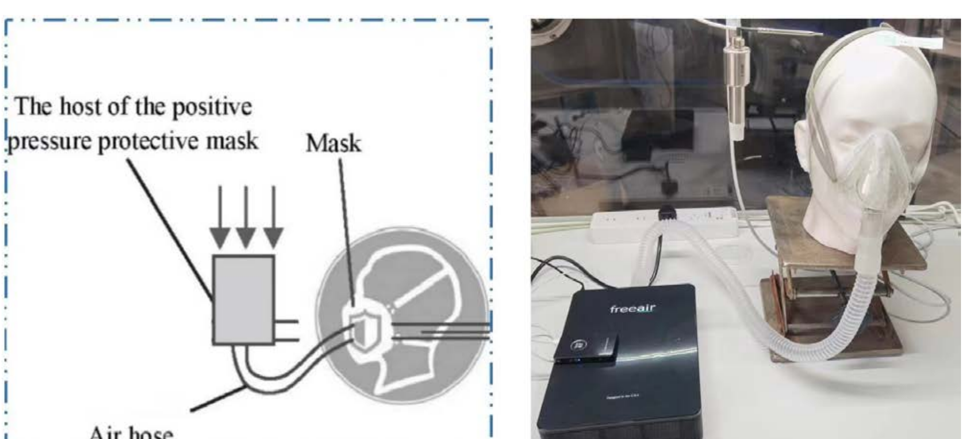


**Figure 1.** A powered air purifying respirator.

### 5.1. Measurements of 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 (a quick test based on CCSIT, European Olfactory Ability Test, COT[7]): COT has been validated as an olfactory test in New Zealand, USA, UK and China. Since odor recognition is influenced by culture and dietary habits, it is necessary to modify the substances used in the olfactory test to suit the culture and dietary habits of the local population.[8] 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. After 1 incorrect answer, the subject had to try again after a 5 seconds interval.

The olfactory threshold test (based on the Connecticut Chemosensory Clinical Research Center, CCCRC[9]): The CCCRC test has been shown to have high agreement with the Brief-Smell Identification Test. Meanwhile, CCCRC test is widely used in many countries because of its low cost and easy availability of materials.[10] 1-Butanol 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 1-Butanol: 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 3 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 3 times in a row, at which point the value is the threshold.

## 6. Statistical analyses

All statistical analyses were performed using the SPSS version 26.0 (SPSS Inc., Chicago, Illinois). Normally distributed data were expressed as mean ± standard deviation, and non-normally distributed data were described 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 $P < .05$.

## 7. Results

### 7.1. Trial enrollment

We examined 89 healthcare workers in Guang'anmen Hospital, China Academy of Chinese Medical Sciences and 33 participants were excluded (Fig. 2). Sixteen did not meet the inclusion criteria and 17 participants refused to participate. In the end, 56 healthcare workers from Guang'anmen Hospital, China Academy of Chinese Medical Sciences, were enrolled in this study. Twenty-eight were randomized to the PAPR Group and 28 to the N95 Group.

### 7.2. Baseline characteristics of the study population

The baseline features of the study population, including age, gender, heart rate, and oxygen saturation, were shown in Table 2. There was no significant difference in the baseline. All participants finished this study.

### 7.3. Odor discrimination test

The final results of the odor discrimination test were shown in 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. There was no statistical difference in discrimination test scores before and after wearing the mask in the PAPR Group ($Z = -0.707$, $P = .480$). 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 in discrimination test scores before and after wearing the mask in the N95 Group ($Z = -0.828$, $P = .408$).

Comparison between the 2 groups showed that the proportion of diminished olfactory discrimination was not significantly different ($\chi^2 = 0.187$, $P = .666$).

### 7.4. Olfactory threshold test

The final results of the olfactory threshold test were shown in Table 4. In the PAPR Group, the before-mask threshold test score was 8.5 (8, 10). The after-mask threshold score was 8 (7, 8.75), of which 17 (60%) subjects had a higher concentration of detectable odor than before the mask. There was a statistical difference in threshold scores before and after wearing the mask in the PAPR Group ($Z = -2.595$, $P = .009$) (Fig. 3A). 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 a statistical difference in threshold scores before and after wearing the mask in the PAPR Group ($Z = -2.595$, $P = .009$) and N95 Group ($Z = -2.120$, $P = .034$) (Fig. 3B).

Comparison between the 2 groups showed that the proportion of elevated olfactory thresholds was not significantly different ($\chi^2 = 0.292$, $P = .589$).

## 8. Discussion

In the context of Coronavirus disease 2019, 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 may have various adverse effects on the human body, including headaches and skin damage.[11,12] However, there are fewer studies on whether mask-wearing affects the olfactory.

Our study shows that wearing a mask reduces odor sensitivity but does not significantly affect odor recognition. There was no significant difference in the impact of the PAPRs compared to the N95 masks on the olfactory threshold test. Both PAPRs and N95 masks increased the olfactory threshold, which is different from our original hypothesis.

