Review

# Unveiling the Investigation and Comfort Research in Various Scenarios of Mask Protection Equipment against Respiratory Transmission

[1,2]**Xin Zhang**

[1]*Hebei Key Laboratory of Man-Machine Environment Thermal Control Technology and Equipment, Hebei, China*
[2]*Advanced Research Center of Thermal and New Energy Technologies,*
*Hebei Vocational, University of Technology and Engineering, Hebei, China*

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Email: 15512878208@163.com

**Abstract:** Personal Protective Equipment (PPE) is essential to protect medical staff (HCW) from highly infectious diseases such as COVID-19 and masks are indeed important functional small effective defensive equipment in safeguarding the public from infection. However, the thermal comfort, fit, and difficulty breathing when wearing a mask can affect its use and improve filtration efficiency. In addition, there is a lack of available research on thermal comfort, fit, and respiration of masks under actual wearing conditions. To this end, a questionnaire survey and thermal comfort evaluation were used to investigate the thermal comfort and breathing difficulties of 75 volunteers wearing masks in Beijing, Tianjin, and Hebei. The results show that the main types of masks in various scenarios are medical masks. Except for the outdoors, the proportion of people who feel basic comfort and fit is the highest in these four areas. About a quarter of people experienced an average of 50-60 and 20-30 min of breathing difficulties in winter and summer, respectively. This study provides a systematic analysis and useful data for mask design and the development of human public health.

**Keywords:** Personal Protective Equipment, Masks, Thermal Comfort, Dyspnea, Infectious Disease

## Introduction

In December 2019, the outbreak of an unprecedented highly contagious COVID-19 disease in Wuhan, China, raised concerns around the world (Zheng *et al*., 2020). Subsequently, a great number of people were becoming infected in China and many other countries, such as the United States, Japan, Brazil, India, and so on (Fig. 1) (OWD, 2023). What's more, because of the unknown severe acute pneumonia-respiratory syndrome caused by the novel coronavirus pandemic (WHO, 2020), there was no specific drug and the mortality rate continued to rise (OWD, 2023). As of 10 March 2023, there have been 6.76 hundred million COVID-19 cases on a global scale, including 6.88 million loss of life according to the Johns Hopkins (OWD, 2023).

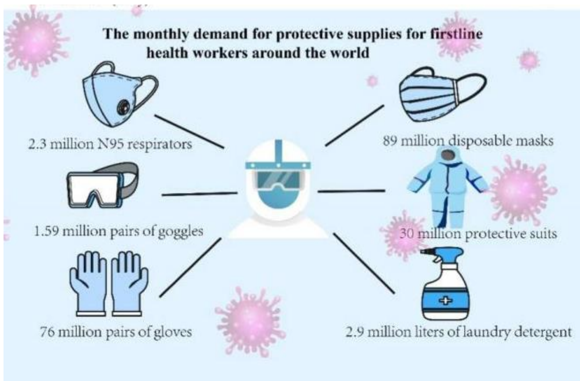


**Fig. 1:** March 2020, WHO schematic diagram of the projected number of protective equipment (WHO, 2020)

A mask's purpose is to prevent the transmission of the virus carried by aerosol particles or respiratory droplets. Particles adhering to the virus vary in size depending on the mode of transmission. Aerosol airborne particles measure less than 5 μm, while respiratory fluid droplets range from 5-10 μm in size. In March 2020, the WHO highlighted the importance of the use of medical masks and N95 respirator-type masks in mitigating the transmission of the virus and estimated 89000000 would be used worldwide each month (Fig. 1) (WHO, 2020). Therefore, masks are necessary to combat the asymptomatic spread of aerosols and droplets.

Gauze masks were among the earliest materials utilized for masks and surgical masks in the past often comprised of multiple layers of cotton yarn, typically ranging from 8-12 layers thick (Ho *et al.*, 2020). The dense accumulation of multiple layers of cotton yarn results in intertwined fibers that have a lattice-like pore arrangement, which can physically block the larger airborne particles or particulate matter, while the cotton thread is easy to absorbs moisture and the efficiency of blocking is very low (Shapiro, 1950). During the 1960s, the technology for non-woven masks emerged, coinciding with the development of disposable masks during the same period (Schrader, 1976). The masks used melt-blowing technology and the material underwent a process where electrical charges were applied to it, generating an enduring electric field that affords enough Particulate Matter pollution (PM) filtering via electrostatic attraction. The most extensively researched raw materials were non-woven fibrous substances, including Polypropylene (PP), Polyethylene (PE), Polylactic Acid (PLA), and Polytetrafluoroethylene (PTFE). PP melt-blown nonwoven fibrous has stable properties and smaller fiber diameter (about 0.5-4 μm), high porosity, optimal air permeability, and filtration resistance. The filtering efficacy of the material made from polypropylene surpasses that of other materials. Furthermore, studies demonstrated that compared with traditional fiber filters, the electret filter exhibits superior filtration efficiency, reduced air resistance, and increased dust retention capacity (Liu *et al.*, 2019). Polypropylene nonwovens can also charge fibers through an electret. Under the effect of coulomb adsorption, the filtration efficiency of polypropylene nonwovens for dust, and air bubbles and the filtration efficiency against viruses reaches 98.9%, with a filtration resistance of only 37.92 Pascal (Wang *et al.*, 2022).

