[Transaction]

Journal of the Korean Society
of Clothing and Textiles
Vol. 31, No. 6 (2007) p.955~965

Physiological Responses of Wearing Safety Helmet with Cooling Pack in Hot Environment

Jeongwha Choi · JoonHee Park*[†]

Dept. of Clothing & Textiles, Seoul National University/Research Institute of Human Ecology of Seoul National University
*Dept. of Clothing & Textiles, Seoul National University

머리 냉각시의 인체생리반응
-안전모 착용을 중심으로-

최정화 · 박준희*[†]

서울대학교 의류학과/서울대학교 생활과학연구소, *서울대학교 의류학과

(2007. 4. 18. 접수)

Abstract

Safety helmets are used widely in various industries by workers since they are legally required to wear them. However, thermal discomfort is one of the major complaints from helmet users. To relieve this problem, frozen gelled packs can be considered for use inside the helmets. In this paper, tests were performed on humans to evaluate the physiological strains of wearing safety helmets and to investigate the effects of using frozen gelled packs inside the helmets. Experiments were conducted in a climatic chamber of WBGT 33±1°C under four differed experimental conditions: 1) not wearing a safety helmet(NH); 2) wearing a safety helmet with frozen gelled pack A(HA); 3) wearing a safety helmet with frozen gelled pack B(HB); and 4) wearing only a safety helmet(OH). The results were as follows. First, when comparing NH with OH, physiological responses such as $\bar{T}_{sk}$, T_r, HR and sweat rate were significantly higher in OH and subjective sensations were reported as less hot and more comfortable than NH(p<.05). Second, in regard to the frozen gelled packs inserted inside the safety helmets, some physiological responses in HA were different from those in HB, according to the two different types of packs. HA was hotter, more uncomfortable and less exhausted than HB. However, result from both HA and HB were lower than those from OH in terms of temperature and humidity inside safety helmet, sweat rate, T_r increase, heat storage(p<.05). When wearing safety helmets with frozen gelled packs, it was shown that heat strain can be alleviated. These results are expected to help millions of workers who complain that wearing safety helmets is uncomfortable and messy.

Key words: Safety helmet, Hot environment, Head cooling, Physiological responses; 안전모, 더운 환경, 머리 냉각, 인체생리반응

[†] Corresponding author
E-mail: jh1811@hanmail.net

This work was supported by the Korea Science and Engineering Foundation(KOSEF) grant funded by the Korea government(MOST) (No. R01-2005-000-10592-0).

I. Introduction

The safety helmet is a personal protective equipment(PPEs) widely used by workers in various industries such as construction, forestry, fire service, etc. Workers must wear safety helmets by law for protecting the head against impacts, falls and objects falling from a height. However, safety helmets can also cause thermal discomfort and physiological load when worn at work, particularly in hot environments, in which case workers become reluctant about wearing them(Abeysekera & Shahnavaz, 1990; Kim & Park, 2004; Liu & Holmer, 1995, 1997). Workers using safety helmets complained of discomforts related to heat, heaviness, bad fit, etc. (Abeysekera & Shahnavaz, 1990) and construction workers responded that in summer the head area was the hottest while working among different parts of the body(Park & Choi, 2006). These facts show that wearing safety helmet imposes heat stress and discomfort on workers.

Hardy and Dubois(1938) showed that the head accounts for approximately 7~10% of the total body surface area and skin temperatures in the head area are typically higher than in any other part of the body. Heat may be gained or lost by conduction, convection, radiation and evaporation from the head, which is a major and effective body area for heat removal (Froese & Burton, 1957; Liu & Holmer, 1995; Proctor, 1982). Making holes in the helmet is prohibited in order to ensure performance, although this can alleviate physiological strain of the head(Lee, 1996). So, a different method must be considered, such as a cooling device.

Many studies have focused on the effect of cooling the head(Brown & Williams, 1982; Cohen et al., 1989; Hayashi & Tokura, 1996; Katsuura et al., 1996; Kissen et al., 1976; McCaffrey et al., 1975). Nunneley and Maldonado(1983) found that cooling the head and torso in hot environment decreased rectal temperature, heart rate and sweat rate and cooling the head region has been found to be two to three times more efficient for reducing heat stress than cooling the torso. The head is thus an important region in terms of heat exchange between man and the environment(Katsuura et al., 1996). In other words, the head is capable of effectively losing heat but effective heat exchange is affected by wearing a safety helmet(Liu & Holmer, 1995).

Thermal discomfort associated with safety helmet wearing at work has been addressed in several studies(Abeysekera & Shahnavaz, 1990; Holland et al., 2002). A few previous studies about evaporative heat transfer characteristics of safety helmets were based on thermal manikin and human wear tests(Kim & Park, 2004; Liu & Holmer, 1995, 1997). However, studies on applying frozen gelled pack to safety helmets are rare and the cooling effect of frozen gelled packs on the head is not widely known. Moreover, frozen gelled packs for use with safety helmets are sold at some retailers but their effect have not been investigated physiologically although it should be also considered that the weight increase caused by inserting frozen gelled pack can affect physiological responses such as fatigue and inefficient productivity. Therefore, utilization of the frozen gelled pack is suggested in this study as a method for improving safety helmets.