The exact mechanism by which mask-wearing leads to reduced olfactory sensitivity is not fully understood. 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. Various reasons can cause olfactory impairment, upper respiratory tract infections, head trauma, and nasal-sinus disease being the most common causes. It has been established that breathing is an integral part of the olfactory system, which is crucial in detecting and perceiving odors in the olfactory system.[13] Nwosu et al[14] 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. Therefore, we speculate that the impact 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. It is accompanied by typical

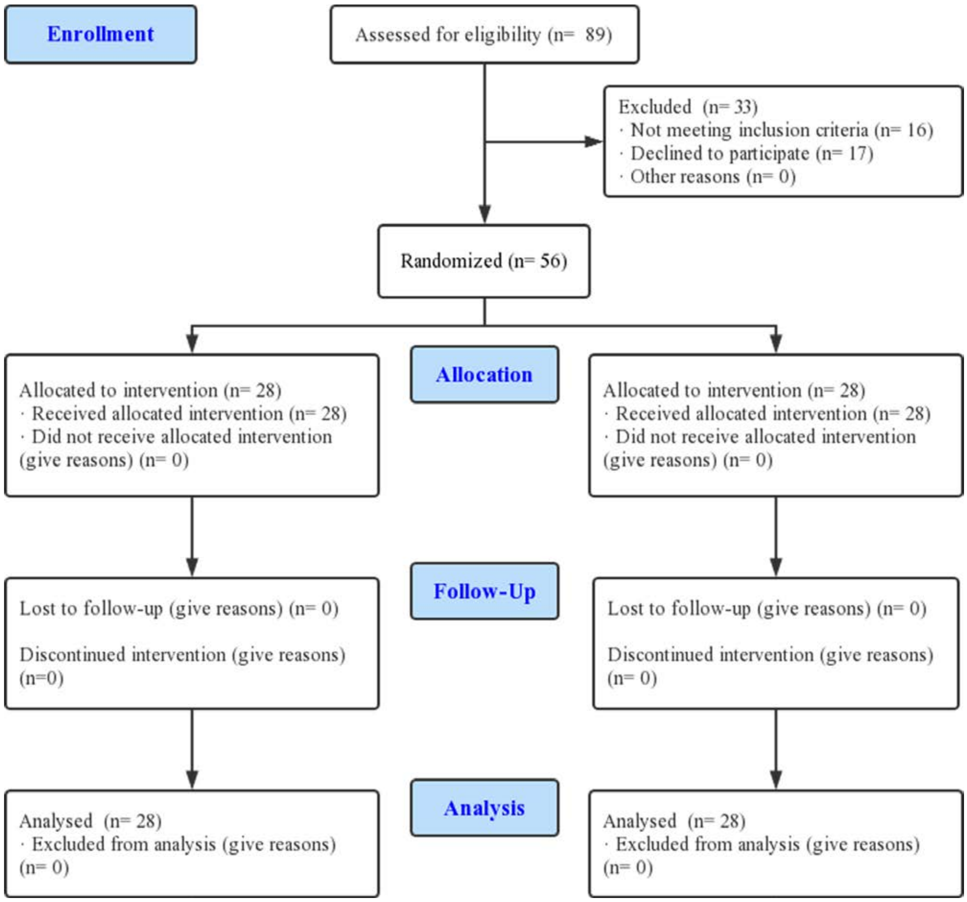


**Figure 2.** Flow chart of the participates through the trial.

**Table 2**

**Characteristics of the participants.**

| Parameters | PAPR group (N = 28) | N95 group (N = 28) | P |
|---|---|---|---|
| Healthcare worker, n (%) | 28 (100) | 28 (100) | – |
| Age (yr) | 23.5 (23, 24) | 24 (23, 25) | .280 |
| Male:Female ratio | 10:18 | 9:19 | .778 |
| HR (/min) | 78 ± 9 | 75 ± 9 | .690 |
| SpO2 (%) | 98 (98, 99) | 98 (98, 99) | .602 |

PAPR = powered air purifying respirator.

**Table 3**

**The results of odor discrimination test.**

| Groups | N | Less odor discrimination (n %) | Before mask | After mask | P | $\chi^2$ | P for the two groups |
|---|---|---|---|---|---|---|---|
| PAPR group | 28 | 2 (7.1) | 6 (6, 6) | 6 (6, 6) | .480 | 0.187 | .666 |
| N95 group | 28 | 4 (14.2) | 6 (6, 6) | 6 (6, 6) | .408 | | |

PAPR = powered air purifying respirator.

changes and symptoms, such as increased breathing dead space volume, increased breathing resistance, increased blood carbon dioxide, decreased blood oxygen saturation, etc.[15] These changes in respiratory physiology have a significant impact on olfactory function. Hypoxia, excessive $CO_2$, and low nasal airflow may affect the sense of smell.[16] 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.[17] The N95 mask consists of 4 layers, which may be related to the shortness of fresh air for inhalation. The combination of low oxygen and high $CO_2$ may contribute to the impact of the N95 mask on the sense of smell.

