The Effect of Safety Hat on Thermal Responses and Working Efficiency under a High Temperature Environment

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Abstract The purpose of this study is to examine the effect of a safety hat on thermal responses and work efficiency under a high temperature environment. Five healthy male subjects participated in the repeated 'Rest' and 'Exercise' periods in order to compare a safety hat without holes (annotated as 'without hole') and a safety hat with holes (annotated as 'with hole') in a climatic chamber of 30°C, 50%RH.

The main findings are as follows: (a) the core temperature (tympanic temperature) and heart rate showed significantly lower levels in the subjects who are under the 'with hole' condition than those who are under the 'without hole' condition; (b) the forehead skin temperature was significantly higher in the subjects who are under the 'without hole' condition than those who are under the 'with hole' condition; (c) blood pressure was significantly lower in the 'with hole' condition; and (d) sweat rate which was measured by weight loss before and after the experiment was higher in the 'without hole' condition; and (e) work ability which was measured by a grip strength dynamometer was higher in the 'with hole' condition.

Making a hole in the safety hat, designed for proper ventilation and hygiene, is practical in letting out heat and decreasing the physiological burden under a hot working environment. The safety hat with holes is useful in maintaining the homeostasis of the body temperature by releasing body heat efficiently and it is meaningful to keep the working efficiency. *J Physiol Anthropol Appl Human Sci* 23 (5): 149–153, 2004 <http://www.jstage.jst.go.jp/browse/jpa>

Keywords: thermal response, safety hat, hot working environment, tympanic temperature, working efficiency

Introduction

The human brain is the control center for all physiological responses, which are essential in our existence. The blood volume that circulates in the brain is about 650–700 ml/min, and the oxygen consumption by the brain is 49 ml/min which is equivalent to twenty percent of the whole body oxygen

consumption. Since the human brain is working continuously, it produces a lot of heat. Under an outdoor environment the head is influenced by the heat of the sun, so we must consider to control the internal heat production while we try to control the external heat transfer. The head should be protected, since it is the most susceptible to damage.

A safety hat which protects the head in the work place is a meaningful device for a behavioral thermoregulatory response under a hot working environment. While wearing the safety hat, heat, sweat and vapor as negative products or adversely effective products are released from the safety hat, otherwise, the microclimate of the safety hat would get worse. The safety hat, which is designed for proper ventilation and hygiene, can maintain the homeostasis of body temperature by releasing the head temperature efficiently.

In relation to the safety hat, the effects of a wearing hat on thermophysiological responses under hot and cold environments were studied by Midorikawa and Tokura (1992; 1994). Diffey and Cheeseman (1992) had investigated the sun protection hat for ultraviolet-rays break. Moreover, Thompson and Patterson (1998) examined motorcycle helmets for the prevention of injuries. In addition, Liu and Holmer (1995) looked into the evaporative heat transfer characteristics of industrial safety helmets. Research about hats mostly focused on regular hats, but there were a few studies about safety hats in relation to the thermal responses and working efficiency. Thereof, it is necessary to research and develop the working hat in relation with the thermophysiological responses, work efficiency and safety.

The present study is aimed at investigating the function of the safety hats with holes, which is used by people under a hot working environment in order to protect the head from various injuries and as a regulation of behavioral thermoregulatory responses. Besides, this study also aims to investigate the effect of the safety hats with holes in terms of a balance between the body temperature and work efficiency by observing the physiological responses under a hot working environment. If the findings from our present study can show positive results concerning safety hats with holes on thermoregulatory responses, it would be useful in preventing

head injuries linked to industrial accidents. Furthermore, it will also be useful in developing the industrial safety hat.

Methods

Five healthy male subjects participated in this experiment. The average anthropometrics data for the subjects were as follows; Age (years): 21.8 ± 1.79 (mean $\pm$ SD), weight (kg): 69.24 ± 17.13 , height (cm): 175.4 ± 4.67 , BSA (Body Surface Area, m^2): 1.83 ± 0.21 . The subjects were asked to go to bed at their usual time at night before each experiment. They abstained from taking exercise and consuming caffeine, alcohol before experiment. The experiment was carried out in a climatic chamber which had a controlled temperature of 30°C and relative humidity of 50% RH. The subjects wore undershirts (100% cotton), underpants (100% cotton), socks (100% cotton) and working clothes (35% cotton, 65% polyester). In order to compare two kinds safety hats, the subjects underwent two sessions. They wore safety hat with holes (annotated as 'with hole'). Each hat had 18 holes and each hole had a 5 mm diameters. The subjects also wore safety hat without holes (annotated as 'without hole') according to a randomized crossover design. Two kinds of safety hats had passed the industrial standard of ISO9001. Fig. 1 shows safety hats made of acrylonitrile butadiene styrene.