The aims of this present study were to investigate the physiological responses and load of wearing safety helmet and to examine the effects that frozen gelled packs have on alleviating heat stress when used inside safety helmets. To look into these issues, tests were performed on human users in a hot environment and results were reported.

II. Methods

1. Temperature Test on the Frozen Gelled Packs

Frozen gelled packs are made of super absorbent polymers and water. Super absorbent polymers are a material that has been made insoluble by the cross-linking of polymers. They can absorb over a hundred times their weight in liquid, do not easily release the absorbed fluids under pressure and have a thermal reversibility(Park, 1994). Owing to these characteristics, they are used in the frozen gelled packs.

To evaluate frozen gelled packs that are currently on the market, a test of measuring upper and lower surface temperature was conducted in a climatic chamber(temperature 30.2±0.3°C, relative humidity 27±3% RH) with a portable thermistor logger(LT, Gram Corp., Japan). Frozen gelled packs were placed inside the bag of a heat insulator and the test was repeated 3 times for 4 hours on the heat insulator plate(5cm thick).

Based on a pilot test that evaluated a total of 6 items(2 items for safety helmets, 4 items for cooling vests), two items(frozen gelled pack A from S company, 140g and frozen gelled pack B from H company, 160g) that indicated lower surface temperatures than others were selected, evaluated and used for tests on the human use. Frozen gelled pack A and the frozen gelled pack B is sold on the market, for safety helmets and cooling vests, respectively.

2. Human Wear Test

1) Subject and experimental clothing

Four physically-active males(age 21 years, height 173cm, body mass 77.9±8.3kg, body surface area 1.9±0.1m^2) participated in trials. Subjects provided informed consent before participating in this protocol. Trials were conducted each day at the same hour in order to exclude the effects of circadian rhythms.

The subjects wore undershirts(90g), underpants (74g), long-sleeved shirts(245g), long pants(391g), socks(41g), work uniform vest(249g, 65% polyester, 35% cotton), safety shoes(1,457g) and safety helmet (428g). All clothing was made of 100% cotton except for the work uniform vest. Total clothing weight, excluding the safety shoes, was 1,090g and estimated thermal insulation was 0.7 clo(ISO 9920). The safety helmet was white in color and weighed approximately 428g a popular ABE type for protection against impacts, falls, objects falling from a height and electric shocks.

2) Experimental conditions and test protocol

There were four experimental conditions: NH(not wearing safety helmet), HA(wearing safety helmet with frozen gelled pack A), HB(wearing safety helmet with frozen gelled pack B) and OH(wearing only safety helmet)(Table 1). The frozen gelled pack was inserted between the support band and the body of the safety helmet, before which it was carried in a bag exclusively for the packs.

All tests were conducted in a climatic chamber at WBGT 33±1°C(temp. 33.6±0.9°C, relative humidity 43±6%, black globe temp. 35±1°C). Subjects arrived at the laboratory and rested for 30minutes after changing into experimental clothing and receiving instruments. During trials, subjects repeated exercise periods(walking, 10min) and rest periods(sitting, 5min) for an hour. The walking speed was about 120 steps/min.

3) Thermoregulatory measures

Skin temperatures were measured at ten spots on the forehead, cheek, front neck, back neck, abdomen, arm, hand, thigh, leg, foot and mean skin temperature ($\bar{T}_{sk}$) was calculated as 7-points according to a method by Hardy and Dubois. Core temperature was measured rectal temperature(T_r), with a rectal probe inserted 15cm past the anal sphincter. The innermost surface and the outermost surface temperature were measured in the parietal regions of the safety helmet. These measures were recorded with a portable thermistor logger(LT, Gram Corp., Japan). Heart rate was measured with a Polar Sports Tester (POLAR ELECTRO Inc., Finland). Clothing microclimate at the chest and thigh and safety helmet microclimate was

Table 1. Experimental conditions

	Weight of safety helmet (g)	Weight of frozen gelled pack (g)	Size of frozen gelled pack (cm) (width×length×thickness)
NH	-	-	-
HA	428	140	7×11×2
HB	428	160	10×13×1
OH	428	-	-

Notes. Subjects were wearing experimental clothing for no safety helmet(NH), safety helmet with frozen gelled pack A(HA), safety helmet with frozen gelled pack B(HB), and only safety helmet(OH) conditions.

used with Thermal Recorder(TR-72S, T&D Corp., Japan). All of these measures were taken every minute.

Weight loss was calculated using body mass before and after the experiment using a balance with an accuracy of 0.001kg(F150S, Sartorius Corp., Germany) and local sweating was measured from a 12 cm^2(3×4cm) area on the back of the neck using filter paper(ADVANTEC TOYO 2, Japan). Local sweating was also calculated by mass difference before and after the experiment on chemical balance at an accuracy of 0.0001g(Chemical Balance, Precisa Corp., Swiss). Heat storage was calculated with an equation by Gavhed and Holmer for investigating heat load (Gavhed & Holmer, 1989).

Subjective sensations were determined from ratings of thermal sensation(9-point scale, -4=very cold, +4=very hot), thermal comfort(4-point scale, 0=neutral, 3=very uncomfortable), wet sensation(7-point scale, -3=very dry, +3=very wet), fractionated for the whole body and the head. Subjective workload votes was quantified using a perceived exertion of Borg(7-point scale, 0=very easy, 6=very, very hard).

