Time dependent infrared thermographic evaluation of facemasks

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Abstract.

BACKGROUND:

Few studies have investigated silent versus speaking situations while wearing various types of facemasks over a period of time.

OBJECTIVE:

The main objective of this study is the evaluation of temperature changes with time and the thermal comfort of facemasks under different verbal output conditions.

METHODS:

A two-way within-subject experiment was conducted to find the effects of facemask types and verbal output conditions. The infrared thermographic technology was used to record the video during the experiment. A subjective questionnaire was applied to measure the perception ratings of thermal discomfort.

RESULTS:

Wearing a facemask could result in a higher face temperature compared to the condition in which a facemask was not worn. The N95 mask created the highest temperature value in the cheeks and nose/mouth regions. The speaking condition did not present significant difference on face temperature compared to the silent condition. Participants tended to provide higher subjective ratings of perceived humidity, heat, breathing difficulty and overall discomfort while wearing facemasks, especially while wearing the N95 mask and during the speaking conditions.

CONCLUSIONS:

Facial temperature distribution demonstrated various trends with time under different conditions. Facemask types had significant effects on facial temperature and perceived thermal comfort.

Keywords: Thermal comfort, temperature distribution, subjective perceptions

1. Introduction

Due to infectious diseases and air pollution, facemasks have become an essential piece of personal protective equipment for medical personnel and the everyday person. After the SARS outbreak in 2003, it has been found that frequent mask use was one of significant protective factors [1-2]. Since then it has become very common to see doctors, nurses, teachers, drivers and civilians wearing facemasks during work or while in public for hours. Every time people have a normal cold, they are encouraged to wear facemask. Hence, it is not surprising that sometimes people treat facemasks as a part of their daily wardrobe. In Hong Kong, both N95 and surgical masks are regularly used by general populace [3].

There have been many studies on the evaluation of facemasks using various measures such as temperature, humidity, and breathing to examine the function and performance of the masks [3-6]. Previous studies have shown that there is significant difference among facemasks, including the N95 mask and the surgical mask, when analyzing temperature, humidity and physiological features [5-7]. Skin temperatures have a wide application in the design world, ranging from textile materials testing to designing better clothes. Recently, the use of infrared thermography to measure skin temperature has become widespread [8-10] since it is relatively easy and nonintrusive. Infrared (IR) imaging has also been successful in leak detection during facemask evaluation studies [11-12]. IR imaging software provides several options to acquire temperature profile images, however very few options are available to study temperature over time. The most common one is to spot (location) temperature in a few locations. Therefore was not surprising to see that most studies measured the temperature at one location or within one region but ignored the changes of the temperature distribution over time [10, 11]. The skin temperature changes around nose were found during breathing cycles [9]. When using protective equipment for a long period of time, it is important to know how the distribution or pattern of temperature changed with time and their relationship to discomfort.

Verbal communication is a normal working requirement for many careers including those in the medical field and education. Medical personnel need to speak with patients or colleagues while wearing facemasks. Teachers need to lecture and have discussions with their students for several hours throughout the day within their classrooms. When people are breathing and speaking, hot and humid air is released from the nose and the mouth changing the micro-environment inside the facemask. Researchers have found that more exhaled air is produced from the mouth than the nose while reading a passage [13]. A previous study showed that the temperatures of inhaled and exhaled air and exhaled water for mouth breathing were significantly higher than nose breathing [14]. It can be expected that the temperature will be different when the subject remains silent with normal nasal breathing compared to a situation where the person is speaking while wearing a facemask. However, few studies have focused on this issue.

In this study, the time dependent changes of facial temperature distribution with the surgical mask and the N95 mask were evaluated under the different communication output situations of breathing and continuous talking to better understand the ergonomic issues that may arise from a long term use. Both the N95 and surgical masks were chosen for this study based on the prevalence of use by the general populace in Hong Kong. The results in this study can be used towards designing better facemasks which can maintain the filtering level but release the heat and humidity in the nose and mouth areas more efficiently for the comfort of the user. This would increase the effectiveness of wearing facemasks which are often misused because of discomfort.

2. Methods

2.1. Participants

Ten Chinese participants between the ages of 20 and 57, with an average age of 32, were recruited to participate in this experiment. Five participants were male and five were female. All participants reported no injuries or past surgical procedures on their faces and heads.

2.2. Equipment

The experiment was conducted in a laboratory environment. The experiment utilized a FLIR E33 Infrared Camera (FLIR USA), a Thermoval duo scan thermometer (Hartmann Germany), 3M N95 masks (3M Korea Ltd.), and surgical masks (US Secure Co. Ltd.). The video recording function of the infrared camera was used to record the temperature distribution changes during the entire experiment.

2.3. Experimental design

The approach utilized was a full factorial within-subject experiment (facemask types*verbal output). The facemask types employed in the experiment were the N95 mask and the surgical mask. The two types of verbal output requested from each participant were sitting completely silent and reading aloud from a textbook using their own comfortable speaking rate. Six conditions were identified for the experiment, each lasting for five minutes. The six conditions were as follows: (1) sitting silently with no mask; (2) sitting silently with a surgical mask on; (3) sitting silently with a N95 mask on; (4) reading aloud with no mask; (5) reading aloud with a surgical mask on; and (6) reading aloud with a N95 mask on.

