

## Comparative effects of wearing N95, surgical, cloth, and PM<sub>2.5</sub> masks during six-minute walk test on dyspnea, breathing effort, oxygen saturation, and functional capacity in pre-aging individuals

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### ARTICLE INFO

#### Article history:

Received 29 August 2022

Accepted as revised 20 December 2022

Available online 5 January 2023

#### Keywords:

Face mask, COVID-19, air pollution, pre-aging, dyspnea, six-minute walk test

### ABSTRACT

**Background:** Wearing a face mask became a part of daily life due to the COVID-19 pandemic and fine particulate matter (PM<sub>2.5</sub>) air pollution in Thailand. However, performing activities while wearing different types of masks can cause different physiological effects, especially in the pre-aging population that still performs outdoor activities regularly.

**Objectives:** To compare the impacts of different types of the mask (no mask, N95, surgical, cloth, PM<sub>2.5</sub> mask) on dyspnea, breathing effort, blood oxygen saturation (SpO<sub>2</sub>), and functional capacity (six-minute walk distance and estimated VO<sub>2</sub>max) during the six-minute walk test (6MWT) in pre-aging individuals.

**Materials and methods:** Twenty-four healthy pre-aging individuals (54±3 years) performed five trials of 6MWT wearing different types of masks. Pre-test and post-test of dyspnea, breathing effort, and blood oxygen saturation values were recorded. The estimated VO<sub>2</sub>max was calculated from 6MWT. The satisfaction for each type of mask was collected using questionnaires.

**Results:** SpO<sub>2</sub>, walking distance, and estimated VO<sub>2</sub>max were not significantly different ( $p>0.05$ ) among all trials. Changes in dyspnea, breathing effort, and systolic blood pressure values were statistically different ( $p=0.026$ ,  $p=0.031$ , and  $p=0.028$ , respectively). Despite post hoc analysis revealing a nonsignificant difference in delta changes in dyspnea between walking trials, there was a clinical difference in dyspnea while wearing N95 compared to no mask as well as surgical masks compared to other masks (MCID for Borg scale ≥1). Wearing an N95 or surgical mask resulted in higher dyspnea. Moreover, wearing an N95 mask also resulted in higher breathing effort and systolic blood pressure compared to wearing no mask.

**Conclusion:** Wearing various types of masks in the pre-aging population during moderate-intensity activity did not result in differences in oxygen saturation and functional capacity. Wearing an N95 resulted in higher levels of dyspnea, breathing effort and systolic blood pressure than wearing no mask. Wearing a surgical mask may have resulted in higher levels of dyspnea than wearing no mask, a cloth mask, or a PM<sub>2.5</sub> mask.

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doi: 10.12982/JAMS.2023.012

E-ISSN: 2539-6056

## Introduction

COVID-19 pandemic has had a global impact on human health. Since the beginning of the COVID-19 outbreak, at the time of writing, the number of confirmed cases globally has surpassed 584 million, with over 6.4 million deaths.<sup>1</sup> To prevent further cases and deaths, people should follow individual preventive behaviors, i.e., social distancing, frequent handwashing, and mask-wearing.<sup>2</sup> Since March of 2012, Thailand has faced an air pollution crisis with fine particulate matter (PM<sub>2.5</sub>) that exceeds the standard safe level, especially in the north of Thailand.<sup>3</sup> PM<sub>2.5</sub> can cause irritation of the eyes and respiratory tract. In addition, the long-term effects of PM<sub>2.5</sub> may cause chronic obstructive pulmonary disease (COPD), cardiovascular disease, and cancer, which are leading causes of death.<sup>4</sup> Therefore, the Ministry of Public Health has advised people to avoid outdoor exercise or, if necessary, to wear a mask.<sup>5</sup>

Wearing a mask has become a part of daily life. Various types of masks with different particle filtration efficiency as well as distinct shapes and materials are widely used in Thailand.<sup>6</sup> The N95 respirator is one of the most commonly used because of the high filtration efficiency that prevents droplet and airborne transmission of COVID-19 and protects from PM<sub>2.5</sub>. However, wearing an N95 respirator for a long time may have adverse health effects, e.g., decreased ventilation<sup>7-8</sup> can cause hypoxemia and hypercapnia,<sup>9</sup> leading to dyspnea and decreased functional capacity. In addition, performing activities while wearing an N95 respirator may induce a reduction in exercise capacity and functional capacity.<sup>10</sup>

The pre-elderly (age 50-59) population is a high-risk group for adverse effects when wearing a mask, as mentioned above.<sup>11</sup> Because this population regularly performs activities while wearing a face mask, despite the fact that their bodies are undergoing age-related deterioration.<sup>12,13</sup> Furthermore, the daily routine of the pre-aging population consists of moderate-intensity activities, such as brisk walking, gardening, and housework.<sup>14</sup> As a result, it is critical to assess the impact of performing activities while wearing various face masks on this population. However, there are no studies on the physiological effects of performing activities while wearing different masks in the pre-aging population. Previous research mainly studied the impact of wearing only one type of mask.<sup>15,16</sup> The few studies that compared the effects of wearing different types of masks were all in younger populations.<sup>17,18</sup>

To evaluate a pre-aging population's capacity for moderate-intensity activity, the 6MWT is a suitable test.<sup>19</sup> Therefore, this study aims to determine the physiological effects of wearing N95 respirators, surgical masks, cloth masks, and PM<sub>2.5</sub> masks during the 6MWT for pre-aging participants to further recommend the most appropriate type of mask to protect from COVID-19 or PM<sub>2.5</sub>.

## Materials and methods

### Participants

First, the number of participants was determined using data from a previous study<sup>18</sup> that compared the effects of different masks on the 6MWT in healthy subjects. G-Power version 3.1.9.4 calculations revealed that the study required data from 7 participants. However, the researchers considered this to be an insufficient number for study in the pre-aging population. As a result, the effect size for partial  $\eta^2$  was changed to 0.06 at the medium effect size level, the power was set to 0.80, and the alpha error was 0.05. Data were collected from 24 participants.

Inclusion criteria were healthy pre-elderly (age 50-59) and capable of self-walking safely. Exclusion criteria included respiratory disease (acute or chronic), smoking history  $\geq 20$  packs a year or having quit less than a year prior, unstable cardiovascular diseases, taking medication affecting outcome measurement, and other diseases that prevent the participant from safely performing the walking test. All participants signed a written informed consent before any procedures started.