After the preparation period to attach the sensors for 50 min, each experiment consisted of a rest period (10 min, Rest I), an exercise period (20 min, Exercise I), a rest (10 min, Rest II), an exercise period (20 min, Exercise II) and a rest period (10 min, Rest III). Data collection started with the first rest period. In order to exclude the effects of circadian rhythms on physiological parameters, the subjects were always exposed to the conditions at the same time of a day in two-session periods. Fig. 2 shows the scheduling of the experiment.

Physiological measurements

The tympanic temperature (T_{tm}) as the core temperature was measured with a Thermo Scan Instant Thermometer (IRT1020, USA). Skin temperatures (T_{sk}) at seven sites were measured by thermistor probes and recorded every 1 min with Squirrel Meter Logger (SQ1250, England). This had an accuracy of 0.05°C . The skin temperature probes for T_{sk} were attached with adhesive tape on the skin of the forehead, trunk, forearm, hand, thigh, leg and foot of the participants. The mean skin temperature ($\bar{T}_{\text{sk}}$) was calculated using the following equation proposed by Hardy and DeBois (1938): $\bar{T}_{\text{sk}} = 0.07T_{\text{forehead}} + 0.35T_{\text{trunk}} + 0.14T_{\text{forearm}} + 0.05T_{\text{hand}} + 0.19T_{\text{thigh}} + 0.13T_{\text{leg}} + 0.07T_{\text{foot}}$. The microclimate between the top point of the head and the safety hat was measured by the thermistor probe and humidity sensor and was logged on the Squirrel Meter Logger.

The work efficiency was determined from a Grip Strength Dynamometer (100 ± 1 kg, TKK5010, Japan) at the points before and after exercising. The heart rate was measured with a Sport Tester (PE3000, Finland) every 1 min. The sweat rate

Fig. 1 Technical drawing of experimental safety hat.

Fig. 2 Schedule of experiment.

was evaluated by the body mass loss. The body mass was weighed before and after the experiment with balance of an accuracy of 0.001 kg (Sartorius, Germany).

Data analysis

A repeated one-way analysis of variance (ANOVA) was used for two kinds of hat with periods. The sweat rate was assessed by paired t-test. The values are given as means $\pm$ SD. In all cases, the level of significance was considered to be $P < 0.05$.

Result

Fig. 3 showed the time-courses for the average tympanic temperature for the two kinds of safety hats worn by the five subjects. The tympanic temperature was measured during last time period for all subjects, although there were not any significant differences between the two kinds of safety hats, but it showed a higher level in the 'without hole' condition in the periods. Fig. 3 showed an increase in Exercise I, a slight decrease in Rest II, and a peak in Exercise II but recovered in Rest III with a higher level than Rest II.

Fig. 4 showed the forehead skin temperature. During the exercise period, the forehead skin temperature gradually increased, but in the rest period it decreased. It showed a significantly lower level in the 'with hole' condition than in the

Fig. 3 Time course of average tympanic temperature during the experiment. Solid line; Safety hat with hole. Dotted line; Safety hat without hole. Values are mean $\pm$ SD obtained from 5 subjects.

Fig. 4 Time course of mean forehead skin temperature during the experiment. Solid line; Safety hat with hole. Dotted line; Safety hat without hole. Values are mean $\pm$ SD obtained from 5 subjects.

‘without hole’ condition ($F=5.76 > F_{0.05}(1,138)=3.91$). The mean skin temperature of the seven body points also increased during the periods of exercise and decreased during the rest periods.

Fig. 5 showed a comparison of the heart rates between the two kinds of safety hats. It showed a significant lower rate in the ‘with hole’ condition ($F=6.69 > F_{0.05}(1,138)=3.91$).

Fig. 6 showed a comparison of the sweat rates between the two kinds of safety hats. It showed a significant higher level in the ‘without hole’ condition (596 ± 6.0 g) than in the ‘with hole’ condition (500 ± 7.2 g) ($P < 0.05$).

Fig. 7 showed the results of the grip strength in every exercise period. It showed higher grip strength in the ‘with hole’ condition than in the ‘without hole’ condition. The grip strength decreased with the progress of experiment. With a view point of a separated period, the grip strength showed a significant difference in both conditions (‘with hole’ and ‘without hole’) with Exercise I and Exercise II. But it didn’t

Fig. 5 Time course of heart rate during the experiment. Solid line; Safety hat with hole. Dotted line; Safety hat without hole. Values are mean $\pm$ SD obtained from 5 subjects.

Fig. 6 Sweat rate during the experiment in 5 subjects.