The dependent variables for this experiment were thermal images of facial temperature during the five minutes and the participant's perceptions related to the four categories of subjective feelings on 'Humid', 'Hot', 'Difficult to breathe', and 'Overall discomfort' related to the six conditions. Facial temperatures were video recorded with the infrared camera. Perceptions were gathered using an 11-point Likert scale where 0 indicated that the perceived levels were "not at all noticed" and 10 indicated that the perceived levels were "strongly noticed".

The order of all conditions was randomized prior to the selection of participants. The temperature of the room was around 23° Celsius and relative humidity was around 30%.

2.4. Procedure

Participants were briefed on the experimental procedure and then they signed a consent form. The researcher then recorded the participants' height and weight. Participants were taught how to wear the surgical mask and the N95 mask correctly [15]. After, participants were requested to rest silently for more than thirty minutes. During the resting time, participants' facial temperature was monitored using a digital thermometer on both cheeks and on the forehead between the eyebrows until their core temperature and face temperature were stable. After thirty minutes the core temperature of the participant was recorded. A thermal image of the participants' faces was then captured to identify the base temperatures for later comparison.

The participants were then instructed to sit in a chair facing the FLIR E33 Infrared Camera and the experiment proceeded through the conditions. Before beginning each condition, facial temperatures were taken with a digital thermometer in order to maintain the base temperature on the face. After each condition, a five-minute period of resting silently without a mask was completed. Between each of the six conditions and the rest period, the perception questionnaire was given to the participants. Each condition and rest period was video recorded with a thermal imaging camera to note the changes in facial temperature over time and the way the masks distributed heat across the face.

2.5. Data Analysis

The video from the infrared camera recorded the facial temperature distribution changes with time for 5 minutes during all of the conditions. Recording continued to capture the facial temperature distribution for 5 more minutes after participants removed the facemasks in order to measure the effects of conditions. The video frequency was 30 frames per second. The videos were converted to infrared images in order to measure the temperatures. A custom software program written in MathWorks' Matlab was used to process the IR images. Figure 1 shows an example of original infrared image data. We can see that facemasks caused obvious temperature changes in the lower facial area. The temperature distribution was related to different facemask types.

Insert Fig. 1 here

Since the original data had different temperature colour scales and participants had different face sizes, alignments of temperature scales and face size were conducted for all participants before further data processing. Firstly, the colour coding of all images was processed to be consistent for all image data (Figure 2). Secondly, the unnecessary image data was removed and the face sizes were scaled to be same for every participant.

Insert Fig. 2 here

The average temperature changes with time in the forehead, cheeks, and nose and mouth (nose/mouth) regions on the face were selected to be analyzed. The size of the forehead and nose/mouth regions was a square area with 3*3 cm^2 separately (Figure 2). The size of cheeks region included two 3*3 cm^2 regions for the left and right cheeks. The temperatures of the cheeks were calculated by the average temperatures of the right and the left cheeks.

3. Results

3.1. Temperature distribution changes with time

The plots of the temperature changes with time in the three regions showed that the forehead temperature did not change much in all experimental conditions and the 5 minutes resting time (Figure 3). However, the temperatures in the cheeks and nose/mouth regions varied depending on time and the different conditions. When participants did not put on any facemask, the temperatures were stable, no matter silent or speaking. When participants wore the facemasks for 5 minutes, the temperatures in the cheeks and nose/mouth regions increased; this was especially noticeable during the speaking conditions. After 5 minutes rest, the temperatures dropped back to the original steady state temperature.

Insert Fig. 3 here

Further statistical analyses studied temperature changes at 4 time points in order to compare the different conditions. The chosen 4 time points were the first image of each experimental condition including no facemask, just wearing the surgical mask or the N95 mask (time point 1); the last image of each experimental condition including no facemask, wearing the surgical facemask or the N95 mask for 5 minutes already (time point 2); the first image right after removing facemask if applied (time point 3); the last image of resting for 5 minutes already (time point 4). The average face temperatures within the selected regions were calculated for time point 1 (forehead_1, cheeks_1, nose_1), time point 2 (forehead_2, cheeks_2, nose_2), time point 3 (forehead_3, cheeks_3, nose_3) and time point 4 (forehead_4, cheeks_4, nose_4).

In order to compare temperature change for experimental time (first 5 minutes) and resting time (last 5 minutes) in the selected regions, changes in temperature between time points 1 and 2 (forehead_2-1, cheeks_2-1, nose_2-1), were calculated using subtraction between forehead_2 and forehead_1, subtraction between cheeks_2 and cheeks_1, and subtraction between nose_2 and nose_1 respectively. Changes in temperature between time points 3 and 4 (forehead_4-3, cheeks_4-3, nose_4-3) were calculated using the same method.

Two-way ANOVA analyses were conducted by facemask type and verbal output on the temperatures of each region (Table 1). For the forehead region, both facemask type and verbal output did not have significant effect on the average temperature at all 4 time points. At the time point 1, facemask type had significant effects on the cheeks (cheeks_1) and nose/mouth (nose_1) temperatures (Figure 4). Further Turkey Post Hoc test showed that the difference was between without and with facemasks. Since facemasks had covered the infrared radiation of cheeks and mouth, the temperatures had dropped significantly. At the time point 2, facemask types still had significant effect on the cheeks (cheeks_2) and nose/mouth (nose_2) temperatures (Figure 4). Further Turkey Post Hoc test showed that there was no difference between the surgical mask and the N95 mask for cheeks_2 but there were significant differences among no mask, the surgical mask and the N95 mask for nose_2. The N95 mask had a lower temperature in the nose/mouth region compared to the surgical mask after talking for 5 minutes.