### Outcome measurements

Physiological variables were measured at rest, the end of test, and the recovery period. The primary outcome was dyspnea (Borg CR10 scale), and the secondary outcomes were breathing effort (Borg CR10 scale), blood oxygen saturation (SpO<sub>2</sub>), and functional capacity (six-minute walking distance and estimated VO<sub>2</sub>max).<sup>20</sup> VO<sub>2</sub>max (ml/kg<sup>-1</sup>/min<sup>-1</sup>) was calculated from  $70.161 + (0.023 \times 6MWT [m]) - (0.276 \times \text{weight [kg]}) - (6.79 \times \text{sex, where male } = 0, \text{ female } = 1) - (0.193 \times \text{resting HR [beats per minute]}) - (0.191 \times \text{age [y]})$ .<sup>21</sup> Furthermore, heart rate recovery at 1 and 2 minutes was recorded, which was calculated from the heart rate at the end of the 6MWT and the heart rate after one or two minutes, respectively.

### Study Design

This study is a randomized, prospective, cross-over trial. The study protocol was approved by the ethics committee of the institute (AMSEC-64EX-029). After familiarization with the test, each participant performed five trials (two on the first day and three on the second day) of the 6MWT with no mask and wearing four different types of masks; N95 respirator (3MTM 1870+ N95, Minnesota, USA), surgical mask (Medima SKTM, Bangkok, Thailand), cloth mask (handmade mask with 2 layers fabric), PM<sub>2.5</sub> mask (UnicharmTM 3D mask, Japan). The sequence of face masks used in each trial was generated using a balanced Latin square method. The 6MWT was performed in accordance with the American Thoracic Society guidelines.<sup>22</sup>

The participants rested for at least 30 minutes before starting each walking trial (dyspnea Borg CR10 scale =0). Then the Self-perceived dyspnea (Borg CR10 scale), breathing effort (Borg CR10 scale), blood pressure (Omron™ HEM-7130, Kyoto, Japan), heart rate, and SpO<sub>2</sub> (Nonin™ Onyx II 9550, Minnesota, USA) were measured while wearing a mask for 5 minutes, at the beginning and end of the test, and then at minutes 1, 2, and 5 after the test. The six-minute walk distance was also recorded to calculate the estimated VO<sub>2</sub>max. Using two questionnaires, participants were asked to rate their level of satisfaction with a mask at the end of each walking trial (Supplementary Table S1). Furthermore, after completing all of the walking trials, the participants ranked their satisfaction with the four types of masks (Supplementary Table S2).

### Statistical analysis

All data were tested for normality using the Shapiro-Wilk test. Depending on whether the data is normally distributed, one-way repeated ANOVA or Friedman test was used for the comparative analysis. The statistically

significant level was set at 0.05. If the data were statistically significant, pairwise comparisons between group means (post hoc analysis) were performed using Bonferroni or Wilcoxon signed-rank test with Bonferroni-adjusted significant level value, which the Bonferroni-adjusted significant level value is calculated as the significant level value divided by the number of pairwise comparisons, 0.05 divided by 10, so the value is 0.005 ( $p \leq 0.005$ ). Data with a normal distribution were presented as mean±SD, whereas data with a non-normal distribution were presented as median (upper-lower quartile).

### Results

Twenty-four participants (male: female 8: 16; age 54±3 years; weight 63±13 kg; height 158±8 cm; BMI 25.1±4.4 kg/m<sup>2</sup>) participated in this study.

### Physiologic variables at rest

Physiologic variables at rest are presented in Table 1. Most of the variables were not significantly different between the walking trials ( $p > 0.05$ ), with systolic blood pressure (SBP) ( $p = 0.006$ ) being the exception.

**Table 1** Comparison of the physiologic variables at rest.

| Outcome                              | No mask                                  | N95              | Surgical         | Cloth            | PM <sub>2.5</sub> | p value       | Effect size        |
|--------------------------------------|------------------------------------------|------------------|------------------|------------------|-------------------|---------------|--------------------|
|                                      | median (upper quartile - lower quartile) |                  |                  |                  |                   |               |                    |
| Dyspnea (Borg (CR10) scale)          | 0 (0-0)                                  | 0 (0-0)          | 0 (0-0)          | 0 (0-0)          | 0 (0-0)           | -             | -                  |
| Breathing effort (Borg (CR10) scale) | 0 (0-0)                                  | 0 (0-0)          | 0 (0-0)          | 0 (0-0)          | 0 (0-0)           | -             | -                  |
| Oxygen saturation (%)                | 98.0 (97.0-98.0)                         | 98.0 (98.0-98.0) | 98.0 (97.0-98.8) | 98.0 (98.0-98.0) | 98.0 (97.0-98.0)  | 0.483         | 0.036 <sup>b</sup> |
| Heart rate (bpm)                     | 79 (69-88)                               | 81 (72-88)       | 80 (72-88)       | 78 (71-90)       | 78 (68-90)        | 0.143         | 0.072 <sup>b</sup> |
|                                      | mean±SD                                  |                  |                  |                  |                   |               |                    |
| Systolic blood pressure (mmHg)       | 120±18                                   | 115±17           | 116±20           | 113±17           | 115±19            | <b>0.006*</b> | 0.153 <sup>b</sup> |
| Diastolic blood pressure (mmHg)      | 74±11                                    | 74±10            | 73±9             | 73±9             | 74±10             | 0.814         | 0.012 <sup>a</sup> |

Note: One-way repeated ANOVA reported with mean±SD, Friedman test reported with median (upper-lower quartile). \*Statistically significant indicating that at least one pair of masks is significantly different ( $p \leq 0.05$ ). <sup>a</sup> Effect size estimates of one-way repeated ANOVA are Partial Eta Squared ( $\eta^2$ ) =  $SS_{\text{effect}} / SS_{\text{effect}} + SS_{\text{error}}$ ;  $\eta^2 = 0.01$  indicate small effect,  $\eta^2 = 0.06$  indicate medium effect and  $\eta^2 = 0.14$  indicate large effect, <sup>b</sup> Effect size estimates of the Friedman test is Kendall's W value ( $W$ ) =  $\chi^2 / N(K-1)$ ;  $w = 0.10$  indicates a small effect,  $w = 0.30$  indicates a medium effect, and  $w = 0.50$  indicates a large effect.

### Physiologic variables after wearing a mask for five minutes

Between-group comparisons of physiologic variables after wearing a mask for five minutes showed significant differences in dyspnea and breathing effort ( $p = 0.042$  and  $0.001$ , respectively) (Table 2).

### Physiologic variables at the end of the 6MWT

At the end of the 6MWT, generally there were no statistically significant differences on physiological variables except for dyspnea, breathing effort, and SBP ( $p = 0.026$ ,  $p = 0.031$ , and  $p = 0.028$ , respectively) (Table 3).