3. Data Analysis

SPSS 12.0 package was used and the values are given as means±SD. The paired t-test was conducted to compare the differences between frozen gelled packs A and B. A repeated one-way analysis of variance(ANOVA) and correlation analysis were used for the four experiment conditions.

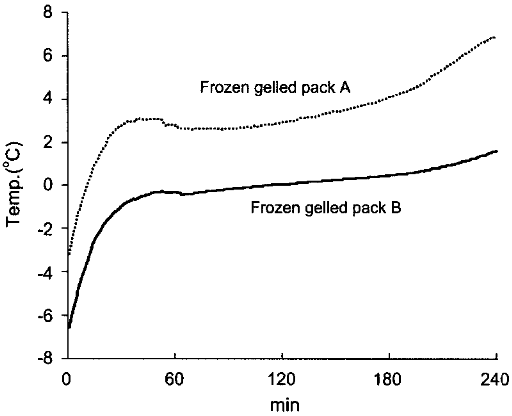

Fig. 1. Changes of surface temperature of frozen gelled packs.

III. Results and Discussion

1. Temperature Test of Frozen Gelled Packs

Surface temperature of frozen gelled pack B was lower than A throughout the entire time-courses ($p<.05$, Fig. 1). Lower surface temperature of frozen gelled pack B went down as low as -1.3°C, followed by upper surface temp. of B(0.9°C), upper surface temp. of A(2.3°C) and lower surface temp. of A(4.4°C), in order($p<.05$). It shows that the cooling capacity of frozen gelled pack B is better than that of frozen gelled pack A.

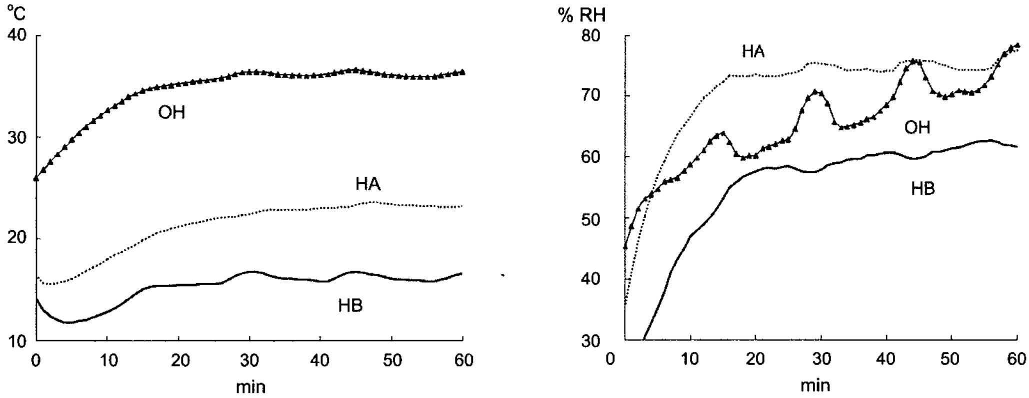

Fig. 2. Changes of microclimate inside safety helmets(Left: Temperature, Right: Humidity).

2. Human Wear Test

1) Safety helmet microclimate

Temperature inside safety helmet was 21.2°C, 15.2 °C and 34.7°C and humidity inside safety helmet was 71%RH, 54%RH and 65%RH in HA, HB and OH, respectively($p<.05$, Fig. 2). Microclimate inside safety helmets significantly differed($p<.05$). Temperatures inside safety helmets in HA and HB was significantly higher(by 15°C) than that in OH. This difference suggests that the application of frozen gelled packs within safety helmets reduces physiological strain by lowering temperature inside the helmets.

Humidity inside safety helmet showed gentle inclination in HA and HB but severe variations in OH between exercise and rest period(Fig. 2). It means that heat transfer occurred from the inside of safety helmet to the exterior in OH. This is probably due to the increased airflow through the helmet caused by the movement of participants like clothing and this finding is consistent with the results from previous studies(Liu & Holmer, 1995, 1997).

In the case of HA, therefore, humidity becomes high and heat loss is less effective. On the other hand, the temperature and humidity inside the safety helmet in HB were the lowest, and this suggests the possibility that HB could be used. Still, the weight of frozen gelled pack should be considered. The weight of safety helmets will be dealt with later in the section of subjective sensation.

The innermost and the outermost surface temperature inside the safety helmet was the highest in OH ($p<.05$, Table 2). The difference between the innermost and the outermost surface temperature inside safety helmet was also the highest in OH(Fig. 3). The absolute value of this measure means that the higher, the cooler and the lower, the hotter. It was higher when the frozen gelled pack was used.

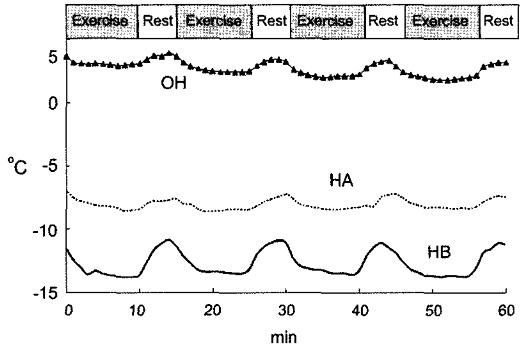

Fig. 3. The difference between the innermost surface temperature and the outermost surface temperature of safety helmet.

