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ORIGINAL RESEARCH

The proper use of masks in the COVID-19 pandemic era: an experimental pilot study

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Abstract

Community mask wearing and personal hand hygiene behaviors are emphasized as among the primary ways to impede the transmission of the coronavirus disease 2019 (COVID-19). However, there is a lack of studies on the efficacy of masks in ensuring safety. This pilot study was designed to investigate the proper use of masks by estimating the changes in temperature and humidity inside masks and examining the bacterial culture of used masks. Two points were set 100 m apart. Two masked participants were made to stand side by side then walk from the first to the second point. When the subjects arrived at the designated destination, we measured the temperature and humidity of each mask and recorded the subjective degree of discomfort on a scale of 10 points. This experiment use the same mask (cotton mask, KF94, anti-droplet mask, dental mask) was repeated ten times. Our results showed that irrespective of the mask used, the inside temperature of a mask was at an average of 2 to 3 degrees higher than the atmospheric temperature, and the humidity inside the mask was twice that on the outside. In all four types of masks investigated, bacterial culture experiments detected similar bacteria found mainly on the skin and mouth for that of the participant. For the walking test, the subjective discomfort was the highest 7.8 $\pm$ 1.2 with the anti-droplet mask (p = 0.005). Power walking test, the subjective discomfort was the highest 9.4 $\pm$ 0.5 with the KF94 (p = 0.063). Proper mask ventilation is advised, especially in case of subjective discomfort, but only when there is no other person within social distance or while outdoors. For hygienic reasons, discarding a used mask is recommended.

Keywords

COVID-19; KF94; Mask; Ventilation

1. Introduction

Severe acute respiratory syndrome coronavirus 2 was first confirmed in Wuhan, China, in December of 2019, then spread to Asia, Europe, America, and the rest of the world. This disease was named by the World Health Organization (WHO) the coronavirus disease 2019 (COVID-19) [1–3]. In Korea, the number of confirmed cases has been gradually increasing across the whole country. The nation's response to this highly transmissible infectious disease was then upgraded to a "serious" level, the highest grade [4]. Behaviors such as community mask wearing and personal hand hygiene have since been emphasized as the primary measures to prevent the spread of COVID-19 [5]. Cloth and medical masks have been reported to effectively control the spread of COVID-19 [6]. In addition, the government also recommends using masks to reduce the risk of respiratory infections. They are considered effective in preventing exposure to pathogens and particulates in the air and aerosols [7–9]. However, there is a lack of studies on factors that may influence safe mask use, including changes in temperature and humidity inside masks and bacterial accumulation on used masks, especially during the summer. This study was designed to investigate the proper use of masks by estimating the changes in temperature and humidity in masks and assessing the bacterial culture of used masks.

2. Methods

2.1 Settings

Two measuring points, A and B, were set 100 m apart for a total of 1 km, and participants were requested to walk from point A to point B (Fig. 1). Two staff members were placed at each point to measure the humidity and temperature inside the participants' masks. Between the two points, the research manager directed each subsequent step. Beverages and shade screens were prepared for the participants to prevent heat-related illness. Two GoPro cameras (HERO10 Black, San Mateo, CA, USA) were set at each measuring point to document the process. The temperature and humidity measurements were recorded using the GoPro cameras to measure in detail. Four types of masks were worn to investigate differences