At the time right after removing the facemasks (time point 3), facemask types had significant effects on the temperatures in the cheeks (marginal, $p=0.052$) and the nose/mouth regions ($p=0.045$). Further Turkey Post Hoc test demonstrated that there was significant difference between no mask and the N95 mask for cheeks_3. No mask had lowest temperature (mean=33.933 °C; SD=0.762 °C), the N95 mask had highest temperature (mean=34.5 °C; SD=0.598 °C), and the temperature for the surgical mask was in the middle (mean=34.2 °C; SD=0.775 °C). For nose_3, similar results were found. Significant difference was found between no mask and the N95 mask. For the nose/mouth region, no mask had lowest temperature (mean=33.8 °C; SD=1.457 °C), the N95 mask had highest temperature (mean=34.7 °C; SD=0.762 °C), and the temperature for the surgical mask was in the middle (mean=34.2 °C; SD=0.911 °C). At the end of the 5 minutes resting time, facemask types and verbal output both had no significant effects on the temperatures.

In general, results showed that forehead temperature was stable with and without facemasks. However, face regions which were covered by facemasks including the cheeks and nose/mouth regions had significantly increased temperatures after wearing masks for 5 minutes, especially the N95 mask. The N95 mask created the highest facial temperature in the cheeks and nose/mouth regions. Surprisingly, the speaking condition did not cause significant temperature increase compared to the silent condition. After 5 minutes rest, the facial temperatures in the cheeks and the nose/mouth regions were reduced and had no significant difference to the silent and no mask conditions.

Insert Table 1 here

Insert Fig. 4 here

In addition, two-way ANOVA analyses were conducted by facemask type and verbal output on the change in temperatures of each region (Table 2). For the forehead region, both facemask type and verbal output did not have significant effect on the change in temperature for both experimental time and resting time. At the experimental time, verbal output had significant difference on the cheeks (cheeks_2-1) and facemask type had significant effects on nose/mouth (nose_2-1) temperature changes (Figure 5). Further Turkey Post Hoc test showed that the difference was between surgical mask and N95 masks. At the resting time, facemask types had significant effect on the temperature changes in cheeks (cheeks_4-3) and nose/mouth (nose_4-3) regions (Figure 5). Further Turkey Post Hoc test showed that the difference was between no mask and N95 mask for cheeks_4-3 and nose_4-3.

Insert Table 2 here

Insert Fig. 5 here

T-tests were performed to compare the gender differences for all temperature measurements. Results showed that there were significant differences between male and female in the cheeks and the nose/mouth regions during resting time (time point 3 and 4) (Table 3). Female participants had significantly lower temperature than males in the lower face regions.

Insert Table 3 here

3.2. Subjective perceptions

A two-way ANOVA by facemasks and verbal output was conducted on the participants' perception rating related to the humidity, heat, breathing difficulty and overall discomfort. Results showed that both facemask types and verbal output had significant effects on participants' perceptions (Table 4). The average perception ratings are plotted in Figure 6. Participants felt that the N95 mask caused significantly more thermal discomfort than the surgical mask, and the surgical mask caused more thermal discomfort compared to the no facemask situation. Speaking introduced a higher rating compared to the silent condition in all the subjective perceptions.

Insert Table 4 here

Insert Fig. 6 here

An independent sample T-Test was conducted on gender for all the four perception ratings. However, results did not show any significant differences between the male and female participants.

4. Discussion

Facemasks are widely used in hospitals as well as in everyday settings during respiratory infections. Many people are wearing them for long periods of time during the day. However, since facemasks cover the entire lower facial area, especially the nose/mouth region, thermal discomfort and breathing difficulty could be an issue for some facemasks with multiple layers of filters, especially in the hot and humid weather of Hong Kong. In order to have a good filtering function for small particles, the textile of the N95 mask is thick with multiple layers and the fit is relatively tight. Compared to the N95 mask, the surgical mask is designed to be simple having fewer layers of filters, softer textile material and has a looser fit on the face. Therefore, the N95 mask was expected to have highest temperature increases and thermal discomfort.

The temperatures in different facial regions demonstrated various trends with time under different experimental conditions. In general, temperatures for the no mask condition were stable during the 5 minutes experimental time and the 5 minutes resting time. The no mask condition was utilized as a control condition in order to compare the surgical mask and the N95 mask conditions. After putting on the facemasks, the temperatures in the forehead region remained stable but the temperatures in the cheeks and the nose/mouth regions started to increase, especially for the N95 mask. Right after removing the facemask, there was a high temperature area surrounding the lower face area which was obviously similar to the facemask's coverage. The temperatures in the cheeks and nose/mouth regions then started to drop to normal steady state temperature during the 5 minutes resting time. This showed that facemasks could change the temperature distribution within a short period of time.