Table 2. Microclimate inside safety helmets during wear test

Inside safety helmets	HA	HB	OH
Temperature (°C)	21.19±2.6^b	15.24±1.5^a	34.66±2.7^c
Humidity (%RH)	71±9^c	54±11^a	65±7^b
Innermost surface temp. (°C)	23.43±3.5^b	19.32±3.6^a	35.11±2.5^c
Outermost surface temp. (°C)	30.79±2.7^a	32.01±2.2^b	32.39±2.6^c
Difference between the innermost and the outermost surface temp. (°C)	-7.37±2.5^b	-12.70±2.5^c	2.71±1.3^a

$p<.05$

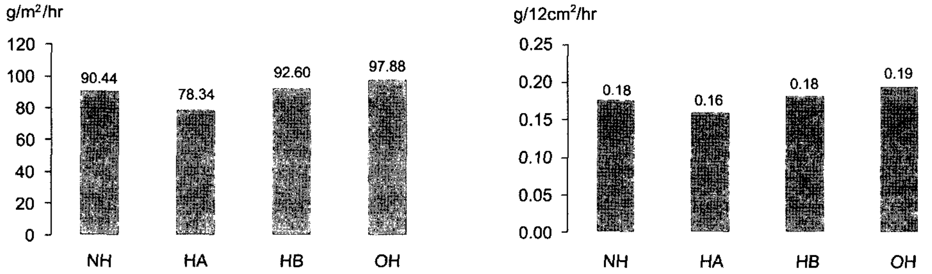

Fig. 4. Weight loss and local sweating(Left : weight loss, Right : local sweating on the back of the neck).

Unlike in OH, the innermost surface temperature inside the safety helmet was lower than the outermost temperature inside the safety helmet in HA and HB(p<.05, Table 2). The reason that the outermost surface temperature inside the safety helmet in HA was lower than that in HB is because of the thick frozen gelled pack used in HA.

2) Weight loss and local sweating

Weight loss and local sweating did not show a significant difference. However, both weight loss and local sweating were the lowest in HA, at 78g/m^2/hr and 0.16g/12cm^2/hr, respectively, and these parameters increased in the following order: NH<HB<OH (Fig. 4). Taken as a whole, local sweating was also high in the case of significantly high weight loss. This finding is consistent with results from previous studies(Jung, 1994; Kim & Park, 2004).

Thermal balance becomes more and more dependent on evaporative heat loss from sweating(Liu & Holmer, 1995). Comparing OH with NH, OH was higher 7.5g/m^2/hr in weight loss and 24g/m^2/hr in local sweating than NH. This is why wearing a safety helmet reduces airflow over the head, which may affect heat loss from the head to the external environment (Holland et al., 2002). The higher weight loss was, the more $\overline{T}_{sk}$ increase rose in this study. Heat loss was promoted by increasing weight loss through rising skin temperature when safety helmet was worn.

Weight loss and local sweating in HA and HB were lower than in OH and those of HB was higher than HA. As mentioned above, humidity inside the safety helmet was lowest in HB but weight loss and local sweating were lower in HA than in HB. These results are due to the 1cm thickness of frozen gelled pack B. It is considered that HA has high humidity inside safety helmet due to 2cm thickness of frozen gelled pack A. Frozen gelled pack B performed lower than frozen gelled pack A in cooling capacity test(Fig. 1) but HB was higher than HA in weight loss and local sweating. It is considered that the reason for this result is an increase in weight. While HA was less effective by inserting lower cooling capacity but lighter in the weight of the frozen pack, the superior cooling capacity in HB was offset by the heavy weight of the frozen gelled pack. Therefore, a lightweight frozen gelled pack of high cooling capacity needs to be developed.

3) Skin temperature and rectal temperature

Skin temperatures in OH were higher than those in NH except for leg temperature. $\overline{T}_{sk}$ was the lowest in

Table 3. Physiological responses during wear test

		NH	HA	HB	OH
Skin temp. (°C)	Forehead	35.53 ± 0.6^{a}	35.66 ± 0.7^{b}	35.69 ± 0.6^{b}	35.81 ± 0.8^{c}
	Cheek	34.96 ± 1.3^{a}	35.24 ± 1.0^{b}	35.32 ± 0.8^{b}	35.37 ± 1.0^{b}
	Front of neck	34.43 ± 0.7^{a}	34.65 ± 0.7^{bc}	34.71 ± 0.6^{c}	34.61 ± 0.8^{b}
	Back of neck	35.82 ± 0.6^{a}	36.07 ± 0.6^{c}	36.09 ± 0.5^{c}	35.97 ± 0.6^{b}
	Abdomen	34.02 ± 0.7^{a}	34.18 ± 0.9^{b}	34.27 ± 0.6^{b}	34.25 ± 0.7^{b}
	Arm	33.96 ± 0.6^{a}	34.29 ± 0.8^{b}	34.72 ± 0.4^{c}	34.28 ± 0.7^{b}
	Hand	34.11 ± 1.1^{a}	34.31 ± 1.4^{b}	34.46 ± 0.8^{c}	34.43 ± 0.7^{bc}
	Thigh	33.87 ± 1.0^{a}	34.14 ± 0.8^{b}	34.30 ± 0.9^{c}	34.23 ± 0.9^{bc}
	Leg	34.92 ± 0.9^{b}	35.23 ± 0.9^{c}	35.30 ± 0.9^{c}	34.68 ± 1.1^{a}
	Foot	34.75 ± 2.4^{a}	35.83 ± 0.5^{c}	35.65 ± 1.6^{c}	35.23 ± 2.0^{b}
	$\overline{T}_{sk}$	34.26 ± 0.7^{a}	34.59 ± 0.7^{c}	34.68 ± 0.6^{d}	34.50 ± 0.6^{b}
T_r (°C)		37.25 ± 0.1^{a}	37.33 ± 0.2^{c}	37.29 ± 0.2^{b}	37.29 ± 0.2^{b}
Heart Rate (beats/min)		89.7 ± 11.2^{a}	94.0 ± 11.3^{c}	90.2 ± 10.8^{ab}	91.5 ± 12.5^{b}
$\overline{T}_{b}$ increase		0.87	0.72	0.81	0.97
Heat storage (W/m^2)		68.41	71.63	58.47	76.89

