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Surgical masks do not increase the risk of heat stroke during mild exercise in hot and humid environment

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Abstract: Surgical masks are widely used for the prevention of respiratory infections. However, the risk of heat stroke during intense work or exercise in hot and humid environment is a concern. This study aimed to examine whether wearing a surgical mask increases the risk of heat stroke during mild exercise in such environment. Twelve participants conducted treadmill exercise for 30 min at 6 km/h, with 5% slope, 35°C ambient temperature, and 65% relative humidity, while wearing or not a surgical mask (mask and control trials, respectively). Rectal temperature (T_{rec}), ear canal temperature (T_{ear}), and mean skin temperature (mean T_{skin}) were assessed. Skin temperature and humidity of the perioral area of the face (T_{face} and RH_{face}) were also estimated. Thermal sensation and discomfort, sensation of humidity, fatigue, and thirst were rated using the visual analogue scale. T_{rec}, T_{ear}, mean T_{skin}, and T_{face} increased during the exercise, without any difference between the two trials. RH_{face} during the exercise was greater in the mask trial. Hot sensation was greater in the mask trial, but no influence on fatigue and thirst was found. These results suggest that wearing a surgical mask does not increase the risk of heat stroke during mild exercise in moist heat.

Key words: Core body temperature, Skin temperature, Hyperthermia, Respiration, Evaporative heat loss, Heat load, Fatigue, Respiratory resistance

Introduction

Face masks have been used for various purposes. In some work environments, masks must be worn for protection from harmful substances, such as gas and dust, in industrial fields[1)] or infectious substances, such as bacteria and virus, in medical fields[2)]. However, because of the recent increase in the risk of viral infections (e.g., influenza, SARDS, MARDS, and COVID-19), wearing masks seem to become a lifestyle-choice among common people. Leung *et al.* reported[3)] that surgical masks reduce the transmission of human COVID-19 and influenza viruses. In addition, the importance of surgical masks in preventing respiratory infections from spreading in the entire community was suggested[4)]. Surgical masks are basically meant for health care workers; however, this evidence may facilitate the use of surgical masks among common people.

In 2020, the Ministry of Environment and the Ministry of Health, Labor and Welfare in Japan announced the risk of heat stroke due to the wearing of hygiene masks during intense work or exercise in a hot and humid condition, and

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encouraged taking off masks in such condition[5]. However, the mechanism for the risk of heat stroke has not been identified. Moreover, it remains unclear whether mild intensity work and/or exercise could bear such risk. One possible mechanism underlying the risk of heat stroke may be increased respiratory resistance, which augments the work of respiratory muscles and the oxygen demand. Wearing a mask may also increase respiratory dead space, thereby increasing the inspiratory CO_2 level. One report showed no clear effect of surgical masks on cardiopulmonary functions during vigorous exercise[6]; however, Fikenzer *et al.* suggested an increase in respiratory resistance[7]. Other possible mechanisms may be changes in the thermal and humidity environment of the upper airway[8], which suppress dry and evaporative heat loss. In addition, the changes may also affect thirst and subsequent drinking behavior, resulting in the risk of heat stroke. However, we do not know if wearing a surgical mask alters the local environment of the upper airway and affect heat dissipation and thirst during mild exercise.

When evaluating the influence of wearing a mask on exercise, thermal and humid sensations of the face should be considered. Scarano *et al.*[8] reported increases in facial temperature and humidity with breathlessness, and discomfort when subjects wore N95 masks. It was reported that the face is more sensitive to heat than other body sites[9]. Armada-da-Silva, Woods, & Jones[10] showed that fatigue increases with facial skin temperature. Therefore, we may have misinterpreted the augmented hot sensation and/or fatigue for the risk of heat stroke.

The aim of the present study was to test the hypotheses that i) the risk of heat stroke is increased by wearing a surgical mask during mild exercise in a hot and humid condition, and ii) wearing a surgical mask augments thermal sensation and fatigue during mild exercise. Moreover, we aimed to clarify the mechanisms for the possible risk of heat stroke. Participants conducted treadmill exercise of mild intensity for 30 min a hot (ambient temperature (T_a) of 35°C) and humid (65% relative humidity (RH)) condition, while wearing or not wearing a surgical mask. We also measured the temperature and humidity under the mask and assessed the physiological and psychological responses during the exercise.