**Table 2** Physiological variables after wearing a mask for five minutes.

| Outcome                                                                                | No mask                                  | N95                   | Surgical              | Cloth                 | PM <sub>2.5</sub>     | p value | Effect size        |
|----------------------------------------------------------------------------------------|------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|---------|--------------------|
|                                                                                        | median (upper quartile - lower quartile) |                       |                       |                       |                       |         |                    |
| Dyspnea (Borg (CR10) scale)                                                            | 0 (0-0)                                  | 0 (0-0)               | 0 (0-0)               | 0 (0-0)               | 0 (0-0)               | 0.042*  | 0.103 <sup>b</sup> |
| Breathing effort (Borg (CR10) scale)                                                   | 0 (0-0)                                  | 0 (0-0.5)             | 0 (0-0)               | 0 (0-0)               | 0 (0-0)               | 0.001*  | 0.190 <sup>b</sup> |
| Oxygen saturation (%)                                                                  | 98.0<br>(97.3-98.0)                      | 98.0<br>(97.0-98.0)   | 98.0<br>(97.0-98.0)   | 98.0<br>(97.0-98.0)   | 98.0<br>(97.0-98.0)   | 0.687   | 0.024 <sup>b</sup> |
| Systolic blood pressure (mmHg)                                                         | 118<br>(108-128)                         | 112<br>(97-126)       | 111<br>(105-122)      | 108<br>(96-119)       | 108<br>(99-126)       |         |                    |
| Change in systolic blood pressure (mmHg) while resting and wearing a mask five minutes | 0<br>(0-0)                               | -1.50<br>(-6.00-2.75) | -3.50<br>(-8.25-1.75) | -2.50<br>(-8.50-3.50) | -5.00<br>(-8.00-0.25) | 0.176   | 0.066 <sup>b</sup> |
| Diastolic blood pressure (mmHg)                                                        | 74<br>(66-80)                            | 72<br>(67-77)         | 72<br>(66-79)         | 70<br>(66-77)         | 72<br>(64-78)         | 0.268   | 0.054 <sup>b</sup> |
|                                                                                        | mean±SD                                  |                       |                       |                       |                       |         |                    |
| Heart rate (bpm)                                                                       | 78±11                                    | 78±10                 | 80±10                 | 78±10                 | 77±10                 | 0.345   | 0.047 <sup>a</sup> |

Note: One-way repeated ANOVA reported with mean±SD, Friedman test reported with median (upper-lower quartile). \*Statistically significant indicating that at least one pair of masks is significantly different ( $p \leq 0.05$ ), <sup>a</sup> Effect size estimates of one-way repeated ANOVA are Partial Eta Squared ( $\eta^2$ ) =  $SS_{\text{effect}} / (SS_{\text{effect}} + SS_{\text{error}})$ ;  $\eta^2 = 0.01$  indicate small effect,  $\eta^2 = 0.06$  indicate medium effect and  $\eta^2 = 0.14$  indicate large effect, <sup>b</sup> Effect size estimates of the Friedman test is Kendall's W value ( $W = \chi^2 / N(K-1)$ );  $w = 0.10$  indicates a small effect,  $w = 0.30$  indicates a medium effect, and  $w = 0.50$  indicates a large effect.

**Table 3** Physiological variables at the end of 6MWT.

| Outcome                                                                                                      | No mask                                  | N95                    | Surgical               | Cloth                  | PM <sub>2.5</sub>      | p value | Effect size        |
|--------------------------------------------------------------------------------------------------------------|------------------------------------------|------------------------|------------------------|------------------------|------------------------|---------|--------------------|
|                                                                                                              | median (upper quartile - lower quartile) |                        |                        |                        |                        |         |                    |
| Dyspnea(Borg (CR10) scale)                                                                                   | 0.50<br>(0.50-1.75)                      | 2.00<br>(0.50-3.00)    | 1.50<br>(0.63-3.00)    | 1.00<br>(0.50-2.00)    | 1.00<br>(0.50-2.75)    |         |                    |
| Change in dyspnea (Borg (CR10) scale) during wearing a mask for five minutes and the at the end of test      | 0.50<br>(0.50-1.75)                      | 1.00<br>(0.50-2.75)    | 2.00<br>(0.50-3.00)    | 1.00<br>(0.50-2.00)    | 1.00<br>(0.50-2.00)    | 0.026*  | 0.115 <sup>b</sup> |
| Breathing effort (Borg (CR10) scale)                                                                         | 0.50<br>(0-1.00)                         | 0.50<br>(0-2.00)       | 1.50<br>(0.50-2.75)    | 0.50<br>(0-2.00)       | 0.50<br>(0-1.00)       |         |                    |
| Change in breathing effort (Borg (CR10) scale) during wearing a mask for five minutes and at the end of test | 0.50<br>(0.00-1.00)                      | 1.00<br>(0.50-2.00)    | 0.50<br>(0.00-2.00)    | 0.50<br>(0.00-1.88)    | 0.50<br>(0.00-1.00)    | 0.031*  | 0.011 <sup>b</sup> |
| Oxygen saturation (%)                                                                                        | 98.0 (97.0-98.0)                         | 98.0 (97.0-98.0)       | 98.0 (97.0-98.0)       | 98.0 (97.0-98.0)       | 97.0 (96.3-98.0)       | 0.202   | 0.062 <sup>b</sup> |
| Systolic blood pressure (mmHg)                                                                               | 140.13±22.85                             | 140.88±21.18           | 143.38±22.66           | 135.75±17.93           | 136.83±20.54           |         |                    |
| Change in SBP (mmHg) during wearing a mask for 5 minutes and the end of test                                 | 18.50<br>(10.25-30.75)                   | 22.50<br>(18.25-42.00) | 26.00<br>(15.25-41.25) | 20.50<br>(13.50-37.75) | 24.00<br>(14.50-37.75) | 0.028*  | 0.113 <sup>b</sup> |
|                                                                                                              | mean±SD                                  |                        |                        |                        |                        |         |                    |
| Heart rate (bpm)                                                                                             | 112±20                                   | 115±19                 | 116±17                 | 114±17                 | 112±18                 | 0.479   | 0.033 <sup>a</sup> |
| Diastolic blood pressure (mmHg)                                                                              | 76±10                                    | 78±9                   | 77±8                   | 76±10                  | 77±10                  | 0.533   | 0.031 <sup>a</sup> |
| HRR1 (bpm)                                                                                                   | 18±9                                     | 21±7                   | 20±7                   | 20±7                   | 19±11                  | 0.427   | 0.039 <sup>a</sup> |
| HRR2 (bpm)                                                                                                   | 25±10                                    | 26±9                   | 27±10                  | 26±9                   | 27±14                  | 0.099   | 0.084 <sup>a</sup> |
| 6MWT distance (meter)                                                                                        | 509.86±63.15                             | 502.08±66.75           | 507.75±62.79           | 506.55±61.58           | 508.39±61.60           | 0.715   | 0.018 <sup>a</sup> |
| Estimated VO <sub>2</sub> max (ml/kg/ min)                                                                   | 34.84±5.60                               | 34.66±5.40             | 34.79±5.55             | 34.77±5.29             | 34.81±5.43             | 0.715   | 0.018 <sup>a</sup> |