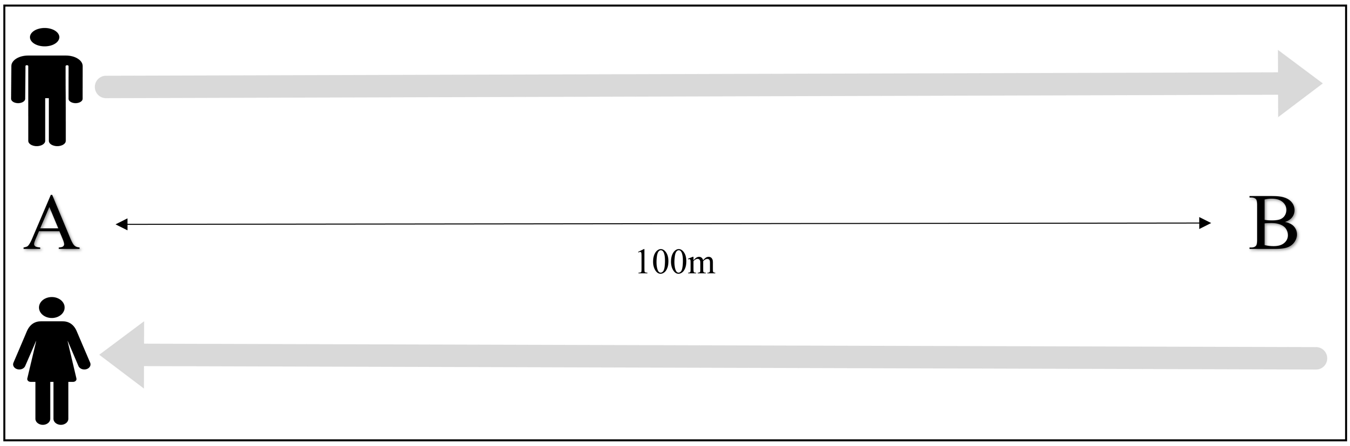

FIGURE 1. A and B point.

between masks in terms of the indicators of interest of this study (Fig. 2). Mask was delivered to the diagnostic test department to request a bacterial culture experiment test.

2.2 Participants

Two men and two women between the ages of 20 and 30 with no past history and no difficulties walking or running were enrolled in this study.

2.3 Sequence

2.3.1 The subjects

The subjects were kept in a climate-controlled vehicle with the air conditioner set to 24 °C. They moved to the starting point together when directed by the research manager at the start of the study. Within 1 min, the subjects put on a mask, and the temperature and humidity of the ambient air, participants' foreheads and inside each mask were recorded. The temperature and humidity inside the mask were measured by placing a thermo-hygrometer from the side of the mask to the inside, and the temperature and humidity of the forehead were measured by placing the thermo-hygrometer (HT-3007SD, LUTRON, Taiwan) on the surface of their forehead (Fig. 3).

2.3.2 Walking test

The two subjects stood side by side and walked from point A to point B. Their walking time from the 2 points was measured using a stopwatch. Then, when the subjects arrived at the destination, the temperature and humidity at the forehead and inside of each mask were measured and requested to describe the degree of discomfort based on the Likert Scale (0–10) [10]. The experiment was repeated ten times. The final values for each mask were compared by calculating the mean and standard deviation (Fig. 4).

2.3.3 Power-walking test

After acquiring the baseline data, the power walking test was conducted in the same way as the walking test, but the participants were instructed to walk faster, and their times were measured using a stopwatch. Power walking was defined as walking at a speed of about 6 to 8 mph [11]. When the subjects arrived at the destination, the temperature and humidity of their forehead and in each mask were measured, and the participants were requested to describe the degree of discomfort using the Likert Scale (0–10). The experiment was repeated 10 times to investigate whether there was a greater rise in temperature and humidity in the mask or the participants' discomfort level due to more intense activity.

2.4 Statistical analysis

All data are presented as median (interquartile range) and mean ± standard deviation as appropriate. Variables with normal distribution were compared using one-way analysis of variance (ANOVA). We performed the Tukey's test as a *post hoc* test. Variables without normal distribution were compared using the Kruskal-Wallis test. Bonferroni's method was used as a *post hoc* test. All statistical analyses were performed using the R software (version 4.0.0 for Windows; R Foundation for Statistical Computing, Vienna, Austria) and SPSS (version 20.0; IBM Corp., Armonk, NY, USA). $p < 0.05$

FIGURE 2. Configuration of mask type. (A) cotton mask; (B) KF94; (C) anti-droplet mask; (D) dental mask.