A mask designed for enhanced capacity, maximum comfort, effective removal of biological aerosols, and optimal filtration of airborne particles. Has always been a concern (Liu *et al*., 2019). The factors affecting the final quality of masks have been focused on improving the efficiency of masks. Due to the larger surface area, smaller hole, small weight, excellent breathability, and effective pore interconnectivity of Nano-fibers, the filtration is usually improved by preparing the Nano-scale fiber arrangements (Li *et al*., 2006; Ogunsona *et al*., 2020).

Nevertheless, with the improvement of mask filtration efficiency, the respiratory resistance of the mask increases significantly, which will inevitably lead to the comfort of wearing masks. Importantly, the effectiveness of any mask largely depends on its actual use. According to different types of people, their true feelings about wearing masks must be different. Therefore, the wearing time is different for different people, occasions, and seasons. So, what is the objective law and relationship between the comfort performance of the mask and these factors? In the case of the epidemic in 2020, there is no report on the relationship between the comfort performance of masks and the characteristics of the wearer, season characteristics, and occasion characteristics. Within this study, the key primary findings are as follows:

- The mask classification advantages and disadvantages were evaluated
- The regularity of comfort, fitness, and dyspnea of wearing masks in different subjects, places, and seasons

On this basis, this article first adopts the questionnaire survey and basic statistical analysis to study the influence of different subjects, seasons, infection levels, and wearing time on mask comfort. This study evaluated the mechanism of advantages, and disadvantages of basic principles of masks and further in part 2.

## Materials and Methods

In the actual process of wearing masks, different people have different feelings when wearing masks in different areas and seasons. Even wearing masks for a long time will cause breathing difficulty, affecting people's health and life. Therefore, studying the comfort, fitness, and breathing difficulty of people wearing masks will contribute to the improvement and development of masks, reducing harm to human health. To study the comfort, fitness, and breathing difficulties of wearing masks in different risk areas, a questionnaire-based survey of 75 volunteers was conducted in this chapter. Comfort and fitness TCV voting was further used for evaluation.

### *Types of Masks*

In the study, 5 types of masks (traditional masks, surgical face masks, N95 masks, full-length face shields, and respirator masks) were used to investigate actual wearing thermal comfort and breathing difficulties in the questionnaire.

### *Basic Principles and Formulas*

### *Heat Balance of the Human Body*

A microclimate is constructed between the human body and the mask. In the microclimate, the human body must meet the following conditions to achieve a comfortable state: First, the human body must be in a state of thermal balance; second, the average skin temperature

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should have a level compatible with comfort; third, the human body has an appropriate sweating rate for comfort.

The heat balance of the human body is as follows:

$$M\text{-}W\text{-}C\text{-}R\text{-}E\text{-}S=0 \tag{1}$$

$$R=\int_0^{\infty} I_{BB}(T,\lambda)\,\varepsilon(\lambda)d\lambda \tag{2}$$

$$I_{BB}(T,\lambda)=\frac{2hc^2\lambda^{-5}}{e^{\frac{hc}{\lambda T k_b}}-1} \tag{3}$$