Note: HRR: heart rate recovery, HRR1: heart rate at the end of 6MWT - heart rate after 1 minute, HRR2: heart rate at the end of 6MWT - heart rate after 2 minutes. One-way repeated ANOVA reported with mean±SD, Friedman test reported with median (upper-lower quartile). \*Statistically significant indicating that at least one pair of masks is significantly different ( $p \leq 0.05$ ), <sup>a</sup> Effect size estimates of one-way repeated ANOVA are Partial Eta Squared ( $\eta^2$ ) =  $SS_{\text{effect}} / (SS_{\text{effect}} + SS_{\text{error}})$ ;  $\eta^2 = 0.01$  indicate small effect,  $\eta^2 = 0.06$  indicate medium effect and  $\eta^2 = 0.14$  indicate large effect, <sup>b</sup> Effect size estimates of the Friedman test is Kendall's W value ( $W = \chi^2 / N(K-1)$ );  $w = 0.10$  indicates a small effect,  $w = 0.30$  indicates a medium effect, and  $w = 0.50$  indicates a large effect.

There was no difference between the delta changes of dyspnea between walking trials, according to the post hoc analysis value obtained from the Friedman test ( $p>0.005$ ) (Figure 1).

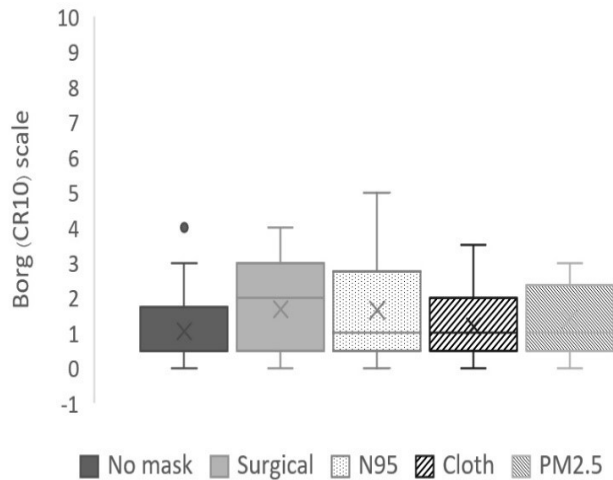


Figure 1 Post hoc analysis of delta changes of dyspnea.

There was a statistically significant difference in the delta changes of breathing effort between the trials with no mask and an N95 mask ( $p=0.005$ ) (Figure 2).

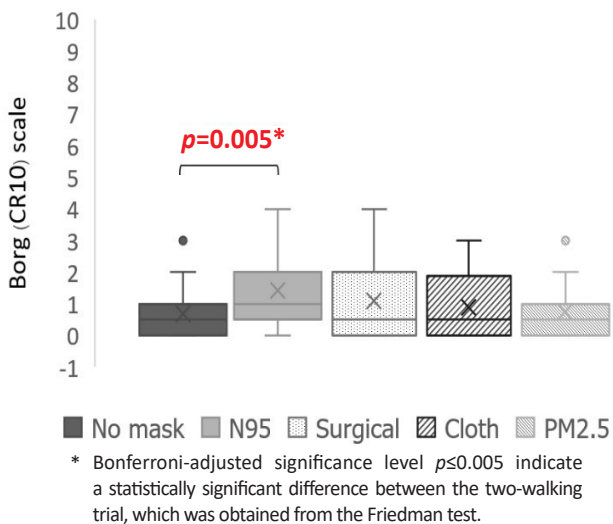


Figure 2 Post hoc analysis of delta changes of breathing effort.

There was a statistically significant difference in the delta changes of SBP score between the trials with no mask and an N95 mask ( $p=0.003$ ) (Figure 3).

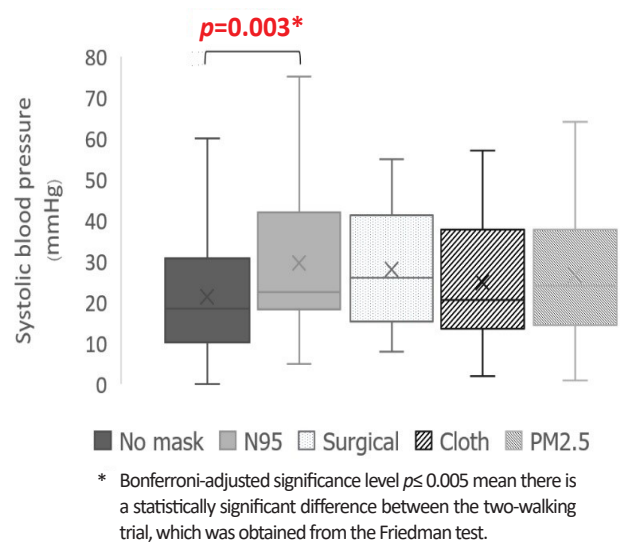


Figure 3 Post hoc analysis of delta changes of systolic blood pressure.

### The satisfaction level of wearing a mask

In summary of supplementary Table S1, PM<sub>2.5</sub> mask received the highest comfort satisfaction rating ( $4.8\pm0.4$ ), while the N95 respirator and the cloth mask were rated the lowest (both are  $4.1\pm1.2$ ). The N95 respirator and surgical mask received the highest score for face and mouth fit ( $4.7\pm0.7$  and  $4.7\pm0.6$ , respectively), while the cloth mask received the lowest rating ( $3.6\pm1.3$ ). The highest scores in breathability were for the PM<sub>2.5</sub> mask ( $4.5\pm0.8$ ), while the lowest score was for the N95 respirator ( $3.8\pm0.9$ ). PM<sub>2.5</sub> mask received the highest score for heat-cooling category ( $4.3\pm0.8$ ), while the N95 respirator was rated the lowest ( $3.4\pm1.1$ ). In the category of confidence, the surgical mask and PM<sub>2.5</sub> mask received the highest scores ( $4.7\pm0.6$  and  $4.7\pm0.7$ , respectively), while cloth mask received the lowest ( $4.1\pm1.2$ ). Finally, N95 respirator received the highest ratings in the appearance category ( $4.7\pm0.7$ ), while cloth mask received the lowest ( $3.8\pm1.3$ ).