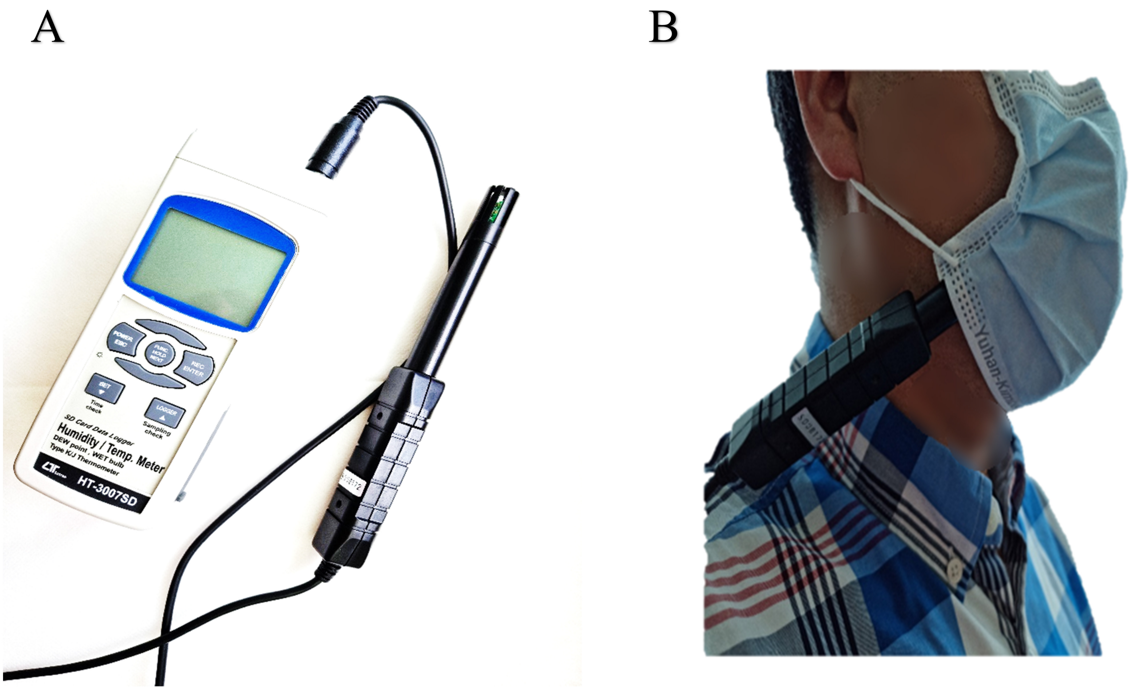

FIGURE 3. The temperature and humidity of the inside the mask. (A) Thermo-hygrometer; (B) Measurement appearance inside of the mask.

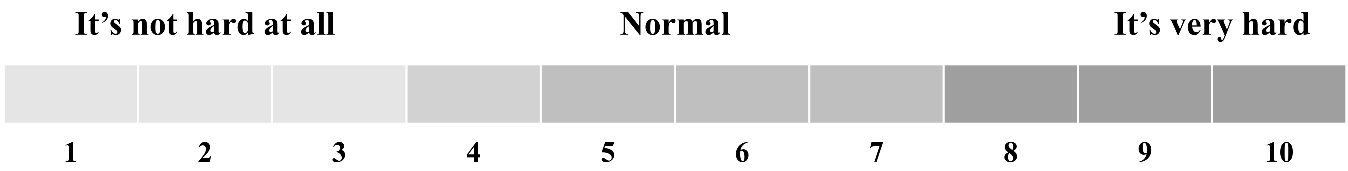

FIGURE 4. Likert Scale (1–10).

was considered significant in all analyses.