Further statistical analyses at the four time points showed that facemask type had significant effects on the temperatures in the cheeks and the nose/mouth regions. At the time points 1 and 2, the temperatures in the cheeks and the nose/mouth regions for surgical mask and N95 mask were much lower than the no mask condition. This was due to the coverage of the infrared radiation of cheeks and mouth by the masks. The temperature in the nose/mouth region for the N95 mask was significantly lower than the surgical mask after wearing the facemasks for 5 minutes (time point 2). Because the N95 mask had a tighter fit and thicker material, exhaled hot and humid air around nose/mouth region would not easily go through the coverage of N95 mask. However, the hot air could go through the thin material of the surgical mask, which created the change in temperatures between time points 1 and 2 in nose/mouth region. Furthermore, the change in temperatures between time points 1 and 2 in cheeks region demonstrated difference in verbal output. It proved that speaking condition created more heat and hot air release at cheeks region with the movement of the face. During resting time, the N95 mask demonstrated significantly higher temperature than the no mask condition in cheeks and nose/mouth regions just after removing the facemasks (time point 3). After 5 minute resting (time point 4), the temperatures did not show any significant differences in different conditions. These results were consistent with previous studies [5, 6]. It also demonstrated that the changes in temperatures between time points 3 and 4 in cheeks and nose/mouth regions for the N95 mask were larger comparing to the no mask condition, and the temperatures dropped fast to the same level eventually within 5 minutes. The temperatures in the forehead region did not change significantly during experiment. It showed that facemasks blocked the inhaled-and-exhaled air flow and created a micro-climate environment inside the facemasks. Participants also felt higher temperature, humidity, breathing difficulty and overall discomfort, which is also supported by literature [5].

This study only required participants to wear facemasks for 5 minutes. Participants all felt high thermal discomfort while wearing facemasks, especially the N95 mask. However, in real life, the wearing time can be much longer for health personnel or even the normal person. Patients including children and elderly are often required to wear facemasks in hospitals to avoid infection. In this study, normal healthy adults already felt a certain level of difficulty when breathing for just 5 minutes, children and elderly who are ill can be expected to have an even higher breathing difficulty and feeling of discomfort. In order to breathe easily, it is common for people to place facemasks below the nose and only cover the mouth. However, this kind of misuse reduces the effectiveness of the facemask. A better design of facemasks should be created to maintain the filtering level but release the heat and humidity in the nose and mouth areas more efficiently.

Even though participants felt significant differences in subjective perceptions of thermal discomfort between the silent and the speaking conditions, the temperature measured from the infrared images did not show any significant differences. One of the reasons could be that the movements of the mouth muscles had released some heat during talking. With similar temperatures for silent and speaking conditions, participants still felt hotter and more discomfort in the speaking condition. This could be caused by the higher humidity levels when speaking [14]. For the same temperature, higher humidity could result in higher thermal sensation or hotter feeling [4, 16]. Further study has to be conducted on relative humidity differences for the silent and different speaking conditions.

In this study, controlled room temperature and relative humidity were simulating the normal office or hospital environment. For outdoor environment of a sub-tropical climate in Hong Kong, the relative humidity and the temperature are normally higher than 70% and 15° Celsius during whole year based on information gathered from the Hong Kong Observatory. The facemasks were more uncomfortable to wear for a long duration in high humidity. Different environments such as those with higher temperature and relative humidity should be tested in future studies.

5. Conclusion

In this study, both the surgical mask and the N95 mask were evaluated and compared to a situation in which no facemask was worn. In addition to facemask type, verbal output was another factor that was tested in order to investigate the differences between silent and speaking conditions. A within-subject full factorial design was applied. Infrared technology was used to monitor the changes of surface temperature distribution with time. The average temperatures of the forehead, cheeks and nose/mouth regions were calculated. Participants' perception ratings in terms of humidity, heat, difficulty of breathing and overall discomfort were also collected for each experimental condition.

This study has demonstrated that wearing facemasks could cause significant temperature distribution changes with time, especially in the lower facial region. Different facemask types had different levels of temperature changes in the cheeks and the nose/mouth regions. The N95 mask caused highest facial temperatures after removing the facemasks. In addition, participants felt higher levels of humidity, heat, breathing difficulty and overall discomfort for the conditions in which they wore an actual mask. The N95 mask gave highest discomfort perception rating in all the subjective feeling questions.

Verbal output did not have a significant temperature effect for all the conditions, although participants did report feeling much higher humidity, heat, breathing difficulty and overall discomfort while speaking.

Males and females had significant temperature differences in the cheeks and nose/mouth regions at the beginning and end of 5 minutes resting time (time point 3 and 4). Females had lower temperatures than male. For subjective perception, there were no significant gender differences.

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Table captions

Table 1. The two-way ANOVA results on temperatures of selected regions.

Table 2. The two-way ANOVA results on change in temperatures of selected regions.

Table 3. Significant gender differences of the temperatures

Table 4. The two-way ANOVA results on subjective perceptions.

Tables

Table 1. The two-way ANOVA results on temperatures of selected regions.

Temperature	Factors	df	F	P value
Forehead_1	Facemask type	2	0.921	0.404
	Verbal output	1	0.285	0.596
	Facemask type* verbal output	2	0.077	0.926
Cheeks_1	Facemask type	2	338.509	0.000*
	Verbal output	1	0.113	0.738
	Facemask type* verbal output	2	0.202	0.818
Nose_1	Facemask type	2	291.892	0.000*
	Verbal output	1	0.000	0.997
	Facemask type* verbal output	2	0.955	0.391
Forehead_2	Facemask type	2	0.556	0.577
	Verbal output	1	1.498	0.226
	Facemask type* verbal output	2	0.174	0.841
Cheeks_2	Facemask type	2	183.834	0.000*
	Verbal output	1	3.364	0.072**
	Facemask type* verbal output	2	2.122	0.130
Nose_2	Facemask type	2	243.998	0.000*
	Verbal output	1	0.929	0.339
	Facemask type* verbal output	2	0.526	0.594

Table 1. The two-way ANOVA results on temperatures of selected regions (continued).