Subjects and Methods

Participants

Twelve healthy volunteers (8 males and 4 females; age, 23 ± 3 years; height, 170 ± 6 cm; and body weight, 63.61 ± 10.53 kg, mean ± standard deviation [SD]) participated in the present study. They were non-smokers and had no clinical history of cardiovascular, metabolic, or respiratory diseases, and were not involved in exercise training. Participants were instructed to refrain from heavy exercise and consumption of high-protein diet, alcohol, and caffeine from one day before the experiment. The experimental protocol was approved by the Ethical Committee of Human Research, Waseda University (2020-098) and was conducted in accordance with the Declaration of Helsinki (1983). Participants provided written informed consent before the start of the experiments.

Experimental protocol

The experiment consisted of two trials, which were separated by at least a two-day interval and finished within a month. In both trials, participants conducted the same treadmill exercise. However, participants wore a mask in one trial and no mask in the other (mask and control trials, respectively). On the day of each trial, participants had two rice balls (420 kcal) with >500 mL of water 3 h before the exercise. In each trial, they arrived at the laboratory, and rested on a chair for 30 min while drinking 300 mL of water. After emptying the bladder, their nude body weight was measured (DP-7900PS-S, Yamato Scale, Akashi, Japan). They changed to a T-shirt, short pants, athletic shoes and ankle-length socks. Participants rested for another 30 min in an environmental chamber (Espec, Osaka, Japan) maintained at T_a of 35°C and RH of 65% with ventilating wind speed of 0.3 m/s. The wet bulb globe temperature (WBGT)[11] was continuously monitored with WBGT thermometer fixed at a height of 1.5 m above the floor, which ranged from 30.0–32.1°C (30.9°C in average, HI-2000SD, Custom, Tokyo, Japan). The setting was chosen to mimic the environmental condition of daytime in middle summer (August) in Tokyo, Japan[12], during which a number of people suffer from heat stroke[13]. Heart rates (HR) were monitored by electrocardiography (BSM-2401, Nihon Koden, Tokyo, Japan). Rectal temperature (T_{rec}) was measured with a thermistor probe (401J, Nikkisho-Thermo, Musashino, Japan) placed 13 cm from the anus, and recorded every 30 s with a data-logger (N543, Nikkisho-Thermo, Musashino, Japan). Ear canal temperature (T_{ear}) was assessed using the infrared sensor placed in the ear canal (Vit Thermo VTB-01, Vitarate, Tokyo, Japan). The ear was covered with a medical film (Tegaderm, 3M company, Saint Paul, USA) to keep the stable position of the sensor in the ear canal and avoid cooling of the sensor by the ventilating wind. Temperature and relative humidity at the perioral area of the face (T_{face} and RH_{face}, respectively), anterior chest, and lateral planes of the upper arm, thigh, and lower leg were measured with a temperature/humidity logger (DS1923 iButton Hydrochron, Maxim Integrated, San Jose, USA) every 30 s. The temperature/humidity loggers were placed on the skin. The temperature sensor was located at the bottom the logger, measuring the skin surface temperature. The humidity sensor was located at the top of the logger, estimating the air humidity ca. 1 cm above the skin surface.

Participants moved on a treadmill (TRM731, Precor, Woodonville, USA) and stood still for 10 min, during which baseline data were obtained. Before the start of the baseline measurement, participants wore a surgical mask in the mask trial. The surgical mask had a size of 175 x 95 mm and was made of three layers of non-woven polypropylene fabric (Level 3 of ASTM-F2100-11, respiratory resistance of <6 mmH_2O/cm^2, Maruoh, Fuji, Japan). The mask was placed such that the gap between the mask and the face was reduced and the temperature/humidity logger was covered. The participants ran on the treadmill for 30 min at a speed of 6 km/h and a slope of 5% at T_a of 35°C and 65% RH. The exercise intensity corresponded to light jogging level or moderate manual labor (4.5 metabolic equivalents)[14]. The slope was adopted to lessen the variation of relative exercise intensity among participants due to changes in the step length and frequency[15]. Participants rested for 1 min after running for 10 and 20 min. During the resting periods, participants reported their psychological responses as described below. Participants' nude body weight was measured at the end of the experiment. The reduction of the body weight was estimated as the water loss during the exercise, which originated from sweating and respiration.

