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REVIEW

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Effectiveness and safety of medical masks in the prevention of respiratory infections: a review

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Abstract

Wearing face masks, the critical measure of non-pharmacological intervention (NPI), should not be underestimated in preventing the spread of coronavirus disease 2019 (COVID-19). The challenge for public health persists with various respiratory pathogens in post-COVID-19. Theoretically, promoting wearing masks will continue to be beneficial for public health. This review summarizes the views of studies on the efficacy and safety of mask-wearing in adults and children to prevent respiratory infections. It aims to provide further information that could benefit government decisions on respiratory infection epidemic control. Adherence is the key factor for the effectiveness of mask-wearing for preventing respiratory infections in adults and children, and it must be given high priority when conducting research to validate the effectiveness of masks or making relevant public decisions. The safety effects of mask-wearing include physiological and psychological. The physiological effects could be moderate during short-term mask-wearing, while the safety problems in long-term mask-wearing are required to be further explored. There is no clear evidence of the adverse physiological effects of mask use in children. However, the disadvantage of mask use in children under 2 years of age warrants vigilance. The psychological repercussions of mask-wearing in adults primarily manifest as emotional discomfort, varying across different cultural contexts. The influence of mask-wearing on children's psychological and social development requires more research, and it should be paid high attention in government decision-making processes.

Keywords Non-pharmaceutical interventions, Masks, Adults, Children, COVID-19, Respiratory infections, Safety, Effectiveness

Introduction

The coronavirus disease-2019 (COVID-19) pandemic that started in early 2020 has remained one of the most severe health emergencies in the world, with approximately 773 million infections and 7 million deaths so far [1]. To cut off the transmission of COVID-19, mainly respiratory droplets and contact transmission [2], countries have adopted non-pharmaceutical interventions (NPIs). NPIs refer to actions that individuals and communities take to help control the spread of respiratory diseases, including strategies such as isolation, physical distancing, quarantine, hygiene practices, and wearing masks [3]. The wearing of masks, also known as medical masks, has been considered an integral part of controlling the spread of COVID-19 and proved to be capable of preventing the transmission of infectious droplets with high feasibility, low cost, and minor disruption to social activity [4–6].

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There are three types of masks that WHO recommends for the public in the COVID-19 pandemic: a. disposable medical masks; b. non-medical masks that comply with standards for safety and efficacy and can be washed prior to reuse; c. if the above options are not available, other types of well-fitting non-medical masks are an acceptable option (according to local policies) [7]. A brief summary of the materials and design, advantages, disadvantages, and applicable scenes of common types of masks is shown in Fig. 1 and Table 1 [8, 9].

In the early stages of the COVID-19 epidemic, areas in which wearing masks was forced implemented in the early days experienced lower incidences than those without forcible policies, for example, forcing mask-wearing protected the German city of Jena from new cases of COVID-19 for 9 consecutive days and achieved a 23% drop in incidences compared to other cities without this policy [10]. Further, even in the period when COVID-19 vaccines were spreading, the relaxation of these policies in America still led to a rebound in the epidemic, with the number of cases and deaths repeatedly reaching new heights [11]. Therefore, the positive effects of mask-wearing are not underestimated in COVID-19.

In the post-COVID period, many respiratory diseases, such as Respiratory syncytial virus (RSV) infections, influenza, and *M. pneumoniae* pneumonia (MPP), resurfaced due to the “immunity debt” [12]. Surges in RSV infections were reported in New Zealand at the end of 2021, in which surveillance numbers were more than 5 times the 2015–2019 peak average [13], and also, MPP