Temperature	Factors	df	F	P value
Forehead_3	Facemask type	2	0.603	0.551
	Verbal output	1	0.899	0.347
	Facemask type* verbal output	2	0.128	0.880
Cheeks_3	Facemask type	2	3.124	0.052**
	Verbal output	1	0.127	0.723
	Facemask type* verbal output	2	0.025	0.975
Nose_3	Facemask type	2	3.277	0.045*
	Verbal output	1	0.010	0.919
	Facemask type* verbal output	2	0.078	0.925
Forehead_4	Facemask type	2	0.407	0.668
	Verbal output	1	1.193	0.280
	Facemask type* verbal output	2	0.039	0.961
Cheeks_4	Facemask type	2	0.189	0.828
	Verbal output	1	0.057	0.813
	Facemask type* verbal output	2	0.269	0.765
Nose_4	Facemask type	2	0.025	0.975
	Verbal output	1	1.012	0.319
	Facemask type* verbal output	2	0.209	0.812

Note: $p<0.05$*, $p<0.1$**

Table 2. The two-way ANOVA results on change in temperatures of selected regions.

Temperature	Factors	df	F	P value
Forehead_2-1	Facemask type	2	0.261	0.771
	Verbal output	1	1.668	0.202
	Facemask type* verbal output	2	0.101	0.904
Cheeks_2-1	Facemask type	2	2.313	0.109
	Verbal output	1	5.094	0.028*
	Facemask type* verbal output	2	2.756	0.073**
Nose_2-1	Facemask type	2	3.346	0.043*
	Verbal output	1	1.844	0.180
	Facemask type* verbal output	2	0.552	0.579
Forehead_4-3	Facemask type	2	0.343	0.711
	Verbal output	1	0.450	0.505
	Facemask type* verbal output	2	0.037	0.964
Cheeks_4-3	Facemask type	2	8.718	0.001*
	Verbal output	1	1.598	0.212
	Facemask type* verbal output	2	1.987	0.147
Nose_4-3	Facemask type	2	8.713	0.001*
	Verbal output	1	3.031	0.087**
	Facemask type* verbal output	2	1.519	0.228

Note: $p<0.05$*, $p<0.1$**

Table 3. Significant gender differences of the temperatures

Temperature	Gender	Mean	SD	df	t	P value
Nose_3	Male	34.656	0.681	58	3.189	0.002*
	Female	33.790	1.321			
Cheeks_4	Male	34.172	0.614	58	2.012	0.049*
	Female	33.793	0.830			
Nose_4	Male	34.421	0.955	58	3.639	0.001*
	Female	33.350	1.299			

Note: only showed $p<0.05$*

Table 4. The two-way ANOVA results on subjective perceptions.

Subjective perceptions	Factors	df	F	P value
Humidity	Facemask type	2	54.940	0.000*
	Verbal output	1	4.727	0.034*
	Facemask type* verbal output	2	0.253	0.777
Heat	Facemask type	2	79.215	0.000*
	Verbal output	1	5.294	0.025*
	Facemask type* verbal output	2	1.116	0.335
Breathing difficulty	Facemask type	2	71.762	0.000*
	Verbal output	1	6.658	0.013*
	Facemask type* verbal output	2	1.669	0.198
Overall discomfort	Facemask type	2	114.903	0.000*
	Verbal output	1	18.556	0.000*
	Facemask type* verbal output	2	3.640	0.033*

Note: $p<0.05$*

Figure captions

Fig. 1. An example of facial temperature distribution from infrared thermography data during each condition

Fig 2. Alignment of temperature colour scale, face size and selection of regions

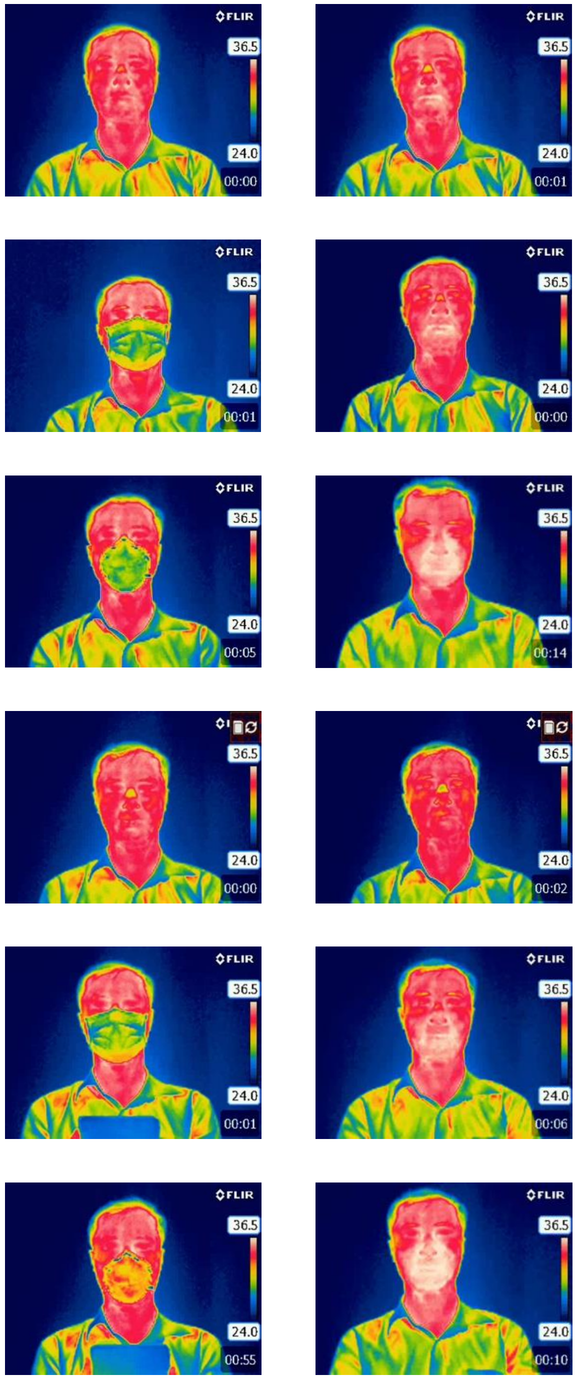
Fig. 3. Changes of temperature measurements with time from the average of all participants (Red is forehead region; green is cheeks region; blue is mouth region)