Participants rated their thermal sensation, thermal discomfort, and humid sensation of the face and whole body, physical fatigue, and thirst sensation separately by drawing a cross line on a visual analogue scale (VAS). The rating was conducted before the running and at 10, 20, 30 min. The scale had a 150 mm length, on which "nothing at all" was labelled 25 mm from the left and "extreme that I have ever had" was labelled 25 mm from the right.

Statistical analysis

The sample size was determined using G*Power 3.1.9.7[16]. For the assessment of physiological variables, an effect size f of 0.25, α error probability of 0.05, number of groups 2, and power of 0.8 were determined, and a sample size of 9 was estimated. For the assessment of psychological variables, an effect size f of 0.25, α error probability of 0.05, number of groups 2, and power of 0.8 were determined, and a sample size of 12 was estimated. We estimated that the required number of participants was more than 12 in each trial in the present study. The assessment was conducted, based on the results from previous studies about physiological and psychological responses to exercise in heat[17].

Mean skin temperature (mean T_{skin}) was calculated using the Ramanathan's formula[18]: 0.3•(skin temperature at the chest + that at arm) + 0.2•(that at the thigh + that at the leg). The data during the one-min resting periods were excluded and averaged every 5 min. Body weight before and after the exercise was compared using the paired t-test. Differences in HR, T_{rec}, T_{face}, and RH_{face} between two trials were evaluated by two-way analysis of variance for repeated measurement. The normality of the data was verified by Kolmogorov–Smirnov test, and the homogeneity of variance was clarified by Levene's test. A post-hoc test was conducted by the Bonferroni method. The comparison of thermal sensation, thermal discomfort, and humid sensation of the face and whole body, physical fatigue and thirst sensation in the baseline period and during exercise between two trials was conducted by Friedman's test. Wilcoxon signed-lank-test was conducted as the post-hoc test. The null hypothesis was rejected at $p<0.05$. R was used for the all statistical analyses[19]. Data are presented as means ± SD.

Results

In both control and mask trials, the body weight at the end of the exercise did not change from that before the exercise (control trial; p=0.917, 63.5 ± 11.0 and 63.0 ± 10.9 kg; and mask trial; p=0.927, 63.5 ± 10.7 and 63.1 ± 10.7 kg before and after the exercise, respectively). Baseline HR, T_{rec}, and T_{ear} were 89 ± 15 beats/min, 37.1 ± 0.4°C, and 37.3 ± 0.3°C for the control trial and 91 ± 15 beats/min, 37.1 ± 0.4°C, and 37.3 ± 0.3°C for the mask trial, respectively.

Fig. 1 illustrates HR in the control and mask trials. HR continued to increase during the exercise ($F_{(1, 6)}$=71.11, p<0.001, 169 ± 15 and 171 ± 14 beats/min at 30 min in the control and mask trials, respectively); however, no significant difference was observed between the two trials.