$$C=hA\Delta T_{cv} \tag{4}$$

$$S=S_v+S_{res} \tag{5}$$

$$S_v=h_c(P_{sk}-P_a) \tag{6}$$

$$S_{res}=0.0014M(34-t_a) \tag{7}$$

where, $M$ represents the human metabolic rate; $W$ represents the mechanical work made by the human body; $H$ represents the heat between the body and the mask due to thermal conductivity; $C$ represents the heat dissipated by the body surface towards the surrounding environment in the form of convection; $R$ represents the heat dissipated by the body surface towards the surrounding environment in the form of radiation; $E$ represents the heat carried away by evaporation of sweat and exhaled water vapor and $S$ represents the heat storage rate of the human body. The units of $M$, $W$, $C$, $R$, $E$, and $S$are W/m$^2$. Under a steady state, the heat storage of the human body is 0. $I_{BB}(T, \lambda)$ is the spectral radiance of a blackbody at temperature $T$ and wavelength $\lambda$ (W·m$^2$). $\varepsilon(\lambda)$ is the skin emissivity. $h$, $c$, and $k_b$ are the Planck constant, velocity of light, and Boltzmann constant, respectively.
where, $h$ is the convection heat exchange coefficient and $\Delta T_{cv}$ is the temperature difference between textile and skin or environment. $h$ relies on the thermos-physical properties of fluid viscosity, density, specific heat capacity, and thermal conductivity, $(m{\cdot}K)$.$hc$, $p_{sk}$, and $P_a$are the clothing heat resistance, skin surface moisture vapor pressure, and vapor pressure of moisture in the ambient, respectively. $t_a$ is the temperature of ambient.

### *Thermal Comfort Evaluation*

The thermal comfort of the human body is defined in the ASHRAE standard 54-1992 as the consciousness pile that the human body is satisfied with the thermal environment. The relationship between human thermal sensation and thermal load is $PMV$, which is calculated as follows:

$$PMV=[0.303\mathrm{e}^{-0.036M}+0.0275](TL) \tag{7}$$

$$TL=M-W-C-R-E \tag{8}$$

$$PPD=100-95e^{[-(0.03353PMV^4+0.2179PMV^4)]} \tag{9}$$

where, $PPD$ is the percentage of the population dissatisfied with the thermal environment.

**Table 1:** Comfort and fitness TCV vote

| | Comfort | Fitness |
|---|---|---|
| -2 | Not comfortable | Not fitness |
| -1 | Slight comfortable | Slight fitness |
| 0 | Comfortable | Fitness |
| 1 | Moderate comfortable | Moderate fitness |
| 2 | Very/good comfortable | Very/good fitness |

The filtering efficiency largely depends on its actual use; comfort and adaptability are important manifestations of performance during the actual wearing process, which may affect its effectiveness. Here we explored the results of the regularity of comfort and fitness during the actual wearing of masks. The results only apply to environmental and human factors at that time. For ease of description, we divided comfort and fitness into five levels, as shown in Table 1. The comfort levels are "not comfortable, slight comfortable, comfortable, moderately comfortable, and very/good comfortable", respectively. The fitness levels are "not fitness, slight fitness, fitness, moderate fitness, and very/good fitness ", respectively.

TCV stands for thermal comfort vote. Thermal comfort vote and matching degree vote indicators are shown in Table 1.

## Results

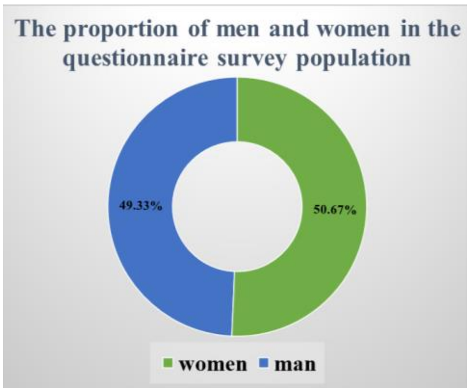
### *Brief Introduction to the Basic Situation of the Questionnaire Survey*

### *Basic Information of Volunteers*

We conducted a simple survey on the age, occupation, and residential city of the volunteers who participated in the questionnaire, and the survey results are shown in Fig. 2. Figure 2 shows the basic profile of the volunteers. The male-to-female ratio is almost 1:1. In the surveyed population, volunteers aged 20-30 accounted for 60%, followed by those aged 10-20, accounting for 17.33%. The overall age distribution was relatively wide, with a small proportion of over 40 years old, mainly in 10-40 years old. The cities where volunteers live are mainly third-tier and fourth-tier cities. There were about 50 volunteers in third-tier and fourth-tier cities, accounting for a relatively high proportion. Of course, there were about 25 residents in other first-tier and second-tier cities and urban areas. Volunteers in the survey worked in a variety of jobs, including government jobs, self-employed jobs, state-owned jobs, and other types of jobs.