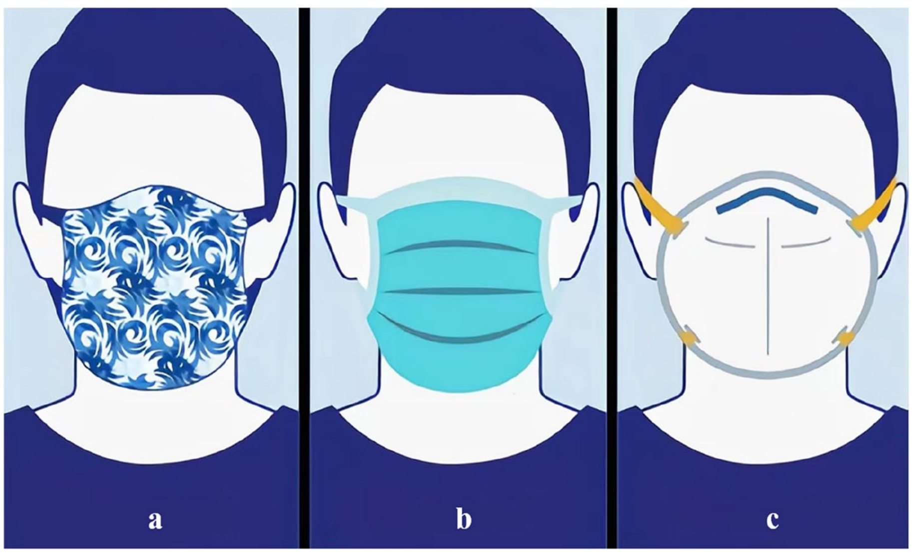

Fig. 1 The common types of masks. **a** Fabric masks; **b** medical masks; **c** N95/KN95

Table 1 The materials and standards, advantages, disadvantages, and applicable scenes of common types of masks

	Materials and standards	Advantages	Disadvantages	Applicable scene
Fabric masks	• Fabrics (cotton, silk, nylon, etc.) • No standardization in design	• Readily available • Washable and reusable	• Less protective • Not tightly sealed	• Daily lives • Unsuitable for healthcare
Medical masks	• The three-ply (three-layer) design, with two layers of nonwoven fabric and a melt-blown fabric layer in the middle. • Standards such as China’s YY 0469–2011, Europe’s EN 14683, and US’s ASTM F2100	• Inexpensive • Microbial filtration • Blood resistance	• Not tightly sealed • Disposable	• General medical environments • Unsuitable for high-risk environments
N95/KN95	• Nonwoven fabric, hot air cotton, and melt-blown fabric. (5-layer structures) • Standards such as: NOISH[a] 42 CFR Part 84, GB19083-2010	• Tightly sealed (internal leakage lower than 8%) • High filtration efficiency (≥ 95% protection against particles larger than 0.3 μm)	• Expensive • Discomfortable • Not readily available	• Used in high-risk environments

[a] The National Institute for Occupational Safety and Health (NIOSH)

and influenza cases in China were reported to reach a high level in 2023, with the incidence of MPP 5.59% in adults and 40.34% in children, and influenza 29.67% in adults and 4.94% in children, which brought heavy pressure on the healthcare system [14, 15]. It seems that mask-wearing would also be beneficial in this period to public health. However, the pros and cons of mask-wearing still merit further evaluation in the post-pandemic era. This article summarizes and discusses the views on the efficacy and safety of masks for adults and children and aims to provide further information that could be beneficial for government decisions.

Main text

Search strategy and selection criteria

Searches were done in PubMed in English using the phrase "masks" or "wearing masks" or "mask-wearing" in combination with "COVID-19" or "influenza" or "respiratory infections" or "virus" or "prevention" or "effectiveness" or "safety" or "adults" or "children". Relevant literature preferential high-impact factor original research, reviews, commentary, and editor letter also included.

Mask-wearing in adults

Effectiveness

Masks are theoretically proposed to have protective effects for infectious droplets/aerosols through mechanisms including gravity sedimentation, straining, interception, diffusion, inertial impaction, and electrostatic attraction [8]. World Health Organization (WHO) also suggest people in the community to wear masks to reduces the spread of respiratory illnesses by reducing the number of infectious particles that may be inhaled or exhaled [7]. A study of 111 symptomatic individuals showed that the detection of influenza virus RNA ($p = 0.01$) and coronavirus RNA ($p = 0.02$) significantly reduced in exhaled aerosols through the masks [16].