Fig. 4. Effects of facemask type and verbal output on temperatures of selected regions

Fig. 5. Effects of facemask type and verbal output on change in temperatures of selected regions

Fig. 6. Effects of facemask type and verbal output on subjective perceptions

Figures



Condition 1

Condition 2

Condition 3

Condition 4

Condition 5

Condition 6

(a) During experimental condition (b) During resting time

Fig. 1. An example of facial temperature distribution from infrared thermography data during each condition

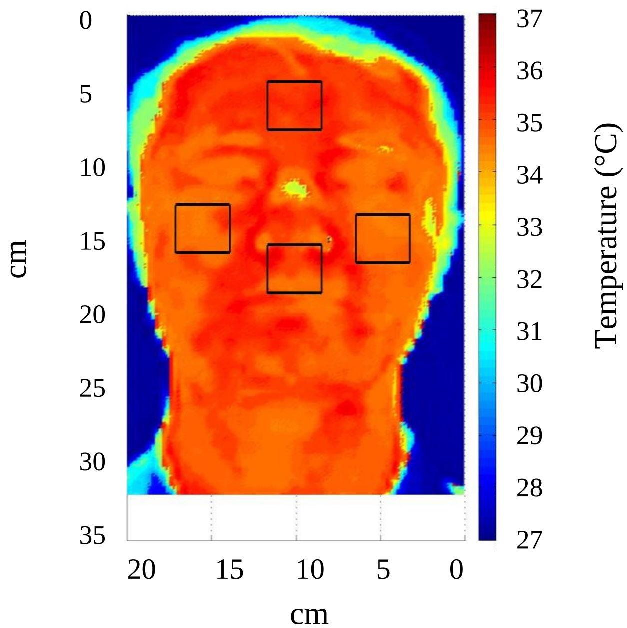
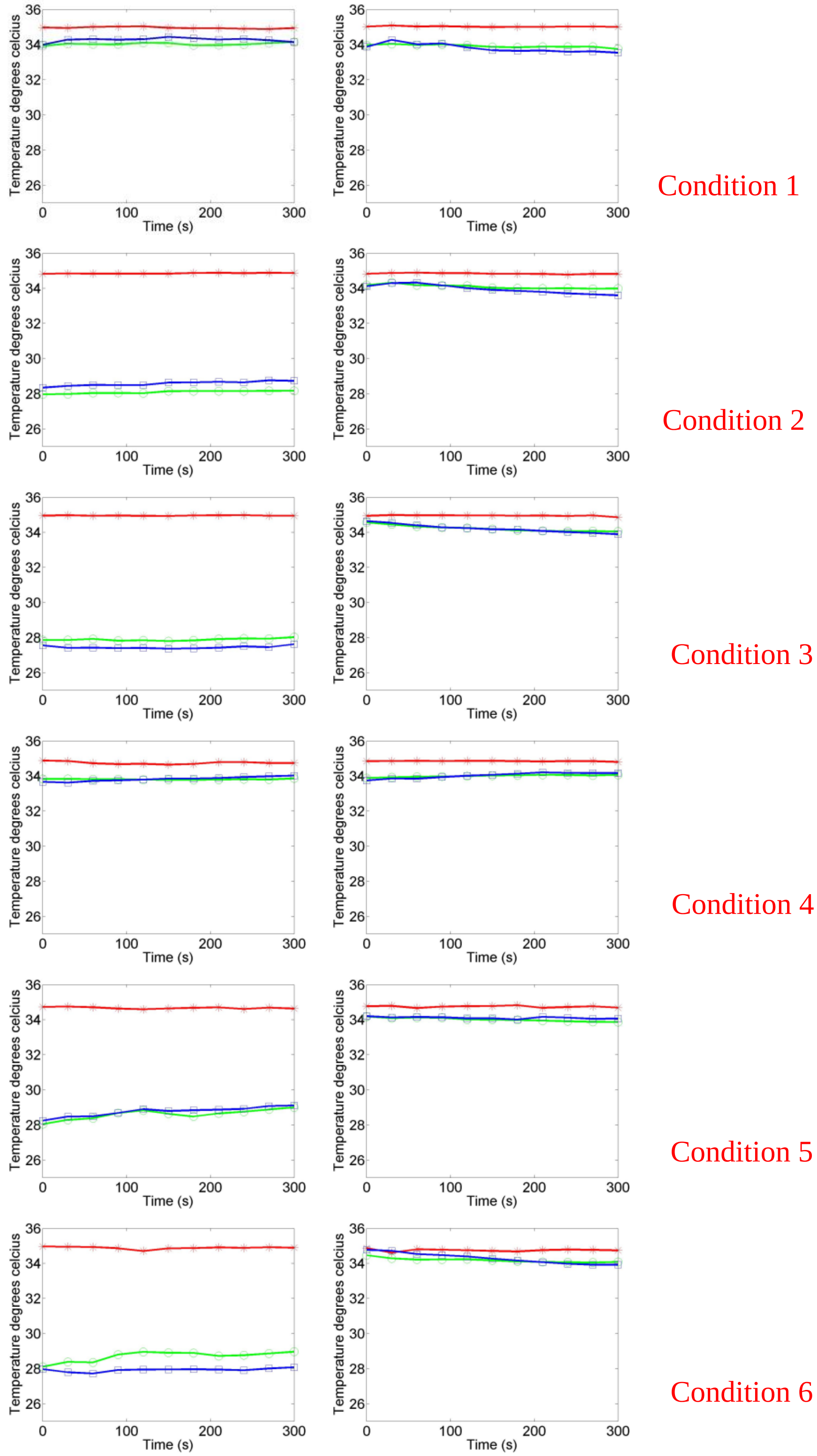