T_{rec}, T_{ear}, and mean T_{skin} in the control and mask trials are shown in Figs. 2A, B, and C, respectively). T_{rec} increased at 25–30 min in both trials ($F_{(1, 6)}$=13.58, p<0.05; 38.0 ± 0.5 and 38.1 ± 0.4ºC at 30 min, respectively); however, there were no significant differences between the two trials. T_{ear} increased at 20–30 min in the two trials ($F_{(1, 6)}$=34.89, p<0.05; 38.5 ± 0.4 and 38.4 ± 0.3ºC at 30 min, respectively) without any significant difference. Mean T_{skin} in the control

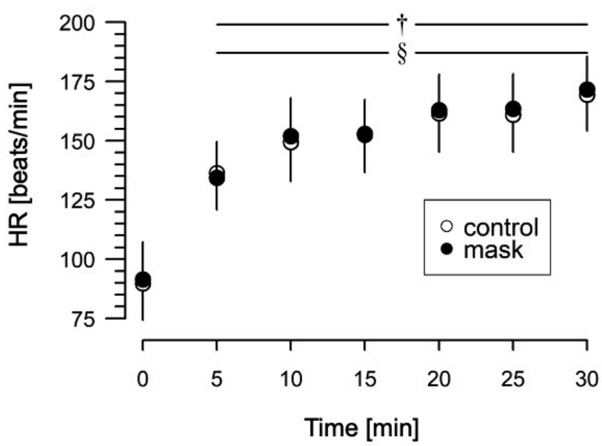

Fig. 1. Heart rates (HR) during the 30-min exercise in the control and mask trials.
Values are presented as means ± SD. †, Significant difference from the baseline value in the control trial, $p<0.001$. §, Significant difference from the baseline value in the mask trial, $p<0.001$.

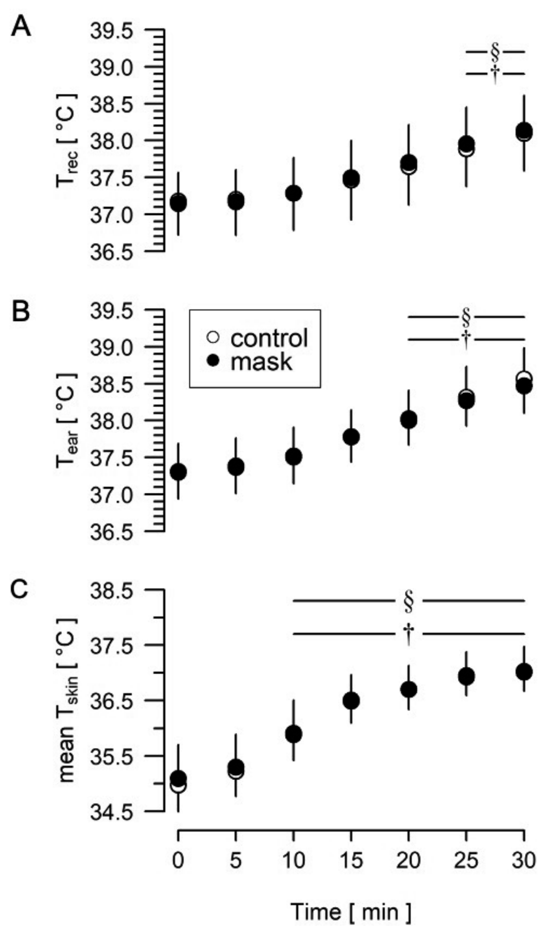

Fig. 2. Rectal temperature, ear canal temperature, and mean skin temperature in the control and mask trials (T_{rec}, A; T_{ear}, B; and mean T_{skin}, C; respectively).
Values are presented as means ± SD. †, Significant difference from the baseline value in the control trial, $p<0.05$. §, Significant difference from the baseline value in the mask trial, $p<0.05$.

and mask trials increased during 10–30 min ($F_{(1, 6)}=66.84$, $p<0.001$; 37.0 ± 0.3 and 37.0 ± 0.4ºC at 30 min, respectively), but no significant differences were observed between the two trials.

Figs. 3A and B show T_{face} and RH_{face} in the control and mask trials, respectively. The baseline T_{face} was not different between the control and mask trials ($p=0.11$; 36.1 ± 0.6 and 36.5 ± 0.4ºC, respectively). T_{face} in the control trial became higher than the baseline at 15–30 min ($F_{(1, 6)}=17.02$, $p<0.001$; 37.5 ± 0.5ºC at 30 min) and at 25–30 min in the mask trial ($p<0.05$; 37.3 ± 0.5ºC at 30 min), but there were no significant differences between the two trials.