3. Results

3.1 Comparison of the masks' temperature and humidity

During the walking test, the ambient temperature outside was 30 °C, and the temperature measured inside the four masks were as follows: cotton mask 32.5 °C, KF94 mask 32.5 °C, anti-droplet mask 33.2 °C, and dental mask 32.6 °C. The humidity in the atmosphere was 47%, and the humidity inside the four masks were as follows: cotton mask 86.8%, KF94 mask 86.8%, anti-droplet mask 89.2%, and dental mask 85.7%. In the power walking test, the air temperature was 30 °C, and the temperature inside the masks were as follows: cotton mask 32.9 °C, KF94 mask 33.3 °C, anti-droplet mask 33.2 °C, and dental mask 32.6 °C. The humidity in the atmosphere was 47% during the power-walking test, and the humidity in the masks were as follows: cotton mask 85.8%, KF94 mask 88.1%, anti-droplet mask 89.2%, and dental mask 85.7% ($p < 0.001$).

3.2 Discomfort due to mask-wearing

The subjects subjectively rated their discomfort level using the Likert Scale for each type of mask. The Likert Scale was scored from 1 to 10 points, whereby 1 point indicated no discomfort and 10 points indicated most uncomfortable. For the walking test, the subjective discomfort was 7.3 ± 0.9 with the cotton mask, 6.9 ± 1.2 with the KF94 mask, 7.8 ± 1.2 with the anti-droplet mask, and 5.6 ± 1.8 with the dental mask ($p = 0.005$). In the power walking test, the subjective discomfort was 9.0 ± 0.5 with the cotton mask, 9.4 ± 0.5 with the KF94, 8.8 ± 1.6 with the anti-droplet mask, and 8.0 ± 1.5 with the dental mask ($p = 0.063$).

3.3 Bacterial colony counts by masks

We used the "M9 minimal" as the bacterial media. The bacterial culture was incubated at 37 °C for 18 h in a shaking incubator. Bacterial culture from the KF94 mask showed the largest number of bacteria, with more than 100 bacterial colonies per 1 cm^2. In all four types of masks, bacterial culture experiments detected Staphylococcus epidermidis, Streptococcus sanguinis, Bacillus subtilis, and Staphylococcus aureus (MRSA), which are found mainly in the skin and mouth (Fig. 5).

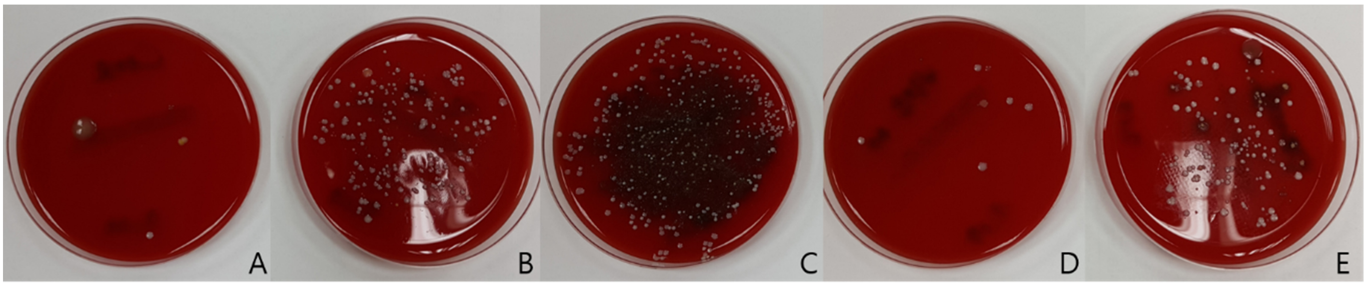

FIGURE 5. Bacterial culture on mask. (A) control; (B) cotton mask; (C) KF94; (D) anti-droplet mask; (E) dental mask.