p<.05

NH and this parameter increased in the following order: OH<HA<HB(p<.05, Table 3). However, $\overline{T}_{sk}$ increase was the highest in NH(2.44) and increased in the following order, OH(1.73)<HA(2.01)<HB(2.09) as shown in <Fig. 5>. This means that wearing a safety helmet causes physiological strain and discomfort through skin temperature of objective measure and human body in NH tries to maintain thermoregulation primarily with skin temperature. $\overline{T}_{sk}$ consistently increased in the course of time and was higher during exercise period than during rest period(Fig. 5). It is considered that the lower $\overline{T}_{sk}$ during exercise period is due to the fact that heat loss is affected from skin because ventilation inside clothing is induced by physical movement in the exercise period.

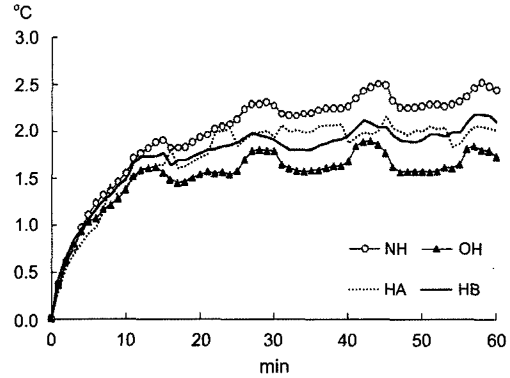

Fig. 5. Changes of mean skin temperature increases.

Skin temperatures on the forehead, cheek, front of neck and back of neck could be seen as regions affected by wearing safety helmet. OH was higher 0.3°C at forehead and 0.4°C at cheek than NH. Crawshaw et al.(1975) found the forehead to show much greater sensitivity per unit area than other regions. It showed that skin temperatures not only on the forehead but on the cheek are affected by wearing safety helmet in this result. In considering the frozen gelled packs, forehead and cheek skin temperature in HA