The baseline RH_{face} in the mask trial was higher than that in the control trial ($F_{(1, 6)}=797.60$, $p<0.001$; 67.0 ± 3.4 and 79.9 ± 2.3% in the control and mask trials, respectively). The value in the control trial remained unchanged during the exercise period ($p=1.00$; 69.0 ± 2.8% at 30 min). However, RH_{face} in the mask trial became greater than the baseline at 30 min ($F_{(1, 6)}=5.54$, $p=0.04$; 84.3 ± 4.3% at 30 min), and significant differences in RH_{face} ($p<0.001$) were observed between the two trials during the exercise. The rela-

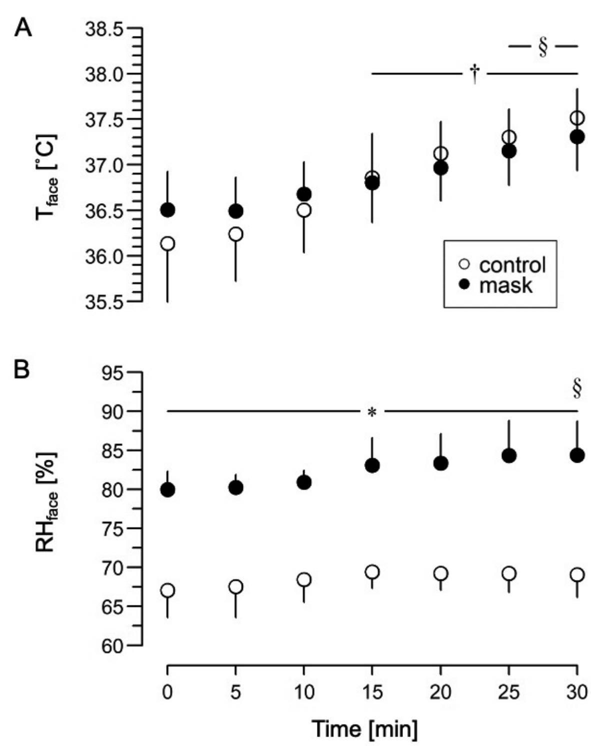

Fig. 3. Skin temperature and relative humidity of the face (T_{face}, A; and RH_{face}, B; respectively) in the control and mask trials.
Values are presented as means ± SD. *, Significant difference between the control and mask trials, $p<0.05$. †, Significant difference from the baseline value in the control trial, $p<0.05$. §, Significant difference from the baseline value in the mask trial, $p<0.05$.

tive humidity in the chest increased from the baseline at 15-30 min in the control trial and 10–30 min in the mask trial ($F_{(1, 6)}$=13.39, p<0.05; 83.4 ± 5.8% and 82.4 ± 4.8% at 30 min, respectively). Baseline values of relative humidity in the arm, thigh, and leg were not different between the two trials, and remained unchanged during the exercise.

Thermal sensation, humid sensation, and thermal discomfort of the face are illustrated in the Figs. 4A, B, and C, respectively. The baseline value of each perception was not different between the control and mask trials (p=0.36, 0.10, and 0.22, respectively). The thermal sensation, humid sensation and thermal discomfort of the face became higher than the baseline at 10, 20, and 30 min in the control and mask trials (p<0.05). There were no differences in the thermal discomfort of the face between the two trials during the exercise (p=0.052 at 30 min). Thermal sensation and humid sensation of the face in the mask trial were higher than those in the control trial at 30 min (p=0.04 and 0.02, respectively).

The thermal sensation, humidity sensation, and thermal discomfort of the whole body are illustrated in Figs. 4D, E, and F, respectively. The baseline value of thermal sensation and humid sensation of the whole body were not different between the two trials (p=0.78 and 0.81, respectively). All rating values increased (p<0.05) from the baseline at 10, 20, and 30 min. There were no differences in the humid sensation of the whole body between the two trials during exercise (p=0.07). Thermal sensation of the whole body in the mask trial was higher than that in the control trial at 20 and 30 min (p=0.01 and 0.008, respectively). Thermal discomfort of the whole body in the mask trial was greater than that in the control trial at the baseline period and 20 min (p=0.03 and 0.02, respectively).