### Discussion

The main findings indicated that, there were no statistically significant differences in most physiological parameters between walking trials while wearing different masks, but statistically significant differences were found for dyspnea, breathing effort, and SBP ( $p\leq0.05$ ) (Table 3). Wearing an N95 mask resulted in higher breathing effort and SBP compared to no mask ( $p=0.005$  and  $0.003$ , respectively) (Figure 2 and Figure 3). While post hoc analysis could not detect a significant difference in delta changes in dyspnea between walking trials ( $p>0.005$ ) (Figure 1), wearing a surgical mask tended to increase dyspnea compared to wearing other types of masks (Table 3, median 2.0 (0.5-3.0)).

The N95 respirator and surgical mask are effective at preventing the spread of infection. However, the characteristics of these masks (such as being made of nano-micro polypropylene, having shapes designed to fit the mouth, and having multiple layers) result in limited ventilation.<sup>8,23</sup> Wearing these masks while doing moderate-intensity exercise may have an effect on pre-aging individuals. As a result, type of mask used should be determined by the activity and situation.

#### Effects of physiologic variables at rest

At rest, most of the variables were not significantly different between the walking trials ( $p>0.05$ ) (Table 1), with SBP being the exception ( $p=0.006$ ) (Table 1). SBP can vary from 2.5 to 10 mmHg,<sup>24</sup> depending on various factors, e.g., deterioration of the cardiovascular system at pre-aging that could impair SBP adaptation.<sup>13</sup> In this study, the greatest difference in median score of SBP between trials was 7 mmHg. Consequently, these differences were considered normal body adaptations and had no clinical significance.

#### Effects of physiologic variables after wearing a mask for five minutes

After wearing mask for five minutes, significant differences in dyspnea and breathing effort were found ( $p=0.042$  and  $0.001$ , respectively) (Table 2). However, post hoc analysis could not identify the pairs of masks that differed ( $p>0.005$ ) (Table 2) and the median scores were not different among the five trials (dyspnea and breathing effort score=0) (Table 2). Hence, these statistical differences were not clinically significant. Therefore, wearing the masks for five minutes at rest does not seem to change any physiological parameters.

#### Effects of different mask types during 6MWT on dyspnea

At the end of 6MWT, the dyspnea scores were significantly different ( $p=0.026$ ) (Table 3). However, due to a small effect size, post hoc analysis could not identify the pairs of masks that resulted in different scores ( $p>0.005$ ) (Figure 1). Even so, since the change in dyspnea exists with minimal clinically important difference (MCID) ( $\geq 1$  on the Borg CR 10 scale).<sup>25</sup> It could be implied that wearing a surgical mask while performing moderate-intensity activities resulted in higher dyspnea compared to other masks. Moreover, wearing an N95 mask while performing moderate-intensity activities resulted in higher levels of dyspnea than no mask. This finding was consistent with the meta-analysis of Shaw *et al.*<sup>26</sup> and other studies in healthy adults.<sup>18</sup> The characteristics of an N95 respirator and surgical mask (such as material, shapes, and number of layers) are high-filtration effective. However, while performing tasks of moderate intensity, the characteristics of the mask can result in decreased ventilation and impaired gas exchange.<sup>8, 23, 27</sup> Furthermore, it may cause more dyspnea than a cloth and PM<sub>2.5</sub> mask.

Surprisingly, the N95, which has higher carbon dioxide rebreathing, was found to result in less dyspnea compared to the surgical mask.<sup>27</sup> It is possible that this is the case because some N95 respirators use an electrostatically

charged filter to increase filtration effectiveness by trapping microorganisms on the fiber wall. As a result, the manufacturer can design a more open structure without having to reduce the fiber size, maintaining the N95 respirator's good breathability.<sup>8, 28</sup> Additionally, while the surgical mask has a lower fiber resolution and thickness than the N95 respirator, it cannot form 3D shapes like the N95 respirator, therefore, the fiber might be sucked into the nose and mouth while deeply inhaling, resulting in the possibility of increased dyspnea.<sup>23,29</sup> In contrast, the higher open space of N95 expands the respiratory area while decreasing the velocity of airflow entering the respiratory tract resulting in increased ventilation and gas exchange.<sup>3</sup>

#### Effects of different mask types during 6MWT on breathing effort

The result indicated that wearing an N95 respirator while performing moderate-intensity activities resulted in higher levels of breathing effort than wearing no mask (Figure 2). This was consistent with a study in healthy young adults by Dacha *et al.*<sup>18</sup> However, despite being statistically significant, there were still no clinically significant effects ( $<1$  on the Borg scale).

Dyspnea has no direct effect on breathing effort.<sup>31</sup> Breathing effort is caused by the perceived mechanism of respiratory loading and capacity imbalance, which is the normal respiratory response to an increase in physical activity or a limit on ventilation.<sup>32,33</sup> On the other hand, in low-intensity activities carried out by healthy adult, dyspnea is uncommon<sup>34-35</sup> because a normal respiratory function is capable of balancing receptor afferent feedback and neural respiratory drive.<sup>32-33</sup> However, the increasing the neural respiratory drive for this study may come from mechanical factors (such as increasing the intensity or duration of exercise) and chemical factors (such as a ventilation-perfusion mismatch and carbon dioxide rebreathing due to wearing a mask), both of which result in dyspnea.<sup>35</sup>

The shapes, structures, and materials of the mask could result in increased dyspnea and breathing effort. For example, the N95 respirator is made from nanometer to micrometer fibers of polypropylene and has a shape that fits closely to the face,<sup>8, 23</sup> which may lead to limited ventilation<sup>8</sup> and carbon dioxide rebreathing.<sup>27</sup> This was consistent with the lowest satisfaction scores for breathability, comfort, and heat-cooling (Supplementary Table S1).

#### Effects of different mask types during 6MWT on SBP

Wearing an N95 respirator during 6MWT resulted in higher levels of SBP than wearing no mask ( $p=0.003$ ) (Figure 3). Similarly, Cano Carrizal's study<sup>36</sup> found that wearing a surgical mask while performing the Bruce protocol caused a higher level of SBP than wearing no mask. It is possible that the shape and material of the mask cause retention and rebreathing of carbon dioxide.<sup>27</sup> The high level of carbon dioxide stimulates the sympathetic nervous system in the brainstem, causing vasoconstriction and a rise in SBP.<sup>37</sup> The high level of carbon dioxide in the blood can induce a feeling of discomfort and breathlessness which was consistent with the above discussion about

dyspnea and breathing effort. Also, the mask-wearing satisfaction questionnaire results indicated that the N95 respirator scored lowest for comfort and breathability (Supplementary Table S1).