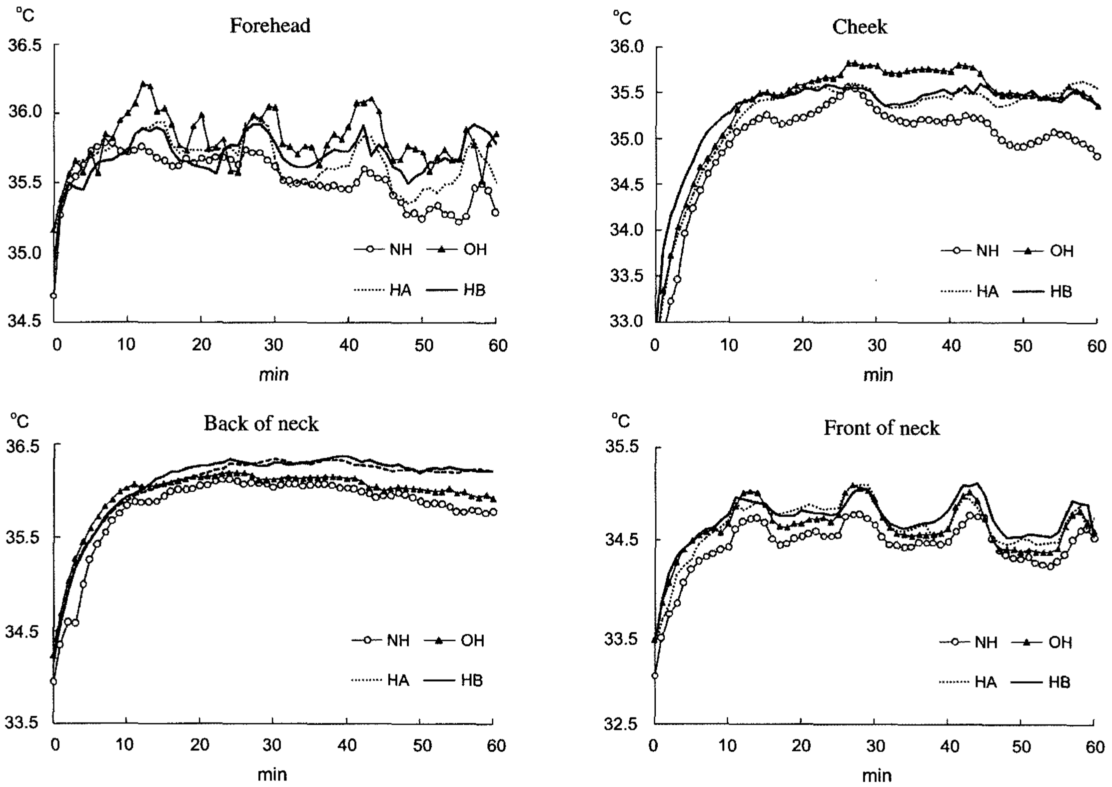

Fig. 6. Changes of skin temperatures at forehead, cheek, back of neck, front of neck.

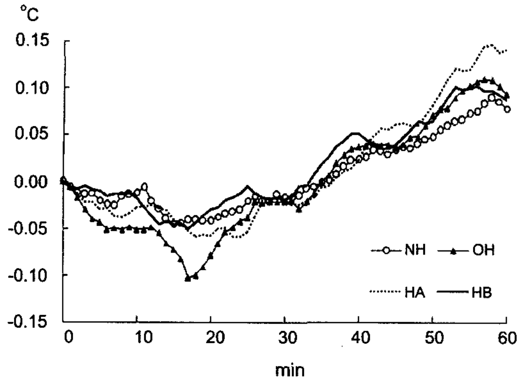

Fig. 7. Changes of rectal temperature increases.

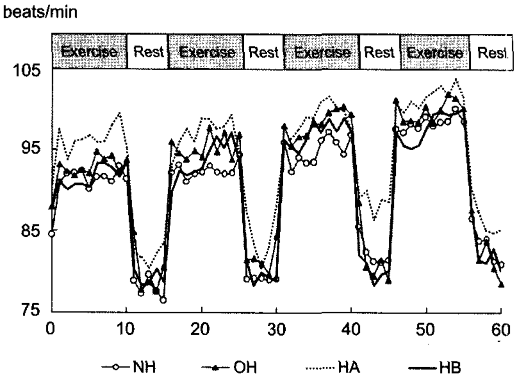

Fig. 8. Time course of heart rates.

Table 4. Clothing microclimate at the chest and thigh

		NH	HA	HB	OH
Chest	Temp. inside clothing (°C)	34.0±1.3^{a}	34.4±1.2^{b}	34.5±1.1^{c}	34.4±1.0^{b}
	Humidity inside clothing (%RH)	70 ±16^{ab}	69 ±19^{a}	71 ±16^{b}	78 ±15^{c}
Thigh	Temp. inside clothing (°C)	33.5±1.2^{a}	33.4±1.2^{a}	33.7±0.9^{b}	33.5±0.9^{a}
	Humidity inside clothing (%RH)	62 ±16^{b}	58 ±16^{a}	66 ±14^{c}	63 ±16^{b}

$p<.05$

Table 5. Subjective sensations

		NH	HA	HB	OH
Thermal sensation	Whole body	2.23	2.14	2.45	2.41
	Head	1.79	1.68	1.61	2.23
Thermal Comfort	Whole body	1.52	1.68	1.75	1.66
	Head	1.32	1.66	1.48	1.73
Wet sensation	Whole body	1.64	1.79	1.77	1.84
	Head	1.25	1.71	1.77	1.75
Subjective workload		1.96	2.07	2.25	2.14

and HB was lower than in OH, but both HA and HB was higher than OH in the front neck and back neck skin temperature($p<.05$). It is considered because the head and cheek are near the frozen gelled pack. However, forehead and cheek skin temperatures in HA and HB were similar with OH from 50 min and higher than OH from 55 min of exposure in the course of time(Fig. 6).

T_r was the lowest in NH and it increased in the following order: HB<OH<HA($p<.05$, Table 3). Time course of T_r showed that it decreased for 20 min at the start of experiment and increased after that in all conditions. T_r increase in HA, in particular, was higher from 50min than others(Fig. 7). In other words, wearing the safety helmet with a light frozen gelled pack raised T_r increase. This result shows that cooling capacity is more effective than weight in core temperature.

However, some skin temperatures except for forehead temperature, $\overline{T}_{sk}$ and T_r in HA and HB were higher rather than in OH(Table 3). The cooling head was positively affected in the head area but it had a opposite tendency in whole body. The increase of weight is regarded as one of the reasons and this results could be considered as the mystery of human body in that cooling head was most affected forehead temperature and was increased other skin temperatures and rectal temperature to maintain homeostasis of body temperature.

4) Heat storage and heart rate

Heat storage was $71.6W/m^2$, $58.5W/m^2$ and $76.9W/m^2$ in HA, HB and OH. Heat storage in HB was the lowest and the difference of it between OH and NH was $9W/m^2$(Table 3).

Heart rate in OH was higher than in NH(p<.05, Table 3). It differed between exercise and rest period and consistently increased according to time course during the same exercise period, as was the case in HA and HB(Fig. 8). Heart rate in HA was higher but in HB was lower than OH(p<.05). This shows that the effects of the frozen gelled pack on physiological responses are different from its cooling capacity, weight and surface area. When heart rate was high, rectal temperature was also high. This finding is consistent with the result of a previous study that rectal temperature correlates positively with heart rate during exercise in hot environment(Kim & Park, 2004). The fact that rectal temperature and heart rate were low in HB shows that heat stress can be reduced when wearing safety helmet with frozen gelled pack B, as compared to wearing only the safety helmet.