Fig. 5A shows the rating of fatigue in the two trials. The baseline value was not different between the two trials. The rating during the exercise increased from the baseline at 10, 20 and 30 min in both trials (p<0.05), and there were no

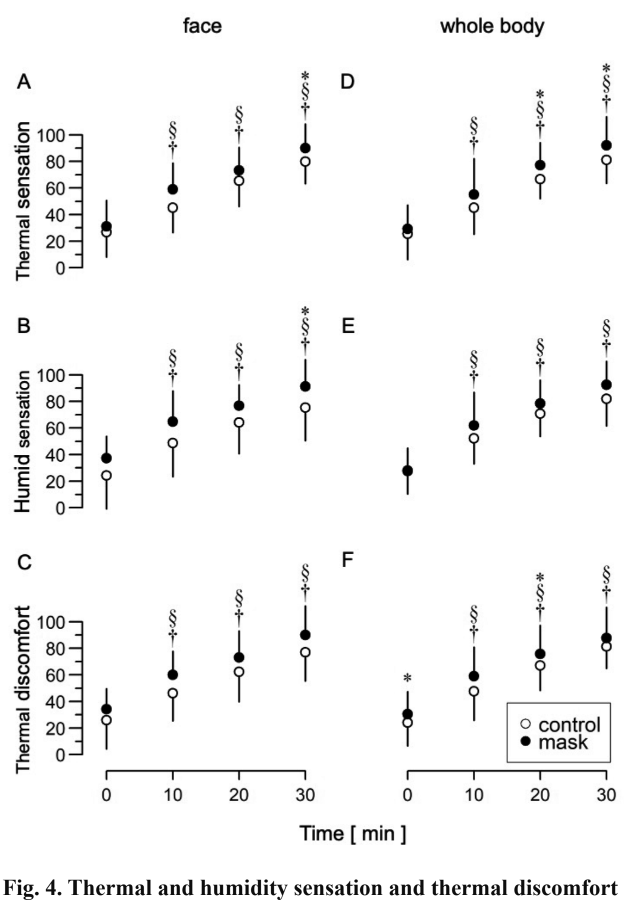

Fig. 4. Thermal and humidity sensation and thermal discomfort of the face (A, B and C, respectively) and whole body (D, E and F, respectively) in the control and mask trials.
Values are presented as means ± SD. *, Significant difference between the control and mask trials, p<0.05. †, Significant difference from the baseline value in the control trial, p<0.05. §, Significant difference from the baseline value in the mask trial, p<0.05.

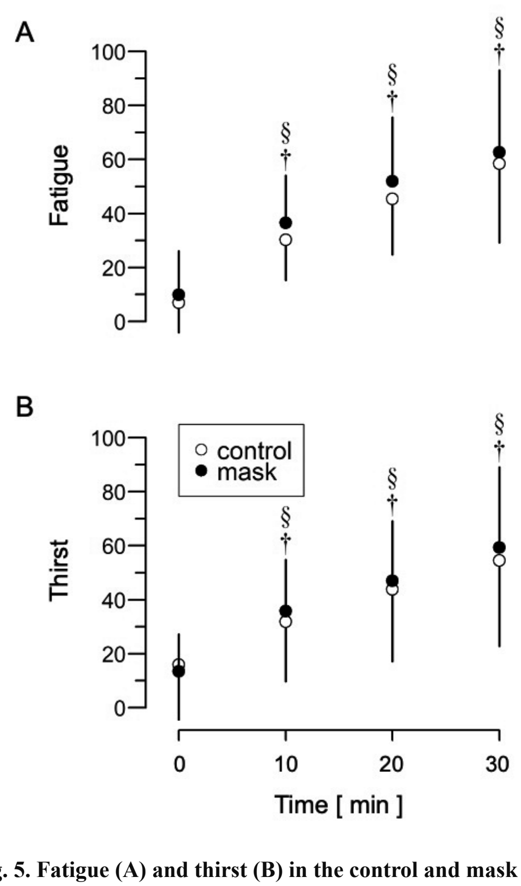

Fig. 5. Fatigue (A) and thirst (B) in the control and mask trials.
Values are presented as means ± SD. †, Significant difference from the baseline value in the control trial, p<0.05. §, Significant difference from the baseline value in the mask trial, p<0.05.