Further, there are numerous studies evaluating the practical effectiveness of wearing masks in adults. A trial ($N=245$) in China reported that mask-wearing provided no statistical benefits in incidences of influenza-like illness (ILI), larger trials are needed to confirm the efficacy of medical masks as source control [17]. Another trial undertaken in Denmark ($N=3030$) reported a slight reduction in incidences of SARS-COV-2 (from 2.1 to 1.8%) with no statistical significance ($p=0.38$), but the results might influenced by inconclusive results, missing data, variable adherence [18], while a trial undertaken in Bangladesh reported an estimated 11.6% reduction ($p<0.01$) in COVID-19-like symptoms between intervention villages ($N=797{,}715$ observations) with 42.3% population of high-adherent mask-wearing and villages ($N=806{,}547$ observations) with 13.3% of that [19]. In general, mask-wearing demonstrates a positive effect on mitigating the transmission of respiratory diseases, contingent on high adherence to mask-wearing.

Safety: physiological effects

WHO mentions that masks should not be worn during vigorous physical activity because of the risk of reducing your breathing capacity [7]. Mask-wearing is proposed to have 2 major effects on human respiration: (1) lower exchanges in O_2 and CO_2 during each breath; (2) Expansion of the dead space volume.

Elbl et al. used a spontaneous breathing lung simulator (set to match the predicted values for a 175-cm male subject) to measure indices of gas exchange when breathing through different types of masks during quiet breathing and during moderate exercise, and the outcome shows that all masks significantly increased airway dead space between 89 and 204 mL ($p<0.05$) which resulted in significant increase in $P_{et}CO_2$ (+17.4 mmHg on average, $p<0.05$), even more pronounced in the moderate exercise setting (+25.9 mmHg on average, $p<0.05$), but the effect on inspiratory oxygen concentration and resistance to breathing was only marginal [20]. Long-term and repeated mask-wearing might lead to various chronic diseases, such as headaches, respiratory tract irritation and asthma, increases in blood pressure and heart rate, and vascular damage [21, 22].

However, some studies argue that these slight physiological changes have no significance and will not cause irreversible physiological damage. A small crossover study showed none of the participants' (mean age 76.5 years, $N=25$) S_pO_2 fell below 92% while wearing masks, and the results do not support claims that wearing nonmedical face masks in community settings is unsafe [23]. A study investigated mask-induced physiological effects among eight healthy participants in both normoxia and hypobaric hypoxia and reported a significant effect on P_aCO_2 (overall $+1.2 \pm 1.7$ mmHg), as well as a higher rate of dyspnea and discomfort but it claimed that mask-wearing showed no clinically relevant impact on gas exchanges, even in hypobaric hypoxia and during moderate exercise, and showed no detectable effect on resting cognitive performance [24]. However, this study ignored the potential safety issues caused by continuous and long-term mask-wearing; therefore, it is unable to well-roundly evaluate the safety of mask-wearing.

Safety: psychological effect

Wearing masks is uncommon in our daily lives, and most of the population, except for those with specific occupational demands, will not wear masks on their own initiative. In most cases, public mask-wearing is forced by governments and authorities in specific periods, for example, during the COVID-19 pandemic. Therefore, wearing a mask means being deprived of freedom and self-determination, which may lead to public complaints and anger [25]. In addition to the public antagonistic psychology, mask-wearing could lead to discomfort and communication difficulties [26]. A study showed that wearing mask significantly drops the performance in reading emotions in faces, such as angry, disgusted, happy, and sad ($p < 0.0001$) [27]. Moreover, repeatedly putting on and taking off masks may also lead to tiresomeness and distress. Additionally, the psychological effects of mask-wearing vary across cultural contexts, for example, mask-wearing may be associated with political stances in the USA; however, one Japanese anthropologist has mentioned that Japanese wearing masks is a way of restoring a sense of control in the face of uncertainties and establishing a boundary between a clean and pure inner self and a potentially polluted outside [26].