### *Types of Masks Worn in Different Risk Areas*

For the initial part of the questionnaire, to understand the types of masks that people often use and prepare for follow-up work, the types of masks used in different risk areas were investigated. It should be noted that this study is divided into four risk sites. Open outdoor areas are the first risk area namely place 1; shopping malls, supermarkets, and vegetable markets are the second risk area, namely place 2; high-speed railway stations, trains, and highly speed railways are the third risk areas, namely place 3; and hospital outpatient department, inpatient department are the fourth risk areas, namely place 4.

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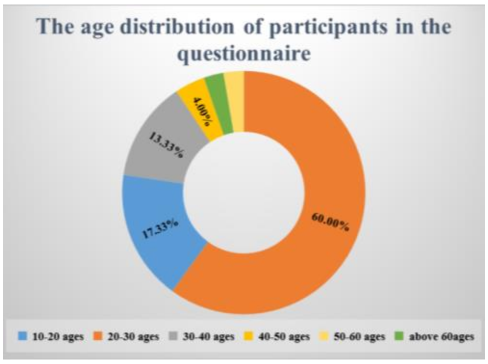


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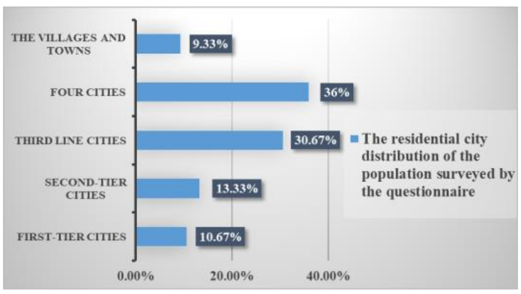


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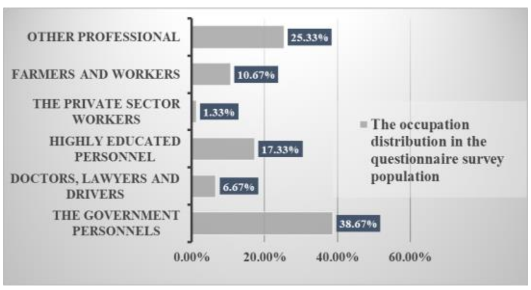


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**Fig. 2:** Basic information of volunteers

**Table 2:** Survey results on the types of masks worn on different occasions

| | Outdoors (place 1) % | Shopping malls (place 2) % | Highly speed railway (place 3) % | Hospital (place 4) % |
|---|---|---|---|---|
| Traditional masks | 0.00 | 0.00 | 1.33 | 0.00 |
| Surgical face masks | 98.67 | 96.00 | 89.33 | 93.33 |
| N95 masks | 1.33 | 2.67 | 9.33 | 5.33 |
| Full-length face shield | 0.00 | 0.00 | 0.00 | 1.33 |
| Respirator masks | 0.00 | 1.33 | 0.00 | 0.00 |

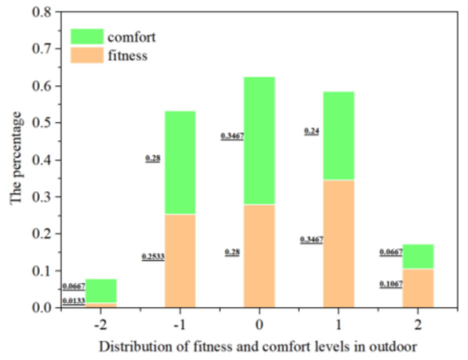
### *Comfort and Fitness of Wearing Masks in Different Risk Places*

#### *Comfortable and Fitness of Volunteers Wearing Masks in Pen Outdoor Areas*

According to Fig. 3(a), 34.67% of respondents believed that using surgical masks was comfortable. The slight comfortable and moderate comfortable were respectively 28 and 24%. The proportion of respondents who felt uncomfortable was the same as those very comfortable (6.67%). The matching results showed that 28% of people felt a match; 25.33% felt a slight match; 34.67% felt a suitable match; only 1.33% felt it was not a match and 10.67% felt it was a good match. As a result, in terms of comfort, most people focus on slightly comfortable, comfortable, and moderately comfortable. Similarly, slight fitness, fitness, and moderate fitness are also key answers to the matching question. The above results are for the comfort and compatibility of masks worn outdoors Table 3.