The results of Salati et al demonstrated that an N95 mask caused excessive $CO_2$ inhalation by approximately 7x greater per breath than normal breathing.[18] Some studies showed that End-tidal $CO_2$ increased significantly after wearing an N95 mask alone. However, it was significantly mitigated when combined with a PAPR, and the rise in $CO_2$ was consistently lower when wearing the PAPR compared to the N95.[19] This may be due to the positive pressure generated by PAPR through increased oxygen concentration in the hood and positive pressure-assisted expiration. However, how hypercapnia affects the olfactory function in humans remains to be investigated.

In addition, the primary mechanism that produces the sensation of nasal patency is a thermal receptor activated by cooling

**Table 4**

**The results of olfactory threshold test.**

| Groups | N | Higher detectable odor (n %) | Before mask | After mask | P | $\chi^2$ | P for the two groups |
|---|---|---|---|---|---|---|---|
| PAPR Group | 28 | 17 (60) | 8.5 (8, 10) | 8 (7, 8.75) | .009 | 0.292 | .589 |
| N95 Group | 28 | 15 (54) | 8 (7, 9) | 8 (6.25, 8) | .034 | | |

PAPR = powered air purifying respirator.

olfaction, especially odor sensitivity. Although the exact mechanism leading to this phenomenon is not clear. This is a reminder that healthcare workers who wear masks for long periods need to be aware of changes in their sense of smell, especially those with abnormal olfactory functions.

## 9. Limitations

There were some limitations of this study. First, this is a pilot study with a small sample size of 56 subjects. Second, due to the limitation of the test, we only conducted the smell test before and after 8 hours 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 2 main clinical tests for smell internationally: subjective and objective. The Sniffin sticks test is the most established personal test and can assess the subject's odor perception threshold, odor discrimination, and identification. The most representative objective test is the olfactory event-related potentials. In contrast, structural imaging of the olfactory system (computed tomography, magnetic resonance imaging, diffusion weighted imaging) and functional imaging of the olfactory system (functional magnetic resonance imaging, positron emission computed tomography, single photon emission computed tomography) have also started to get noticed. Only subjective tests were performed in our study, and further research is needed to evaluate olfaction objectively. Finally, our study only carried out a self-comparison. Future studies will need to have a blank control group to reduce bias.

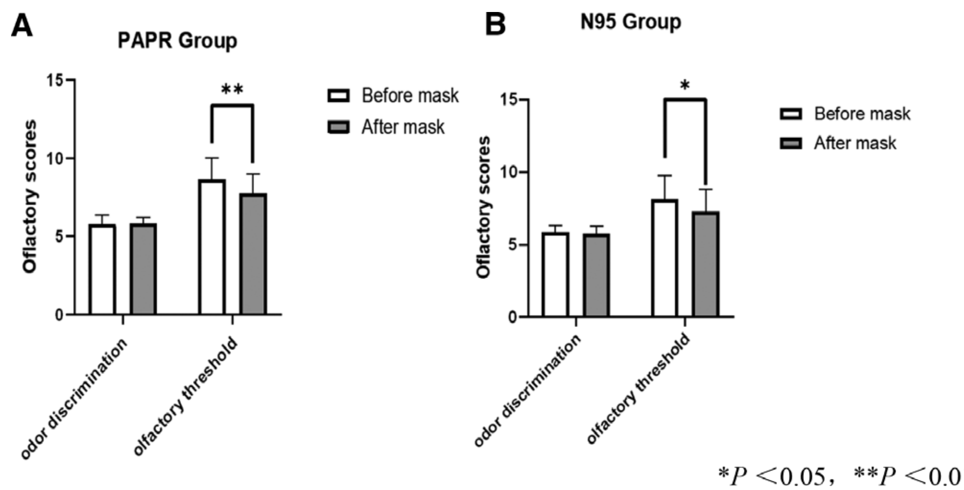


**Figure 3.** Change of olfaction before and after PAPRs and N95 masks in subjects. PAPR = powered air purifying respirator.

the nasal mucosa. While wearing a mask, the humidity and temperature inside the mask increase compared to the air, which impacts 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.[20] Fu et al reported that alteration of nasal airflow affected odor thresholds distinctly.[21] 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.[22] PAPRs have a more significant advantage in mitigating increased temperatures and humidity, which is associated with the respirator circulating fresh air into the mask. Therefore, the PAPRs should theoretically outperform the N95 masks in terms of causing olfactory impairment. However, many subjects reported nasal dryness after wearing PAPRs, which may be the main reason why PAPRs affect the sense of smell.

Furthermore, the sense of smell is adaptive. Like 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.[23] 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.[24] 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.

In summary, our study suggested that wearing a mask, whether PAPRs or N95 masks, affects the healthcare workers'

## 10. Conclusion

In conclusion, wearing a mask affects the healthcare workers' olfaction, especially odor sensitivity. Healthcare workers have a higher olfactory threshold after long-term mask wear, whether wearing PAPRs or N95 masks. This impact should be noted in healthcare workers who wear masks for long periods.

## Author contributions

**Conceptualization:** Shixu Liu, Guangxi Li.

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**Supervision:** Guangxi Li.
**Writing – original draft:** Xiao Xia.
**Writing – review & editing:** Shixu Liu, Kun Xia, Guangxi Li.

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