In sum, mask-wearing could cause physiological changes, such as increased levels of PetCO2 and airway dead space, thus, masks should not be worn during vigorous physical activity because of the risk of reducing breathing capacity [7]. These physiological effects could be moderate during short-term mask-wearing, while the safety problems in long-term mask-wearing are required to attach more importance. Also, mask-wearing, regardless of the wearing time length, is reported to cause public complaints and a series of emotional problems, such as discomfort, inconvenience, tiresome, and distress. Thus, governors should consider these effects and cultural contexts when making mask-related policies during epidemics.

Mask-wearing in children

The safety and effectiveness of wearing masks must be re-evaluated; masks could not be appropriately used among children (especially children under the age of 6), and mask-wearing may lead to more serious psychological problems compared to adults.

Here, we highlighted several guidelines from WHO and UNICEF for children's mask-wearing as follows:

- The children's ability to appropriately use masks;
- Adults' ability to properly supervise and instruct children on how to safely put on, take off, and wear masks;
- The feasibility of mask-wearing among children under the age of 2, for masks could lead to asphyxia due to their smaller airways [28].

These guidelines exhibit a more cautious regulation of children's mask-wearing. In fact, there are also different views regarding the effectiveness, safety, and feasibility of wearing masks for children.

Effectiveness

Theoretical studies have proved the effectiveness of Children's mask-wearing in the prevention of respiratory infections. However, practical applications exhibit variation in different situations and between different age periods, in which children's ability to properly mask-wearing (adherence) could be one of the most significant factors. Many studies have gone into this field:

In 2011, a trial in Thailand investigated the effectiveness of NPIs in reducing influenza transmission among children, in which 495 children confirmed with influenza were randomly divided into groups of control ($N = 155$), hand washing (HW, $N = 155$), and hand washing plus paper surgical face masks (HW + FM, $N = 155$) and were monitored for their causing of secondary influenza in their family. The results showed no significance (control vs. HW, OR = 1.2; 95% CI [0.76–1.88], $p = 0.442$; control vs. HW + FM, OR = 1.16, 95% CI [0.74–1.82], $p = 0.525$) of applying NPIs in children, indicative of factors such as transmission that occurred before the intervention and poor facemask compliance [29]. Another trial undertaken in Matsumoto City, Japan, in 2016 provided results supporting the protection effects of mask-wearing in elementary schoolchildren (OR = 0.859, 95% CI [0.778–0.949]); however, they also reported adherent effects, with 12.0% the effectiveness among higher grade (grades 4–6) children, and 5.3% among lower grade (grades 1–3) children [30]. In addition, data from North Carolina schoolchildren ($N > 15{,}000$) reported a protective effect of mask-wearing in the secondary transition of COVID-19 under high adherence (more than 80% of proper mask-wearing) [31]. In conclusion, the effectiveness of mask-wearing in children is strongly related to adherence to mask-wearing, and factors, such as time intervals and situations of wearing masks, deserve further investigation.

Safety: physiological effects

The physiology of children in respiration is significantly different from that of adults, in which children show increased demands of O_2, decreased respiratory reserve, smaller airways, higher resistance when the airway becomes narrow, and more sensitivity to hypoxia in the central nervous system. Therefore, more concerns and investigations are required regarding the safety issues of children's mask-wearing. Here, results from trials provide us with useful information in the safety evaluation.

An investigation from Singapore in 2019 provided specific data on N95 mask-wearing in children: End-Tidal CO2 (ETCO2) and Fractional concentration of Inspired CO2 (FICO2) in the mask space reached 30.9 mmHg and

34.3 mmHg at rest, and 28.2 mmHg and 32.9 mmHg on mild exertion, respectively; however, these records are still below safety standards [32], while another investigation in 2022 argued that an 18-min-mask-wearing could lead to a significant raise ($p = 1 \times 10 - 9$), from 0.2 to 1.30 Vol%, with 0.2 Vol% excess from safety standard [33]. However, the results from the latter investigation are relatively controversial due to its non-rigorous CO_2 data acquisition [34]. Moreover, an experiment undertaken in London in 2020 recorded self-reported hotness ($p < 0.0001$) and negative subjective perception of breathing ($p < 0.03$) in 24 children on exertion, indicative of discomfort in mask-wearing, regardless of physiological safety [35].