Fig 2. Alignment of temperature colour scale, face size and selection of regions



(a) During experimental condition (b) During resting time

Fig. 3. Changes of temperature measurements with time from the average of all participants (Red is forehead region; green is cheeks region; blue is mouth region)

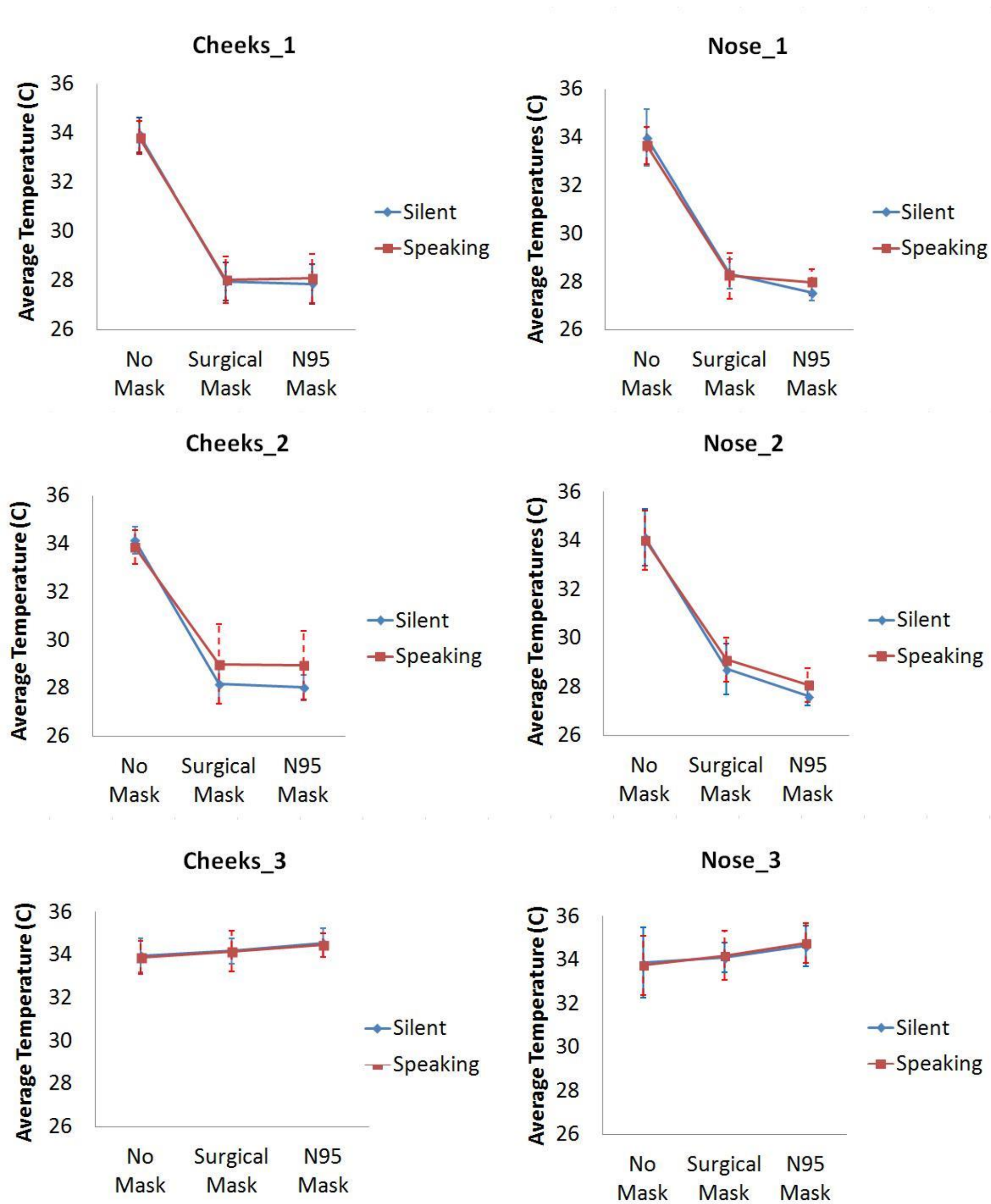


Fig. 4. Effects of facemask type and verbal output on temperatures of selected regions