4. Discussion

The WHO declared COVID-19 a global pandemic in March 2020 [12] and reported that the initial symptoms typically appear five to six days after COVID-19 infection. However, there have also been reported cases where the initial symptoms appeared two weeks to a maximum of 40 days after the infection, depending on the incubation period, patient's age, or degree of the patient's immune response [13, 14]. Symptoms of infection by the virus can range from mild to severe, often including flu-like symptoms, such as fever and cough. Some patients even develop severe acute respiratory syndrome and multi-organ failure, which may be fatal [15–17]. Various countries are testing and developing drugs or vaccines against COVID-19, including HIV drugs, antiviral drugs, and plasma derivatives, but no treatment has been officially approved [18]. Under these circumstances, the importance of using masks has been emphasized as an effective preventative measure to minimize the spread of respiratory infections, especially COVID-19 [15]. However, while the use of masks is recommended, there is a lack of recommendations on their proper ventilation and safe duration of use [7–9]. In addition, research on the discomfort and risk of using a mask in the summer, such as maximum temperature, humidity, and bacterial culture inside the mask, remains insufficient.

This study assessed the temperature, humidity, and potential degree of contamination inside the mask used by individuals to suggest potential improvements for safer use. The experiments were conducted on four types of masks: cotton, KF94, anti-droplet, and dental masks, which are currently the most common types of masks used. The humidity and temperature inside the masks were measured every 100 m for a total of 1 km during regular walking and power walking tests. Regardless of the mask type, we observed that the average temperature inside the mask was warmer by 2 to 3 degrees than the ambient outside temperature. In addition, the humidity inside the mask was two times higher than the humidity in the atmosphere. These results indicate that one might be at a higher risk of suffering from heat-related illness when wearing a mask for an extended time during the summer.

Bacterial infections caused by Staphylococcus and Streptococcus can be fatal in immunocompromised individuals or the elderly. Some studies have shown that elderly patients are low immunity, resulting in slower recovery from disease than younger patients and are at higher risks for complications and mortality, especially if they have a history of heart failure or chronic obstructive pulmonary disease [19]. This study suggested that proper mask ventilation would be necessary, and ventilation to relieve subjective discomfort could be appropriate only when there is no other person within social distance and in outdoor environments. There are reports suggesting that the minimum distance to prevent the spread of infection by aerosols is about 1 to 2 meters; however, robust scientific evidence is still lacking [20]. For hygienic reasons, changing or discarding the mask after 1 day of use is recommended.

This study has several limitations. First, it was performed with healthy participants in their 20 s with no history of diseases. Thus, the results might not be generalizable to elderly or at-risk populations. Second, only a small number of participants were enrolled, and larger cohorts of patients are still required to confirm these findings. However, the results from this pilot study provide the basis for larger-scale studies to be conducted in the future. Third, it was difficult to measure the proper time to wear a mask because of the small number of subjects and the short duration of the experiments. Fourth, the experimental area was in Bucheon-si, Gyeonggi-do, Republic of Korea and was carried out in an area within 20 meters above sea level. Therefore, there may be changes in experimental values according to changes in atmospheric conditions. In addition, in discussing the use of masks, the infection rate or prevalence of COVID-19 by region was not considered. Fifth, an exact method for adequate ventilation was not investigated. Overall, further research is needed to determine the ventilation length needed to normalize masks' temperature and humidity, and determine a safe ventilation distance.

5. Conclusions

Irrespective of the type of mask used, the temperature inside the investigated masks was 2 to 3 degrees higher than the outside ambient temperature, and the humidity inside the mask was twice as high as the outside ambient humidity. In all four types of masks, bacterial culture experiments detected bacteria found mainly on the skin and mouth. Thus, we suggest that proper mask ventilation is necessary as it could alleviate subjective discomfort.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

HJK, HBK—designed the research study. HJK, HBK, HJC, KHK—performed the research. HBK, HJC and KHK analyzed the data. HBK and HJC—wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The method of the study was conducted as a simple observation study, not a clinical study for patients, Soonchunhyang University Bucheon Hospital waived the ethics approval. Informed consent was obtained from all participants involved in the study.

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Not applicable.

FUNDING

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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