In addition, a study in 2021 provided physiological data on children's surgical mask-wearing ($N = 47$, aged from 10 months to 12 years). The results showed no influence on physiology properties when children wear masks at rest while showing apparent raises in pulse rate (PR, $p < 0.05$) and respiratory rate (RR, $p = 0.02$) when children wear masks accompanied by 12-min walking [36].

In conclusion, the physiological safety of mask-wearing in children is quite controversial, with studies providing physiological data and results with large variations. There is insufficient evidence to support the significant physiological effects of mask-wearing in children. Further research is needed to determine the impact of masks on children's health. Additionally, the decision to require masks for children under 2 years of age, who have limited autonomy and mobility, should be made with caution and careful consideration of the disadvantages involved.

Safety: psychological effects

Long-term mask-wearing could lead to discomfort and other psychological problems, regardless of age. However, this requires more careful concern and investigations in children, for its possible impacts on their psychological development, such as perception of facial emotion and verbal ability.

Studies in this field largely depend on self-reported data. A trial in Germany in 2021 reported 53% headaches, 50% distraction, 49% unhappiness, 25% anxiousness, etc., among 25,930 participating children [37]. Mickells et.al. reported several psychological problems among students, including events described as related to stress, anxiety, and "meltdown" over wearing the mask or being asked to continually fix/wear the masks, which was mentioned 13 times, 8 times that students were frustrated by difficulty hearing and communicating with both the teachers and their classmates, 6 times that students complained about difficulty breathing, 7 times that the students were hot from the masks, etc., which total of 59 [38].

Several trials have focused on the psychological development of children. A study demonstrated that face masks could significantly influence children's ability to infer emotions by observing facial configurations($p < 0.001$) [39], whereas another study reported no significant impact from mask-wearing on vocabulary learning among 24 babies ($p = 0.46$) [40].

Together, the effectiveness of mask-wearing in children strongly depends on children's ability to proper mask-wearing (adherence), and the effectiveness may be promoted if proper education and surveillance are implemented. The safety of mask-wearing in children should be carefully measured, given that mask-wearing might lead to asphyxia in babies and other physiological problems in children. Moreover, the impact of mask-wearing on children's psychology should also be evaluated before making mask-related policies, for example, children's perception of facial emotions.

Conclusions

Various respiratory pathogens have coexisted with humans for a long time and threaten public health. The government could formulate flexible mask-wearing policies to respond to the epidemic of some respiratory pathogens to benefit public health.

No matter whether children or adults, properly wearing masks (adherence) is still heavily highlighted, and proper education and surveillance could promote the effectiveness of mask-wearing. The strategies of trials relevant to mask-wearing require careful designs to ensure a high adherence. At the same time, the government should pay high attention to it when making public health decisions relevant to mask-wearing.

Mask-wearing might cause physiological changes in people of all ages, which could be moderate during short-term mask-wearing, but more concern and studies are required about long-term mask-wearing. Mask-wearing may cause public complaints and a series of emotional problems, such as discomfort, inconvenience, tiresome, and distress, and varying across different cultural contexts, these may influence the adherence to wearing masks [26, 27].

Infants and children under 2 years of age have poor autonomy, a limited range of activities, and requirements for psychological and social development; strategies for this population should be considered and evaluated separately. The disadvantage of mask-wearing on children's psychological development requires careful consideration and more investigation.

Abbreviations

COVID-19	The coronavirus disease-2019
NPIs	Non-pharmaceutical interventions
RSV	Respiratory syncytial virus

MPP	*M. pneumoniae* Pneumonia
SARS-COV-2	Severe acute respiratory syndrome coronavirus 2
PetCO2	End-expiratory carbon dioxide
S_pO_2	Transcutaneous arterial oxygen saturation
P_aCO_2	Partial pressure of arterial blood carbon dioxide
WHO	World Health Organization
UNICEF	United Nations International Children's Emergency Fund
ETCO2	End-Tidal CO2
FICO2	Fractional concentration of Inspired CO2
PR	Pulse rate
RR	Respiratory rate

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