#### *Comfort and Fitness of Volunteers Wearing Masks in Shopping Malls, Supermarkets or Vegetable Markets*

This section is a comfort and fitness survey for shopping malls, supermarkets, or vegetable markets. Figure 3(b) shows the results related to comfort and fitness. The proportion of respondents who felt comfortable, moderately comfortable, very comfortable, slightly comfortable, and uncomfortable were 36, 25.33, 6.67, 26.67, and 5.33%, respectively. It can be seen that the proportion of volunteers with different levels of comfort distribution in shopping malls and other areas is similar to that in outdoor areas. The results of matching degree showed that felt matched, slightly matched, and suitable match was 36, 26.67 and 30.67% respectively; only 1.33% felt it was not fitness and 9.33% felt good match. Similarly, the proportion of respondents with different levels of match distribution in shopping malls and other areas was similar to that in outdoor areas.

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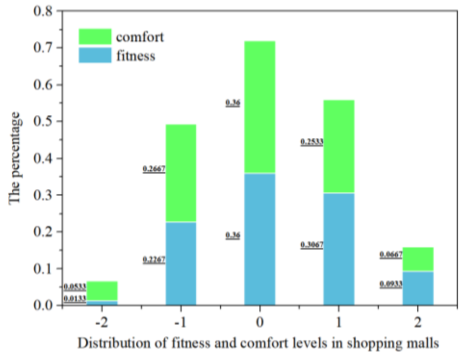


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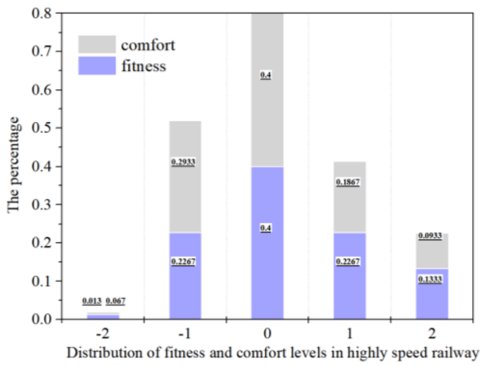


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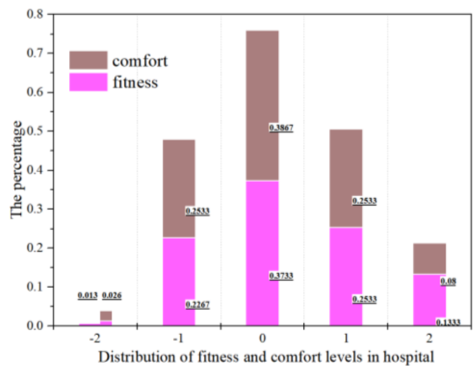


(d)

**Fig. 3:** The comfort and fitness of wearing masks for people; (a) Outdoors; (b) Shopping malls; (c) Highly speed railway; (d) Hospitals

**Table 3:** Comfort and Fitness Rating

| | Comfort | Fitness |
|---|---|---|
| -2 | Not comfortable | Not fitness |
| -1 | Slight comfortable | Slight fitness |
| 0 | Comfortable | Fitness |
| 1 | Moderate comfortable | Moderate fitness |
| 2 | Very/good comfortable | Very/good fitness |

### *Comfort and Fitness of Volunteers Wearing Masks in Highly Speed Railway Station, Train or Highly Speed Railway*

Figure 3(c), a total of 40% of respondents felt very comfortable when wearing a mask at a high-speed railway station, train, or high-speed rail. About 29.33% felt moderately comfortable, which was higher than slightly comfortable (18.67%). Only 9.33% felt uncomfortable and this is the highest proportion among all regions. 6.77% of respondents felt very comfortable when wearing surgical masks in risk areas such as railway stations. The results show that the proportion of respondents who felt comfortable was the highest, felt uncomfortable was the lowest, and felt very comfortable, slightly comfortable, and moderately comfortable was moderate. In terms of matching, 40% considered that wearing a mask was a match. 13.33% thought that they were not suitable to wear surgical masks at railway stations. This is the highest proportion among all regions. Considering the outdoors, shopping malls, and high-speed railways, the proportion of fitness levels tends to increase gradually, which is caused by individual differences, environmental differences, and individual uncertainty.

### *Comfort and Fitness of Volunteers Wearing Masks in Hospital Outpatient Department, Inpatient Department*

Figure 3(d) shows the comfort and fitness of wearing masks for outpatient and inpatient staff in hospitals. It can be seen from Fig. 3(d) that 38.67% felt comfortable and 25.33% felt moderately comfortable. The proportion of mild comfort to moderate comfort is the same, with comfort second only to moderate comfort. In addition, the proportion felt uncomfortable and very comfortable was 8 and 2.6%, respectively. Regarding the compatibility of the masks, 37.33% thought wearing surgical masks was fit. However, 25.33% found it was moderate fitness, which experienced a higher level of match. In addition, 22.67% thought wearing masks was slight fitness, which may have less impact on the wearing. We are also concerned that up to 13.33% felt uncomfortable when wearing masks, which is the worst level of comfort. Among all comfort levels, the proportion of respondents who felt very comfortable was the lowest (1.33%), which means wearing a mask can cause some discomfort.