### Effects of different mask types during 6MWT on oxygen saturation

Wearing different types of masks did not affect oxygen saturation ( $p>0.05$ ) (Table 3), which was consistent with the previous studies except for a study by Salles *et al.*<sup>38</sup> in post COVID-19 patients.<sup>18,26</sup> In general, oxygen saturation may decrease after activity or exercise,<sup>39</sup> especially when the exercise is prolonged until  $VO_2\max$  is attained.<sup>40</sup> However, since the level of exercise in this study was not extreme, most participants were still able to maintain a good oxygen transport balance. As a result, oxygen saturation was only slightly reduced and not clinically significant (Table 3), causing only a short-term effect.

### Effects of different mask types during 6MWT on functional capacity (six-minute walk distance and estimated $VO_2\max$ )

Indirect maximum oxygen consumption (estimated  $VO_2\max$ ) was calculated. There were no statistically significant differences ( $p>0.05$ ) (Table 3) in walking distance and  $VO_2\max$ , which was consistent with the previous studies on the effects of mask wearing on 6MWT.<sup>15,18,26</sup> The 6MWT is a submaximal exercise test that measures functional capacity. Therefore, this test could not directly represent cardiorespiratory endurance. However, evidence suggests that wearing an N95 respirator or surgical or cloth mask during cardiopulmonary exercise tests (CPET) can lower the maximum oxygen consumption ( $VO_2\max$ ), heart rate, and exercise time.<sup>10, 41-42</sup>

### Strengths, limitations, and recommendations

A key strength of this study was that the research questions were relevant to current problems. The prospective crossover trials on the same participant eliminate the interference effect of between-group variance. However, the post hoc analysis could not determine the pair of masks that differ, indicating a small sample size. Therefore, the result should be interpreted with caution. Future studies should investigate a larger sample size and consider the effect of activity duration if the activity is performed for more than 6 minutes.

### Clinical implications

Pre-aging individuals should choose an appropriate mask for each activity and situation. For example, wearing an N95 mask is tolerable when performing low-intensity activities. However, when performing moderate to high-intensity activities, wearing other masks might be a better option to reduce the impact of dyspnea and breathing effort. Furthermore, masks should not be worn while performing vigorous activities.

### Conflict of interest

All authors declare that they have no conflicts of interest that are relevant to the publication of this research.

### Conclusion

For pre-aging individuals, wearing various types of face masks during moderate-intensity activity did not result in differences in blood oxygen saturation and functional capacity. However, wearing an N95 mask during moderate-intensity activity resulted in higher levels of dyspnea, breathing effort, and systolic blood pressure than wearing no mask. In addition, wearing a surgical mask during moderate-intensity activity may result in higher dyspnea than wearing no mask, a cloth mask, or a  $PM_{2.5}$  mask.

### References

- [1] WHO coronavirus (COVID-19) dashboard [Internet]. Switzerland: World Health Organization; 2022 [updated 2022 Aug 1; cited 2022 Aug 12]. Available from: <https://covid19.who.int/>.
- [2] How to protect yourself and others [Internet]. Atlanta GA: Center of Disease Control and Prevention; 2022 [updated 2022 Feb 25; cited 2022 Jul 30]. Available from: <https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html>.
- [3] Ponpiboon T, Jayasvasti I, Roongpisuthipong A. Disaster in the winter of particle matter ( $PM_{2.5}$ ). EAU Herit J. 2014; 8: 40-6 (in Thai).
- [4] Thangavel P, Park D, Lee Y-C. Recent insights into particulate matter ( $PM_{2.5}$ )-mediated toxicity in humans: an overview. Int J Environ Res Public Health. 2022; 19: 7511. doi:10.3390/ijerph19127511.
- [5] Medical and public health operation manual for particulate matter with a size less than 2.5 microns in 2020 [Internet]. Thailand: Ministry of Public Health; 2020 [updated 2019 Dec; cited 2022 Jul 29]. Available from: [http://envocc.ddc.moph.go.th/uploads/downloads/do\\_manual\\_PM2.5.pdf](http://envocc.ddc.moph.go.th/uploads/downloads/do_manual_PM2.5.pdf) (in Thai).
- [6] Face mask crisis of another design [Internet]. Thailand: Thailand Development Research Institute; 2020 [updated 2020 May 27; cited 2022 Jul 29]. Available from: <https://tdri.or.th/en/2020/05/face-mask-crisis-of-another-design/>.
- [7] Harber P, Barnhart S, Boehlecke BA, Beckett WS, Gerrity T, McDiarmid MA, et al. Respiratory protection guidelines. this official statement of the American thoracic society was adopted by the ATS board of directors, March 1996. Am J Respir Crit Care Med. 1996; 154: 1153-65. doi: 10.1164/ajrccm.154.4.8887621.