significant differences between the trials. The rating of thirst is shown in Fig. 5B, and the baseline value was not different between the two trials. The rating during the exercise increased from the baseline at 30 min in the control ($p<0.01$) and at 10, 20 and 30 min in the mask trial ($p<0.05$), but no significant differences were observed between the two trials.

Discussion

In the present study, we examined whether wearing a surgical mask increases the risk of heat stroke during mild treadmill exercise in a hot and humid condition. In addition, the influence of wearing a mask on the micro-environment (i.e., temperature and humidity) under the mask was evaluated, which may affect physiological and psychological responses to the exercise.

The Japanese government warned about the risk of heat stroke induced by intense work and/exercise while wearing masks in a hot and humid condition[20]; however, there was no information regarding the specific workload and/or environmental condition. Most cases of exertional heat stroke occur during mild intensity work or exercise[21]. Thus, we raised a fundamental question that, do we need to take off a mask even when conducting mild intensity exercise or work in a hot and humid condition?

Factors inducing exertional heat stroke could be divided into 1) environmental conditions including ambient temperature, humidity, radiation, and clothes etc.; 2) relative workload for individuals; and 3) physical conditions such as hydration state and heat tolerance. At the WBGT level in the present study, the American Society of Sports Medicine recommends that all work and sports activities should be prohibited[22, 23]. These experimental conditions might clarify whether surgical mask augments the risk of heat stroke during work and/or exercise in a hot and humid condition that we usually have in summer.

Changes in skin temperature and humidity under the surgical mask

In the U.S., commercially available surgical masks are cleared by the U.S. Food and Drug Administration[24]. These surgical masks, made of non-woven fibrous filters with triple layers, were used in the present study[25]. During the baseline period, there was no difference in T_{face} between the control and mask trials (Fig. 3A). Scarano *et al.* assessed the perioral skin temperature before and after wearing surgical mask among resting subjects in a condition of 22–24°C T_a and 50% RH, and reported no difference in the skin temperature, similar to the present study[8]. In a normal ambient condition, the temperature of the expiratory air reaches the level of the body temperature[26]. However, the warm expiratory air did affect the perioral skin temperature under the mask. These results may suggest that, in the resting condition, the expiratory air rapidly diffuses to the environment through the mask. However, RH_{face} in the mask trial was higher than that in the control trial at rest. Courtney and Bax reported that wearing a surgical mask increased the relative humidity of the inspiratory air, which may indicate that humid air space was built under the mask[27]. It was reported that expiratory air has a relative humidity of 78%, which is close to the level of the baseline in the mask trial[26], or the fibers of the mask might absorb the expiratory water, adding water constantly to the inspiratory air.

During the exercise, T_{face} increased without any difference between the two trials. The increase was linearly linked with T_{rec}, T_{ear}, and mean T_{skin} (Fig. 2). Therefore, the increase in T_{face} may simply reflect the increase in body temperature. RH_{face} in the mask trial remained greater than that in the control trial. RH_{face} in both trials remained unchanged from the respective baseline value, except for the increase in the mask trial at 30 min. These results may suggest that the influence of wearing a surgical mask on the humidity of the expiratory and inspiratory air was not changed by the exercise.

The influence of wearing surgical mask on cardiac and thermal load.