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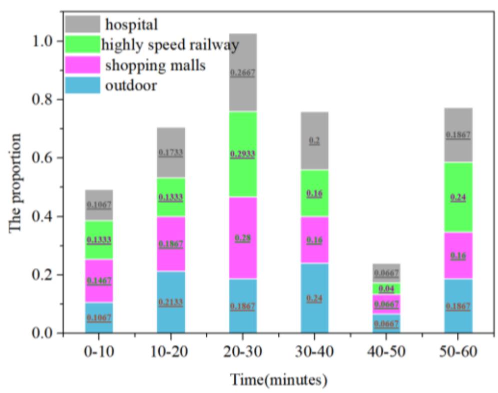
### *Breathing Conditions of Wearing Masks in Different Seasons*

#### *Breathing Difficulty Experienced by Wearing a Mask on Different Occasions in Summer*

To comprehensively explore the time of respiratory distress related to breathing, summer, and winter were selected as the two seasons with significant temperatures in northern China. Figure 4(a) shows that the time of breathing difficulty on different occasions in summer. It can be seen from Fig. 4(a) that 24% found it difficult to breathe when they spent 30-40 min in place 1 (outdoor). In other situations, however, breathing difficulty may occur between 20 and 30 min (28% for place 2, 29.33% for place 3, 26.67% for place 4). The reason for this phenomenon may be the varying degrees of sensation between people wearing masks, which may be caused by physical factors. In addition, these four risk areas account for at least 15% of the population with 50-60 min of difficulty breathing (18.67% for place 1, 16% for place 2, 24% for place 3, 18.67% for place 4). In these four risk areas, at least 10% of people experienced breathing difficulties immediately after wearing a mask, in which case the wearer's lungs may not function properly (10.67% in place 1, 14.67% in place 2, 13.33% in place 3 and 10.67% in place 4).



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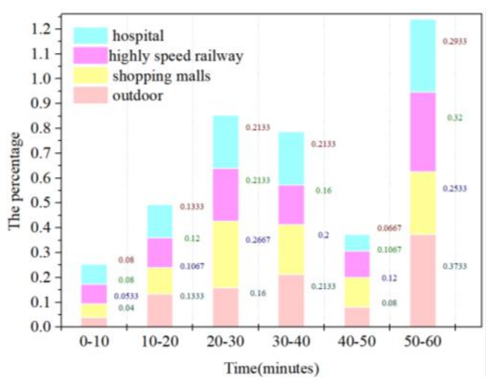

(b)

**Fig. 4:** Time of experiencing dyspnea on different occasions; (a) Summer; (b) Winter

#### *Breathing Difficulty Experienced by Wearing a Mask on Different Occasions in Winter*

In winter, most respondents believed that wearing a mask for 50-60 min was the limit to breathing difficulties. Figure 4(b), in the four risk areas, the highest number of respondents experienced breathing difficulties after 50-60 min (3 places) and 20-30 min (1 place). The proportion of respondents was 37.33, 25.33, 32 and 29.33% for place1, place 2, place 3, and place 4, respectively. It should be noted that in the risk area 2, the proportion experiencing breathing difficulties in 50-60 min was 25.33%, which was less than the in 20-30 min (26.77%). Since the difference was small, it could be considered that the proportion of people experiencing breathing difficulties in 50-60 min in winter was the same as that in 20-30 min. Unlike in the summer, the proportion of respondents experiencing breathing difficulties in 0-10 min decreased and the proportion of people experiencing breathing difficulties decreased to 8% in these four sites.