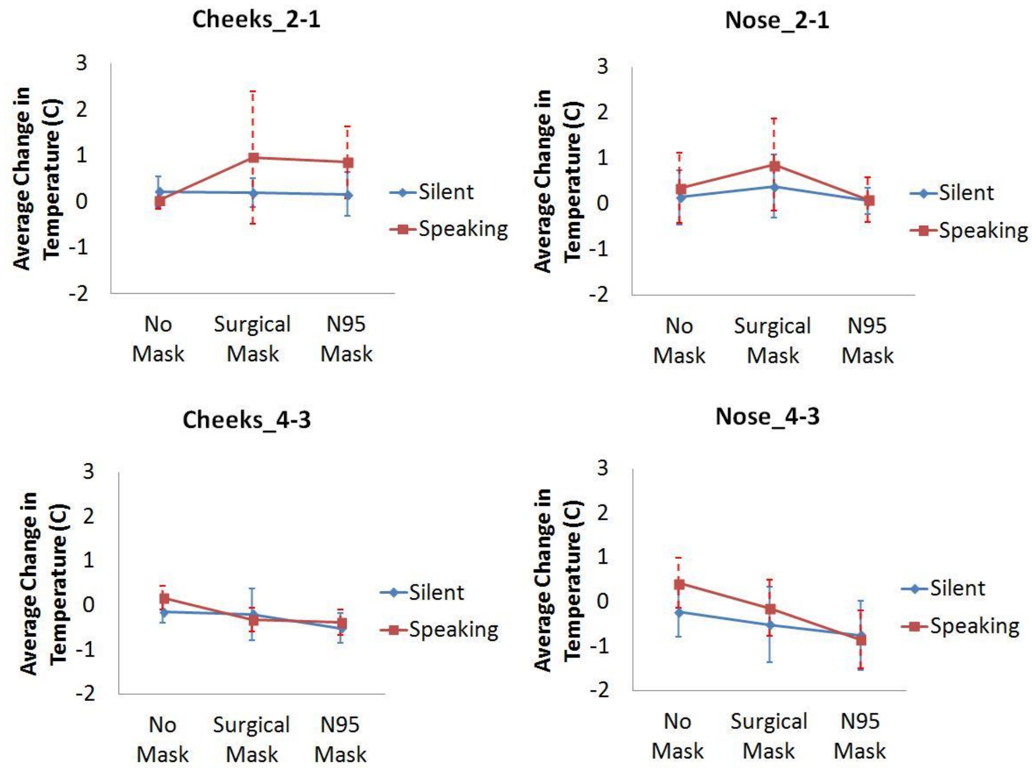


Fig. 5. Effects of facemask type and verbal output on change in temperatures of selected regions

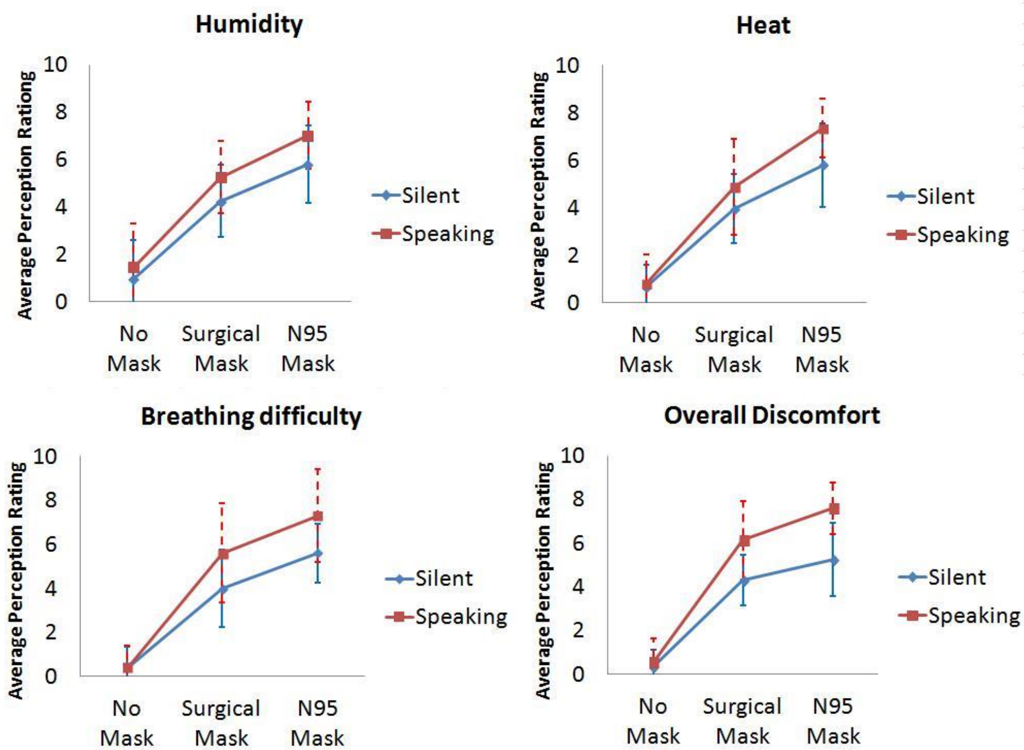


Fig. 6. Effects of facemask type and verbal output on subjective perceptions