The baseline HR were similar in the two trials. Thus, surgical mask had no influence on HR at rest, as previously reported[7]. HR gradually increased during the exercise (Fig. 1), and there were no significant differences between the two trials. During continuous exercise, HR increased with the changes in the relative intensity for individuals, body temperature, and hydration state[28–30]. Since body weight remained unchanged in each trial, the hydration state also remained unchanged. T_{rec} and mean T_{skin} increased with time, but no differences between the two trial were observed. These results may suggest that HR increased under the influence of body temperature. Wearing a mask may increase the respiratory resistance, which increases the work of respiratory muscles and metabolic demand. It was reported that the humidity in the respiratory air does not affect respiratory resistance[31]. Fikenzer *et al.* reported that wearing a surgical mask decreased forced vital capacity and forced expiratory volume[7], which may indicate the increase in respiratory resistance. However, they also showed that surgical masks did not affect cardiopulmonary function as well as arterial O_2 and PO_2 tensions, even during the maximum oxygen uptake test. These results suggest that wearing a surgical masks may increase workload during the mild exercise.

There may be two possible influences of wearing surgical mask on thermoregulation. First, the mask may suppress heat loss from the covered skin area of the face. Second, it may attenuate evaporative heat loss from the airways. It was reported that the respiration of high humidity air decreases heat transfer from the body[32]. White and Cabanac assessed the relationship between respiratory heat loss and core body temperature during exercise, in which subjects inhaled air of low or high humidity[33]. The study showed that the inhalation of humid air induced a greater increase in tympanic temperature (reflecting brain temperature) relative to esophageal temperature (reflecting body trunk temperature), suggesting the involvement of the airways as a measure of the cooling of the brain. However, we found no differences in T_{rec} (also reflecting body trunk temperature), T_{ear}, mean T_{skin}, and T_{face} between two trials (Figs. 2 and 3). A previous study conducted in a cool and dry condition also reported that surgical masks had no influence on core body temperature during exercise[34]. The results may suggest that surgical masks do not suppress heat loss from the skin and airways during mild exercise in a hot and humid condition. In the present study, the humidity of the perioral skin (i.e., RH_{face}) was high enough. Therefore, if we repeated the study under hot and dry conditions, we may have found smaller heat loss from the airway in the mask trial, as speculated by the increase in T_{ear}.

The influence of wearing surgical mask on the psychological responses.

Thermal discomfort of the face, humidity sensation of the whole body, fatigue and thirst sensation increased during the exercise in both trials (Figs. 4 and 5). We did not find any difference in T_{face} and mean T_{skin} between the two trials (Fig. 3A). However, thermal sensation of the face and whole body increased during exercise in the mask trial (Figs. 4A and D). Nakamura *et al.* reported that, in a hot environment, topical warming of the face increases both thermal discomfort of the local skin as well as that of the whole body[35]. However, T_{face} was not a factor modulating the thermal perceptions in the mask trial in the present study. It was speculated that the thermal sensation on the skin is a factor augmenting thermal discomfort in a hot environment[36]. Greater humidity and humid sensation of the face (Figs. 3B and 4B) may have altered the thermal sensation of the face.

It was reported that, during exercise in a cool and dry environment, topical warming of the face decreased work output for the given perception of effort[37]. However, a previous study showed that wearing a surgical mask had no effects on the rating of perceived exertion and time to exhaustion during exercise[6]. Moreover, people are more reluctant to wear a mask when the conditions are warm and humid[38]. Wearing a mask may augment thermal sensation probably due to greater humidity inside; however, may not affect perceived exertion during exercise.

We did not assess the influence of the time length or work intensity of exercise, which may affect physiological and psychological responses. Recently, Morris *et al.*[39] showed that prolonged facemask use induced dyspnea without affecting moto-cognitive performance. Thus, the time length may be another factor affecting some psychological responses. If we conducted an experiment in a mild heat and/or dry condition, the micro-environment in the mask may have been largely different from the ambient air, resulting in greater difference in psychological responses between the mask and control trials.

In conclusion, we did not find any influence of wearing a surgical mask on cardiac and thermal responses during mild exercise in hot and humid environment. Therefore, surgical masks per se could not be a factor augmenting the risk of heat stroke in such work/exercise and environmental conditions. Moreover, a greater increase in humidity under the mask was observed; however, the increase did not affect the fatigue and thirst sensation.

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