From the viewpoint that the method of cooling the head can also lower heart rate in a hot environment, HA was able to lower heart rate and HB not. This result shows that heart rate could be lower if the head is cooled a the frozen gelled pack of intensive cooling capacity in a hot working environment.

5) Clothing microclimate

Temperature inside the clothing at the chest was the lowest in NH. Humidity inside the clothing at the chest was the lowest in HA and both HA and HB, with frozen gelled packs inserted, were lower than OH(p<.05, Table 4). This result shows that the use of frozen gelled pack is effective for lowering humidity inside the clothing at the chest. Clothing microclimate at the thigh did not differ significantly.

6) Subjective sensation

Subjective sensation did not differ significantly but subjects voted that both HA and HB are less hot and less uncomfortable than OH on the head(Table 5). This finding is consistent with the result of a previous study(Katsuura et al., 1996). Thermal sensation, thermal comfort and wet sensation on the whole body were different when frozen gelled pack was used (Table 5), possibly due to the weight of the frozen gelled pack. In subjective sensation of the whole body, HB was hotter, more uncomfortable and more exhausted than HA and in subjective workload, OH was higher than HA and lower rather than HB. The reasons are possibly due to heavy weight of frozen gelled pack B. Because the frozen gelled pack B is 20g heavier than the frozen gelled pack A, the physiological strain might be increased while working in a hot environment. However, future studies should consider the weight of the frozen gelled packs, which, in this study, could not be controlled due to the limited goods available in the market.

OH was the most uncomfortable for the head. This result is consistent with the result of a previous study that showed the increase of sweat has a high correlation with discomfort in hot environment(Gagge et al., 1967).

Thermal sensation, thermal comfort and wet sensation of the head was closely correlated with cheek, $\bar{T}_b$ and cheek, respectively(p<.01).

At this time, this study showed physiological strain when wearing safety helmet and the possibility of reducing heat stress through physiological and subjective measures by using frozen gelled packs. Considering the fact that the head takes up only 7~10% of the total body surface area, it is interesting that head cooling improves physiological responses and thermal sensation. However, further study is suggested for frozen gelled packs that are light in weight and better fitted for the head because it was difficult in this study to explain in full the shape and weight of the frozen gelled packs.

IV. Summary and Conclusions

This study was conducted to investigate physiological responses to safety helmets and to examine the effects of frozen gelled packs inside the helmets in a hot environment. To address these problems, human wear test was performed on four males participant. Experiments were conducted in a climatic chamber at WBGT 33±1°C, under four experiment conditions: NH(not wearing a safety helmet), HA (wearing a safety helmet with frozen gelled pack A), HB(wearing a safety helmet with frozen gelled pack B) and OH(wearing only safety helmet). The results are as follows:

1) When comparing NH with OH, physiological responses such as $\overline{T}_{sk}$, T_r, heart rate and sweat rate were significantly higher and subjective sensation were less hot, more comfort in OH than in NH($p<.05$). In particular, skin temperature increases in OH were high on the forehead, cheek, front neck and back neck area, affected by wearing safety helmet.

2) When considering the frozen gelled packs that were inserted inside the safety helmets, some physiological responses in HA varied from those in HB according to which frozen gelled pack was used. HA was hotter, more uncomfortable and less exhausted than HB. However, temperature and humidity inside safety helmet, weight loss, local sweating, T_r increase and heat storage were lower in both HA and HB than in OH($p<.05$).

3) Both HA and HB were rated less hot and less uncomfortable than OH on the head. Subjective sensations during exercise and rest in hot environment were significantly correlated to the physiological responses. Thermal sensation, thermal comfort and wet sensation were correlated to cheek, $\overline{T}_b$ and cheek, respectively, in hot environment($p<.01$).

This study is expected to help millions of workers who consider wearing safety helmets as uncomfortable and messy.

References

Abeysekera, J. D. & Shahnavaz, H. (1990). Adaptaion to discomfort in personal protective devices: An example with safety helmets. *Ergonomics*, *33*(2), 137–145.

Brown, G. A. & Williams, G. M. (1982). The effect of head cooling on deep body temperature and thermal comfort in man. *Aviation, Space, and Environmental Medicine*, *53*(6), 583–586.

Cohen, J. B., Allan, J. R., & Sowood, P. J. (1989). Effect of head or neck cooling used with a liquid-conditioned vest during simulated aircraft sorties. *Aviation, Space, and Environmental Medicine*, *60*, 315–320.

Crawshaw, L. I., Nadel, E. R., Stolwijk, J. A. J., & Stamford, B. A. (1975). Effect of local on sweating rate and sold sensation. *Pflgers Arch*, *354*, 19–27.

Froese, G. & Burton, A. C. (1957). Heat losses from the human head. *Journal of Applied Physiology*, *10*(2), 235–241.

Gagge, A. P., Stolwijk, J. A. J., & Hardy, J. D. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. *Environmental Research*, *1*(1), 1–20.