## Discussion

With the initial outbreak of the epidemic from late 2019 to early 2020, people have a clearer understanding of the function of masks and the transmission mechanism of the virus. Therefore, the selection of masks is becoming increasingly objective and rational. Different types of masks differ in filtration efficiency, universality, long wear, use occasions, rechargeable, reuse, respiratory resistance, price, fit test, and hearing damage. We have made a detailed summary of this distinction (Table 4). Medical masks show advantages over cloth masks in terms of price and filtration efficiency, but their filtration resistance is inferior to cloth masks. Overall, except for high-risk areas that are not suitable for wearing, medical masks are more suitable for wearing in different places and have universality. The high respiratory resistance of N95 masks and the high price of P100 and PARR restrict residents from wearing and purchasing them regularly:

(a) The types of masks worn in different places were mainly medical masks. From the perspective of risk level, the proportion of wearing N95 masks increased in high-risk areas, while the proportion of people wearing N95 masks was lower in low-risk areas than in high-risk areas. No matter where they are, surgical masks have become the best choice for people to travel. Since the types of masks worn in different places are concentrated in medical masks, it can be considered that the subsequent comfort performance of masks is based on the results of surgical face masks worn in different places in the previous investigation

**Table 4:** Basic comparison of different masks

| Mask type | Cloth masks | Surgical masks | N95 | P100 FFR | Parr |
|---|---|---|---|---|---|
| Filtration efficiency | Low | Moderate | High | Excellent | Excellent |
| Universality | No | Yes | Yes | No | No |
| Long wear | Moderate | Low | Low | Excellent | Excellent |
| Use occasions | Low-risk areas | General-risk areas | General-risk areas | High-risk areas | Higher-risk areas |
| Rechargeable | No | No | No | No | Yes |
| Reuse | Yes | No | No | Yes | Yes |
| Respiratory resistance | Moderate | Moderate | High | Low | Low |
| The price | Low | Low | Moderate | High | High |
| Fit test | No | No | Yes | Yes | No |
| Hearing damage | No | No | No | No | Yes |

(b) It should be noted that the subjects were mainly concentrated in various occupations in third and fourth-tier cities. In these four risk areas, the proportion of people who feel basic comfort and fit was the highest, except for outdoor areas. The proportion of fitness levels gradually increased outdoors, in shopping malls, and highly speed railways, which was caused by individual, environmental, and individual uncertainties. Among all the comfort levels, the proportion who felt very comfortable was the lowest, which means wearing a mask would have a certain degree of discomfort

(c) In summer, 24% of respondents had breathing difficulties in 30-40 min of outdoor activities and 20-30 min of breathing difficulties in other places. In winter, most respondents believed that wearing masks for 50-60 min was the limit of breathing difficulties and the proportion of breathing difficulties, occurring within 50-60 min is 25.33%. This phenomenon may be caused by differences in emotional levels among individuals wearing masks, which may be due to physical reasons

(d) The limitations of this study are that there was no detailed investigation into the sources and brands of masks, the types of respondents were not extensive and this study was limited to Beijing-Tianjin-Hebei of China

## Conclusion

In the context of infectious disease, there is a lack of research on thermal comfort, fit, and respiration of masks under actual wearing conditions. This article mainly adopts the method of questionnaire survey to study the correlation between different populations, places, seasonal characteristics, and masks associated with thermal comfort, adaptability, and breathing difficulties. The thermal comfort, adaptability, and breathing difficulties of masks are the key factors that affect the improvement of mask filtering efficiency. Due to these factors directly affecting the physiological characteristics and health of the human body, studying related physiological parameters such as thermal comfort and breathing difficulties is a future direction. Research can be conducted through a combination of experimental research, simulation research, questionnaire surveys, and various forms.

We advocate wearing medical masks. If the environment is safe, try to remove the mask as much as possible after wearing it for 30-40 min, or change the mask frequently in areas with high virus levels. Compared to summer, wearing clothes in winter prolongs breathing difficulties to 50-60 min. Generally speaking, wearing a mask can achieve general comfort rather than extreme comfort.

Questionnaire data on thermal comfort and adaptability reflect the physiological characteristics of masked populations in third and fourth-tier cities, providing reliable evidence for researchers. The advantage of this article lies in the use of a combination of questionnaire surveys and thermal comfort evaluations to conduct reliability studies at specific times. More importantly, this article will contribute to the use of masks in future major viral pandemics, provide guidance for the production of masks in the future, and have certain theoretical guidance for human health and public health.

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## Author’s Contributions

**Xin Zhang:** Designed and performed the experiments, analyzed the data, and prepared the paper. Participated to collect the materials related to the experiment. Designed the experiments and revised the manuscript.

## Ethics

The authors declare their responsibility for any ethical issues that may arise after the publication of this manuscript.

### *Conflict of Interest*

The authors declare that they have no competing interests. The corresponding author affirms that all of the authors have read and approved the manuscript.