Fig. 7 Grip strength during the experiment in 5 subjects.

reveal the significant difference with a continuous measurement point.

Discussion

The tympanic temperature is an internal temperature which is due to the chemical responses being processed in the body and it is an important factor in controlling the rate and pace of metabolism. In this experiment, we can determine that the 'with hole' condition is physiologically more effective in maintaining the state of homeostasis compared to the 'without hole' condition in a hot environment. Wearing a safety hat under 'without hole' condition accelerated the head surface temperature and affected the tympanic temperature consequently. It is impossible to measure the temperature of the hypothalamus which is the controller of the autonomic nervous system. Since the well-known work of Benzinger et al. (1963), the tympanic membrane temperature has been used extensively as an indicator of the core temperature and perhaps of the hypothalamic temperature in humans. With this in mind, it is believed that the head temperature increased in the safety hats without holes.

The forehead temperature was particularly higher in the 'without hole' condition than in the 'with hole' condition, after the exercise period. The forehead, which was not covered with hat, started to show perspiration in the 'without hole' condition prior to the 'with hole' condition. Wearing the safety hat under the 'with hole' condition makes the head temperature rise more slowly than that in the 'without hole' condition. It delays the onset of perspiration as a result of the ventilation via the holes. In the study of McCaffrey et al. (1975), the increase of the tympanic temperature was revealed to be accompanied by the increase of the head temperature. Their findings suggested that the tympanic temperature might be affected by the thermal exchange that occurs between the arteries and veins in the cervical and cephalic regions.

The heart rate, one of the simple and useful indexes for the function of the cardiac blood relationship, indicates the quantity of work, the heart performs in order to satisfy the increased need in the body due to exercise. The results, a lower level of heart rate and a lower level of the tympanic temperature in the 'with hole' condition, coincide with the results of prior studies (Kamon and Belding, 1971; Engel and Henze, 1989; Zahorska-Markiewicz et al., 1989) in that the change of the heart rate is generally similar to the change of the core temperature. In this experiment, we have a similar rising pattern in the tympanic temperature and heart rate during exercise. Therefore, this experiment coincides with the previous research in which that the change of heart rate follows the change of core temperature. With this in mind, the safety hat with holes and its release of the physical burden on the subject is superior to the safety hat without holes in the physiological aspect.

Sweating is an active evaporative heat loss process. The rate of evaporative heat loss can be deliberately adjusted by means

of sweating, which is an important homeostatic mechanism needed to eliminate excess heat. When the external air temperature exceeds the limits of the ability of skin vasodilatation in order to get rid of excess heat, sweating becomes the dominant factor in maintaining the core temperature. The greater loss of body mass in the 'without hole' condition means a greater sweat rate than that in the 'with hole' condition. A higher sweat rate in the 'without hole' condition didn't indicate better cooling by evaporation because the subject felt hotter in the 'without hole' condition in a subjective sense. The increase in the body temperature was suppressed by ventilation through holes in the hat.

The microclimate of the temperature and humidity in the safety hat was lower in the 'with hole' condition. These results were caused by an increase of the forehead temperature by vasodilatation which was higher in the 'without hole' condition than those in the 'with hole' condition. The amount of vapor and humidity in the atmosphere played an important role in heat transfer by evaporation. It can be considered that the safety hat in the 'with hole' condition was successful in reducing the amount of heat that could be trapped in a hat. The air circulation from holes on the hat caused a lower temperature and more evaporation and brought a lower humidity. Despite of the knowledge of a safety hat's role in head protection, people were unwilling to wear a safety hat due to its pressure, the sensation of perspiration and lack of ventilation. As a result, people would forego the hat and they often met with a head injury while working. In a hot environment, the humidity of the inner part of the safety hat increases through perspiration. Therefore, it is more profitable to wear a hat in the 'with hole' condition in order to reduce moisture and increase ventilation. The factors are connected in relation to the working security and the reduction of the physiological load.

The work efficiency, which was measured by a grip strength dynamometer, was higher in the 'with hole' condition. Even though the grip strength showed no significant difference with continuous measures, it showed higher grip strength in the 'with hole' condition than that in the 'without hole' condition in every period.

Wearing a in the 'with hole' condition suppressed an excessive increase of the core temperature, skin temperature, heart rate and sweat rate. For that reason, subjects felt less fatigued and showed higher grip strength. Besides, we could also determine that the 'with hole' condition was more effective in terms of work efficiency in a hot environment. In every subjective rating, the subjects reported that they felt worse in a 'without hole' condition than in a 'with hole' condition. These were caused by the increased sweat rate and a higher temperature in the 'without hole' condition during exercise. Finally, the increased temperature, more perspiration, and a feeling of more fatigue lead to a lower work capability.

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