Gavhed, C. E. D. & Holmer, I. (1989). Thermoregulatory responses of firemen to exercise in the heat. *European Journal of Applied Physiology*, *59*, 115–122.

Hardy, J. D. & Dubois, E. F. (1938). Basal metabolism, radiation, convection and vaporization at temperatures of 22 to 35°C. *The Journal of Nutrition*, *15*(5), 477–497.

Hayashi, C. & Tokura, H. (1996). Effects of head cooling on sweat rate in exercising subjects wearing protective clothing and mask for pesticide. *Applied Human Science*, *15*(4), 149–154.

Holland, E. J., Laing, R. M., Lemmon, T. L., & Niven, B. E. (2002). Helmet design to facilitate thermoneutrality during forest harvesting, *Ergonomics*, *45*(10), 699–716.

ISO 9920. (1995). *Ergonomics of the thermal environment: Estimation of the thermal insulation and evaporative resistance of a clothing ensemble.* ISO Geneva.

Jung, D. J. (1994). The difference of the sweat rate and skin temperature according to environments during submaximal exercise. *J. Kor. Soc. Tan-Therm. Environ. Sys.*, *1*(1), 49–54.

Katsuura, T., Tomioka, K., Harada, H., Iwanaga, K., & Kikuchi, Y. (1996). Effects of cooling portions of the head on human thermoregulatory response. *Applied Human Science*, *15*(2), 67–74.

Kim, H. E. & Park, S. J. (2004). The effect of safety hat on thermal responses and working efficiency under a high temperature environment. *Applied Human Science*, *23*(5), 149–153.

Kissen, A. T., Summers, W. C., & Buehring, W. J. (1976). Head and neck cooling by air, water, or air plus water in hyperthermia. *Aviation, Space, and Environmental Medicine*, *47*(3), 265–271.

Lee, B. H. (1996). *Safety · Sanitation protective equipment.* Seoul: DongHwa Technology Publishing Co.

Liu, X. & Holmer, I. (1995). Evaporative heat transfer characteristics of industrial safety helmets. *Applied Ergonomics*, *26*(2), 135–140.

Liu, X. & Holmer, I. (1997). Evaluation of evaporative heat transfer characteristics of helmets. *Applied Human Science*, *16*(3), 107–113.

McCaffrey, T. V., Geis, G. S., Chung, J. M., & Wurster, R. D. (1975). Effect of isolated head heating and cooling on sweating in man. *Aviation, Space, and Environmental Medicine*, *46*(11), 1353–1357.

Nunneley, S. A. & Maldonado, R. J. (1983). Head and/or Torso cooling during simulated cockpit heat stress. *Aviation, Space, and Environmental Medicine*, *54*(6), 495–499.

Park, J. H. & Choi, J. W. (2006). Work clothes and working environment of workers at a construction site in summer. *Proceedings of the Korean Society of Clothing and Textiles, 30*, 106.

Park, S. B. (1994). Characteristics of super absorbent polymer and state of the art. *Mokchae Konghak, 22*(1), 91–112.

Proctor, T. D. (1982). A review of research relating to industrial helmet design. *Journal of Occupational Accidents*, *3*, 259–272.

요 약

안전모는 다양한 산업현장에서 머리 보호를 위해 착용되는 보호구로 법적으로도 착용이 의무화되어 있다. 그러나, 안전모 착용에 따른 불쾌감 및 생리적 부담은 작업자들이 착용을 꺼려하는 주된 원인이 된다. 본 연구에서는 이 문제를 해결하기 위한 하나의 방안으로 안전모에 냉매팩을 삽입하는 방법을 제안하였고, 동시에 냉매팩 삽입으로 인한 안전모의 무게 증가가 인체생리반응에 미치는 영향을 규명하고자 하였다. WBGT 33±1°C의 환경에서 인체착용평가 방법을 이용하여, 4가지 실험조건으로 안전모 착용시의 인체 생리반응을 조사하였고, 그 결과는 다음과 같다. 첫째, 안전모만 착용 시(OH)와 안전모 미착용시(NH)를 비교해 보면, 안전모 착용 시에 평균피부온, 직장온, 심박수, 발한량 등이 통계적으로 유의하게 높았고, 주관적인 감각에서도 더 덥고, 더 습하며, 불쾌하고 주관적으로도 힘들다고 느끼는 것으로 나타났다. 둘째, 냉매팩 삽입시의 경우(HA, HB), 냉매팩의 종류에 따라 여러 인체생리반응에 차이를 보였으나, 안전모만 착용한 경우(OH)와 비교 시 안전모내 기후, 발한량, 직장온 상승도, 열저장(heat storage) 등이 더 낮았다. 한서감과 쾌적감에서는 냉매팩 종류에 따라 다른 경향을 보였다. 본 결과를 통해 안전모 착용시의 생리적, 주관적 부담 정도를 객관적으로 파악할 수 있었으며, 안전모에 냉매팩을 삽입하는 방법을 서열 스트레스를 경감시키는 하나의 방법으로 제시할 수 있었다. 추후 연구에서는 냉매팩의 무게, 피복면적, 성분 등을 고려해야 할 것이며, 본 결과가 서열 환경에서 안전모를 착용하고 작업하는 여러 산업 근로자에게 도움이 되기를 기대한다.