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## Appendix

### *The None-Respirator Masks of Ordinary Cloth Masks/Traditional Masks and Surgical Face Masks*

Before the emerged of Novel Coronavirus, cloth masks were used to prevent harmful gases and particles from air pollution. Residents who cannot buy masks choose to make cloth masks at home and then cloth masks have become an option for people facing a shortage of masks. However, health professionals and the public have reasonable concerns about the reliability of cloth masks in providing protection for wearers and community members. Wearing a mask is more effective in blocking the spread of viruses than not wearing a mask. Cloth masks can be used in emergency situations, but due to their thick fiber diameter and large pore size, it is difficult to effectively filter fine particles. Usually, promoting the efficiency of filters depends on increasing the cover layer, reducing fiber diameter, density and that will increasing breathing resistance and uncomfortable wet, hot performance, ultimately making it difficult to wear for a long time (Beesoon *et al*., 2020; Zhao *et al*., 2020).

Surgical masks were not initially crafted to safeguard health care workers from suspended particles, but to reduce the spread of bacterial from human (Lawrence *et al*., 2006). The structure of surgical masks may be described using SMS, which consists of spun bond, melt blown and spun bond, where melt blown is a filter layer, the spun bond is an outermost and an innermost waterproof layer (Lawrence *et al*., 2006; Yao *et al*., 2019). Over the past 10-20 years, surgical masks have also been advocated to protect the wearer's mucous membranes from blood splashes, which may contain infectious particles (Whiley *et al*., 2020). Booth *et al*. assessed the effectiveness of commonly used surgical masks by measuring levels of inert particles and live aerosolised influenza virus in the air (Booth *et al*., 2013).

### *The Respirator Masks of Respirator Masks*

Respirator masks are the Filtering Face piece Respirators (FFRs) that can effectively trap tiny particles and prevent air leakage around the mask edges when inhaling, which are different from surgical masks. This type of air purifying respirator protects the user by filtering particles from the air and is a personal protective device. Generally, in areas with a high risk of respiratory infections or doctors and confirmed patients, it is more appropriate to wear a respirator. FFRS is one of the most commonly used respirators in healthcare settings because of its convenience, ease of use and low cost. Respirators are N95, KN95, N99, KN99, P100, FFP1, FFP2 and more. The National Institute for Occupational Safety and Health (CDCP, 1996) certified the FFR based on a 3-letter name (N (intolerance), R (some tolerance), P (strong tolerance) and a 3-digit name (95, 99 and 100), indicating the percentage of filtration efficiency of a respirator filter. This section focuses on N95/KN95, P100 and powered air-purifying respirators, which are the typical example of respirators.

N95 mask is a respirator with a filtration efficiency of at least 95% as defined by the US Standard System (CDCP, 1996). The filtration efficiency of KN95 masks is the same as that of N95 masks and the minimum particle filtration size defined by Chinese Standard System is 0.3 μm. Compared with surgical and cloth masks, N95 masks offer the benefit of secure facial sealing, minimal face leakage and decreased infiltration of aerosol particles through the filter.

Although N95 respirator has the advantages over disposable masks and cloth mask, there are still some shortcomings to a certain extent. For example, on the one hand, long-term wearing of masks will generate a large amount of water vapor and accumulated water, resulting in significant deformation and failure of filtration efficiency. On the other hand, it is necessary to conduct facial and sexual tests on N95 masks of different populations. N95 masks have poor respiratory and tolerability. It is worth noting that during a pandemic, a shortage of N95 masks may lead to the use of unauthorized masks, thereby increasing the risk of infection (Ippolito *et al*., 2020; Ranney *et al*., 2020).

P100 FFR is used to prevent toxic air particles from petroleum that may be encountered in industrial environments (CDCP, 1996). Facial tightness tests also need to be conducted regularly and based on different facial features. However, in similar conditions, P100 FFR exhibits greater respiratory resistance compared to the N95 mask.

Powered Air-Purifying Respirators (PAPR) is a battery-powered actuate device that allows pressurized air to enter into full or half face masks through filters (P100 or HEPA) and can be used instead of N95 masks. PARR filtration efficiency exceeds 99% and its protective performance is better than that of N95 masks. PARR has many advantages. It not only offers reusability and easy cleaning but also ensures prolonged thermal comfort and a refreshing wearing experience. Not requiring physical fitness testing is more convenient. Therefore, PARR is applicable in environments with elevated levels of infectious aerosols, particularly when the level of risk is unclear or uncertain. PARR also has many disadvantages. PARR comes with a high price tag and involves multiple components, requiring considerable time for assembly and frequent filter checks. The battery requires frequent charging and the airflow noise may cause discomfort for users (Wizner *et al*., 2016).