- [8] Adanur S, Jayswal A. Filtration mechanisms and manufacturing methods of face masks: an overview. *J Ind Text.* 2020; 51: 3683S-717S. doi: 10.1177/1528083720980169.
- [9] Sinkule EJ, Powell JB, Goss FL. Evaluation of N95 respirator use with a surgical mask cover: effects on breathing resistance and inhaled carbon dioxide. *Ann Occup Hyg.* 2013; 57: 384-98. doi: 10.1093/annhyg/mes068.
- [10] Fikenzer S, Uhe T, Lavall D, Rudolph U, Falz R, Busse M, et al. Effects of surgical and FFP2/N95 face masks on cardiopulmonary exercise capacity. *Clin Res cardiol.* 2020; 109: 1522-30. doi: 10.1007/s00392-020-01704-y.
- [11] Meechana P, Khansakorn N, Silawan T, Rawiworrakul T, Phijaisanit P. Readiness of pre-aging population for quality aging society in Nongyasai sub district, Nongyasai district, Suphanburi province. *EAU Herit J.* 2017; 11: 259-71 (in Thai).
- [12] Two-thirds of adults still plan to wear masks in shops and on public transport [internet]. United Kingdom: Office for National Statistics; 2021 [updated 2021 Jul 26; cited 2022 Aug 16]. Available from: <https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/healthandwellbeing/articles/twothirdsofadultsstillplantowearmasksinshopsandonpublictransport/2021-07-16>.
- [13] Pringle E, Phillips C, Thijs L, Davidson C, Staessen JA, de Leeuw PW, et al. Systolic blood pressure variability as a risk factor for stroke and cardiovascular mortality in the elderly hypertensive population. *J Hypertens.* 2003; 21: 2251-7. doi: 10.1097/00004872-200312000-00012.
- [14] Exercise attitudes and behaviors: a survey of adults age 50-79 [internet]. Washington D.C: American Association of Retired Persons; 2002 [updated 2002 May; cited 2020 Oct 29]. Available from: <https://collections.nlm.nih.gov/catalog/nlm:nlmuid-101168240-pdf>.
- [15] Person E, Lemerrier C, Royer A, Reyhler G. [Effect of a surgical mask on six minute walking distance]. *Rev Mal Respir.* 2018; 35: 264-8. doi: 10.1016/j.rmr.2017.01.010.
- [16] Kyung SY, Kim Y, Hwang H, Park JW, Jeong SH. Risks of N95 face mask use in subjects with COPD. *Respir Care.* 2020; 65: 658-64. doi: 10.4187/respcare.06713.
- [17] Cabanillas-Barea S, Rodríguez-Sanz J, Carrasco-Uribarren A, López-de-Celis C, González-Rueda V, Zagarra-Chávez D, et al. Effects of using the surgical mask and FFP2 during the 6-min walking test. a randomized controlled trial. *Int J Environ Res Public Health.* 2021; 18. doi: 10.3390/ijerph182312420.
- [18] Dacha S, Chuatrakoon B, Sornkaew K, Sutthakhun K, Weeranorapanich P. Effects of wearing different facial masks on respiratory symptoms, oxygen saturation, and functional capacity during six-minute walk test in healthy subjects. *Can J Respir Ther.* 2022; 58: 85-90. doi: 10.29390/.
- [19] Sperandio EF, Arantes RL, Matheus AC, Silva RP, Lauria VT, Romiti M, et al. Intensity and physiological responses to the 6-minute walk test in middle-aged and older adults: a comparison with cardiopulmonary exercise testing. *Braz J Med Biol Res.* 2015; 48: 349-53. doi: 10.1590/1414-431X20144235.
- [20] Kendrick KR, Baxi SC, Smith RM. Usefulness of the modified 0-10 Borg scale in assessing the degree of dyspnea in patients with COPD and asthma. *J Emerg Nurs.* 2000; 26: 216-22. doi: 10.1016/s0099-1767(00)90093-x.
- [21] Burr JF, Bredin SS, Faktor MD, Warburton DE. The 6-minute walk test as a predictor of objectively measured aerobic fitness in healthy working-aged adults. *Phys Sportsmed.* 2011; 39: 133-9. doi: 10.3810/psm.2011.05.1904.
- [22] ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med.* 2002; 166: 111-7. doi: 10.1164/ajrccm.166.1.at1102.
- [23] Solano T, Shoele K. Investigation of the role of face shape on the flow dynamics and effectiveness of face masks. *Fluids.* 2022; 7: 209. doi: 10.3390/fluids7060209.
- [24] Perel A. The physiological basis of arterial pressure variation during positive-pressure ventilation. *Réanimation.* 2005; 14. Doi: 10.1016/j.reaurg.2005.02.002.
- [25] Ries AL. Minimally clinically important difference for the UCSD shortness of breath questionnaire, borg scale, and visual analog scale. *COPD.* 2005; 2: 105-10. doi: 10.1081/copd-200050655.
- [26] Shaw KA, Zello GA, Butcher SJ, Ko JB, Bertrand L, Chilibeck PD. The impact of face masks on performance and physiological outcomes during exercise: a systematic review and meta-analysis. *Appl Physiol Nutr Metab.* 2021; 46: 693-703. doi: 10.1139/apnm-2021-0143.
- [27] Martellucci CA, Flacco ME, Martellucci M, Violante FS, Manzoli L. Inhaled CO<sub>2</sub> concentration while wearing face masks: a pilot study using capnography. *Environ Health Insights.* 2022; 2022.05.10.22274813. doi: 10.1101/2022.05.10.22274813.
- [28] 3M™ health care particulate respirator and surgical masks [Internet]. U.S.A: 3M Company; 2020 [updated 2020 Feb 10; cited 2022 Jul 30]. Available from: <https://multimedia.3m.com/mws/media/13878570/health-care-brochure.pdf>.

- [29] Parikh R, Mathai A, Parikh S, Sekhar GC, Thomas R. Understanding and using sensitivity, specificity, and predictive values. *Indian journal of ophthalmology*. 2008; 56(1): 45.
- [30] Face mask brackets for COVID-19: are they safe and effective? [Internet]. U.S.A: Huffpost; 2020 [updated 2020 Oct 5; cited 2022 Aug 13]. Available from: [https://www.huffpost.com/entry/face-masks-covid-safe-effective\\_l\\_5f6cd969c5b653a2bcb1ae24](https://www.huffpost.com/entry/face-masks-covid-safe-effective_l_5f6cd969c5b653a2bcb1ae24).
- [31] Lane R, Adams L, Guz A. Is low-level respiratory resistive loading during exercise perceived as breathlessness?. *Clin Sci (Lond)*. 1987; 73: 627-34. doi: 10.1042/cs0730627.
- [32] Jolley CJ, Moxham J. A physiological model of patient-reported breathlessness during daily activities in COPD. *Eur Respir Rev*. 2009; 18: 66-79. doi: 10.1183/09059180.00000809.
- [33] Moxham J, Jolley C. Breathlessness, fatigue and the respiratory muscles. *Clin Med (Lond)*. 2009; 9: 448-52. doi: 10.7861/clinmedicine.9-5-448.
- [34] Shingai K, Kanezaki M, Senjyu H. Distractive auditory stimuli alleviate the perception of dyspnea induced by low-intensity exercise in elderly subjects with COPD. *Respir Care*. 2015; 60: 689-94. doi: 10.4187/respcare.03533.
- [35] O'Donnell DE, Milne KM, James MD, de Torres JP, Neder JA. Dyspnea in COPD: new mechanistic insights and management implications. *Adv Ther*. 2020; 37: 41-60. doi: 10.1007/s12325-019-01128-9.
- [36] Cano Carrizal R, Casanova Rodríguez C. Surgical facemask: an ally of exercise stress echocardiography during the COVID-19 pandemic?. *Rev Esp Cardiol (Engl Ed)*. 2021; 74: 472-4. doi: 10.1016/j.rec.2020.10.007.
- [37] Boron WF, Boulpaep EL. *Medical physiology*. 3rd ed. London: Elsevier Health Sciences; 2016.
- [38] Salles-Rojas A, Valderrábano C, Madrid W, González-Molina A, Silva-Cerón M, Rodríguez C, et al. Masking the 6 minutes-walking-test in the COVID-19 era. *Ann Am Thorac Soc*. 2020; 18: 1070-4. doi: 10.1513/AnnalsATS.202009-1088RL.
- [39] Mairbäurl H. Red blood cells in sports: effects of exercise and training on oxygen supply by red blood cells. *Front Physiol*. 2013; 4: 332. doi: 10.3389/fphys.2013.00332.
- [40] Hopkins SR. Exercise induced arterial hypoxemia: the role of ventilation-perfusion inequality and pulmonary diffusion limitation. *Adv Exp Med Biol*. 2006; 588: 17-30. doi: 10.1007/978-0-387-34817-9\_3.
- [41] Lin Q, Cai Y, Yu C, Gu W, Tan Y, Wang L, et al. Effects of wearing face masks on exercise capacity and ventilatory anaerobic threshold in healthy subjects during the COVID-19 epidemic. *Med Sci Monit*. 2022; 28: e936069. doi: 10.12659/msm.936069.
- [42] Driver S, Reynolds M, Brown K, Vingren JL, Hill DW, Bennett M, et al. Effects of wearing a cloth face mask on performance, physiological and perceptual responses during a graded treadmill running exercise test. *Br J Sports Med*. 2022; 56: 107-13. doi: 10.1136/bjsports-2020-103758.

### Supplementary Tables

The scoring criteria ranged from 1 to 5, with a score of 1 being the lowest level of satisfaction and a score of 5

being the highest level of satisfaction. Table S1 shows the mean and standard deviation of the satisfaction scores of masks.

**Table S1** Satisfaction when wearing each type of mask.

| Categories                     | Satisfaction level (mean±SD) |         |         |                   |
|--------------------------------|------------------------------|---------|---------|-------------------|
|                                | Surgical                     | N95     | Cloth   | PM <sub>2.5</sub> |
| (1) Comfort                    | 4.6±0.7                      | 4.1±1.2 | 4.1±1.2 | 4.8±0.4           |
| (2) Fit for the face and mouth | 4.7±0.6                      | 4.7±0.7 | 3.6±1.3 | 4.6±0.9           |
| (3) Breathability              | 4.4±0.8                      | 3.8±0.9 | 4.3±1.1 | 4.5±0.8           |
| (4) Heat-Cooling               | 4.1±0.9                      | 3.4±1.1 | 4.0±1.2 | 4.3±0.8           |
| (5) Confidence                 | 4.7±0.6                      | 4.6±0.7 | 4.1±1.2 | 4.7±0.7           |
| (6) Appearance                 | 4.5±0.7                      | 4.7±0.7 | 3.8±1.3 | 4.5±0.7           |

The participants ranked their satisfaction with the four types of masks by filling in numbers 1 to 4. Number one indicated the most satisfied of all groups of masks, and

four indicated the least satisfied mask. The sequence of satisfaction was presented by number and the percentage of participants rating on each mask in Table S2.

**Table S2** Masks ranked in order of satisfaction.

| Title                          | order | Satisfaction (number (%)) |            |            |                   |
|--------------------------------|-------|---------------------------|------------|------------|-------------------|
|                                |       | Surgical                  | N95        | cloth      | PM <sub>2.5</sub> |
| (1) Comfort                    | 1     | 6 (25.0%)                 | 4 (16.7%)  | 5 (20.8%)  | 9 (37.5%)         |
|                                | 2     | 11 (45.8%)                | 4 (16.7%)  | 4 (16.7%)  | 5 (20.8%)         |
|                                | 3     | 7 (29.2%)                 | 7 (29.2%)  | 4 (16.7%)  | 6 (25.0%)         |
|                                | 4     | 0 (0%)                    | 9 (37.5%)  | 11 (45.8%) | 4 (16.7%)         |
| (2) Fit for the face and mouth | 1     | 7 (29.2%)                 | 9 (37.5%)  | 2 (8.3%)   | 6 (25.0%)         |
|                                | 2     | 7 (29.2%)                 | 5 (20.8%)  | 6 (25.0%)  | 6 (25.0%)         |
|                                | 3     | 10 (41.7%)                | 4 (16.7%)  | 3 (12.5%)  | 7 (29.2%)         |
|                                | 4     | 0 (0%)                    | 6 (25.0%)  | 13 (54.2%) | 5 (20.8%)         |
| (3) Breathability              | 1     | 3 (12.5%)                 | 4 (16.7%)  | 9 (37.5%)  | 8 (33.3%)         |
|                                | 2     | 11 (45.8%)                | 1 (4.2%)   | 6 (25.0%)  | 6 (25.0%)         |
|                                | 3     | 10 (41.7%)                | 3 (12.5%)  | 3 (12.5%)  | 8 (33.3%)         |
|                                | 4     | 0 (0%)                    | 16 (66.7%) | 6 (25.0%)  | 2 (8.3%)          |
| (4) Heat-Cooling               | 1     | 2 (8.3%)                  | 3 (12.5%)  | 9 (37.5%)  | 10 (41.7%)        |
|                                | 2     | 11 (45.8%)                | 0 (0%)     | 6 (25.0%)  | 7 (29.2%)         |
|                                | 3     | 10 (41.7%)                | 4 (16.7%)  | 6 (25.0%)  | 4 (16.7%)         |
|                                | 4     | 1 (4.2%)                  | 17 (70.8%) | 3 (12.5%)  | 3 (12.5%)         |
| (5) Confidence                 | 1     | 11 (45.8%)                | 6 (25.0%)  | 1 (4.2%)   | 6 (25.0%)         |
|                                | 2     | 9 (37.5%)                 | 3 (12.5%)  | 3 (12.5%)  | 9 (37.5%)         |
|                                | 3     | 3 (12.5%)                 | 5 (20.8%)  | 8 (33.3%)  | 8 (33.3%)         |
|                                | 4     | 1 (4.2%)                  | 10 (41.7%) | 12 (50.0%) | 1 (4.2%)          |
| (6) Appearance                 | 1     | 3 (12.5%)                 | 10 (41.7%) | 0 (0%)     | 11 (45.8%)        |
|                                | 2     | 14 (58.3%)                | 3 (12.5%)  | 3 (12.5%)  | 4 (16.7%)         |
|                                | 3     | 6 (25.0%)                 | 5 (20.8%)  | 6 (25.0%)  | 7 (29.2%)         |
|                                | 4     | 1 (4.2%)                  | 6 (25.0%)  | 15 (62.5%) | 2 (8.3%)          |