생활과학석사 학위논문

Effects of Cross-Adaptation and Aging on Heat Tolerance of Haenyeo during Passive Heating

노화와 교차적응이 수동적 서열환경에서 해녀의 내열성에 미치는 영향

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Abstract

Effects of Cross-Adaptation and Aging on Heat Tolerance of Haenyeo during Passive Heating

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Korean haenyeo had been well-known for their unique adaptation to cold exposure, diving into cold sea water even in winter with wearing thin cotton-suit. Not only 'cross-adaptational' effect of cold exposure but also repetitive swimming could affect the heat tolerance of haenyeo despite the development of wetsuit.

Heat tolerance induced by passive heat stress was examined through evaluating perspiratory and thermoregulatory responses. In a climate chamber where the air temperature was maintained at 28°C and the relative humidity at 50% RH, total 28 subjects (10 older haenyeos, 8 older females and 10 young females) immersed their leg under knees in 42°C hot tub for an hour. It was showed that haenyeos had the highest total sweat rate and maintained their sweat glands function. The heart rate was significantly lower than the other two groups and blood pressure was as low as young females.

These results suggest that lifetime-cold exposure of haenyeos had affected their heat tolerance positively by cross-adaptational effect and underwater swimming reduced the effect of aging on cardiovascular health.

Keywords: Haenyeo, heat tolerance, cross-adaptation, aging, hot-water immersion
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List of Abbreviations

ASGD	Activated sweat glands density
BP	Blood pressure
BSA	Body surface area
HR	Heart rate
LSR	Local sweat rate
MAP	Mean arterial pressure
SS	Sweat sensation
TC	Thermal comfort
ThS	Thirsty sensation
T_{re}	Rectal temperature
TS	Thermal sensation
T_{sk}	Skin temperature
TSR	Total sweat rate

Chapter 1 Introduction

Haenyeos, Korean women breath-holding divers, still have been working since their youth. They consume much energy while they work in the cold sea water ranging 260~370 kcal (Park, 1985). When they finish under water working, they carry the collected sea food which weighed up to 70 kg to shore although they are over 70 years old. Inoue et al., reported that the highly healthy older showed the same level on total sweat rate with the young but the average older showed lower level of sweat rate than the healthy older and young did during the exercise (Inoue et al., 1999). In this aspect, the older haenyeos who are physically fit due to the daily work are expected to have heat tolerance at the same level as the young. It is reported that an acclimation to a certain environment could affect physiological responses to any other stimulations. Many research suggested a great deal evidence that heat acclimation could have an effect on cold tolerance. In this sense, cold tolerance induced by repetitive cold-exposure also have a possibility to enhance heat tolerance by cross-adaptation.

The physiological function slowly decreases as people age. Aging affects a wide range of systemic functions, which include recognition, sensing, skeletal muscle, sweat responses or etc. Not only reduced physiological responses, but also cognitional absence of increased body temperature can cause heat−shock of the older. Indeed, the older took large portion of patients who visited a hospital due to heat−shock. In summer, when the highest air temperature soars up to 35°C in Korea, the news that old farmer passed away because of heat shock from the field work are easy to be found. Recently, 11 people had died during two weeks in a row in August, 2015 and seven of them were the old (KBS news, 2015). In addition, there have been worries about the aging society problem in Korea. Statistics Korea (KOSTAT) predicted that the population ratio of the old over 65 in age would reach 15% in 5 years, which also means that Korea might be classified as one of the aged societies (KOSTAT, 2014). As a result, the increase of population who cannot respond to heat properly suggests necessity of studies on heat tolerance of the old.

The purpose of the present study was investigating the heat tolerance of haenyeos to find out the possibility of cross−adapatational effect of cold exposure and effects of aging on heat tolerance, comparing physiological responses among the three groups (older haenyeos, older females, young females) during the passive heat stress.

In the present study, we hypothesized that

H1. The heat tolerance of older haenyeos would be superior to that of the older females under the influences of cross–adaptation of cold exposure.

H2. The heat tolerance of the older haenyeos and the older females would be inferior to that of the young females due to the effects of aging.

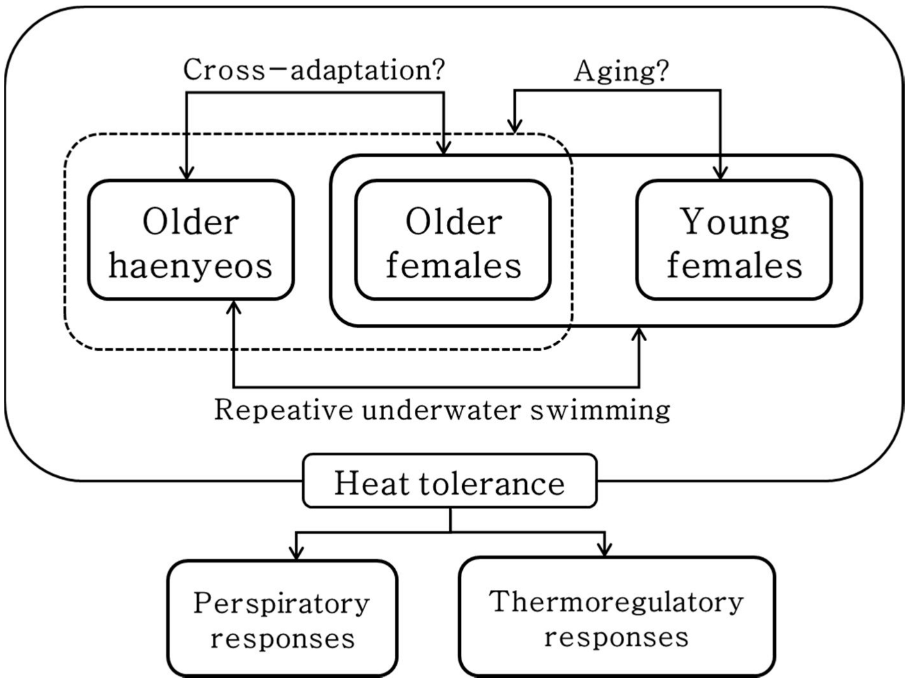

Figure 1.1 The hypothesis and parameters of the present study

Chapter 2 Theoretical Backgrounds

2.1 Haenyeo

Korean woman divers, haenyeos, have been well-known for their occupational uniqueness. They dive into the sea water where the water temperature is lower than body temperature (average water temperature: 25℃ in summer, 10℃ in winter) without breathing equipment. The older haenyeos have experienced the extremely cold environment since the earlier than 1970's when they dived into sea water in winter only with wearing a cotton bathing suit at that time. Until now they still work in the sea water wearing wetsuits and the duration of work is about 2~3 hours (Lee and Lee, 2014).

Due to this repetitive cold exposure, haenyeo is thought to be highly cold-acclimatized. In the 1970's, when they wore cotton-suit, haenyeo showed ~35% higher basal metabolic rate (BMR) in the inter than in warmer seasons. On the other hands, non-divers showed the same level of BMR throughout the year (Kang et al., 1963). The threshold of shivering of haenyeos was significantly lower than the non-divers which is another indicator of cold-acclimation. Haenyeos also showed greater body insulation than the other ethnics groups (Hong, 1973).

Nowadays, haenyeos are thought to be de-acclimatized since they have worn the wetsuits from 1970's. There had been some evidences that indicates the loss of cold acclimatization by time. Haenyeos lost seasonal changes of metabolic rate and BMR (Gisolfi and Mora, 2000). They also lost the difference of skin temperature and blood flow during cold water hand-immersion compared to non-divers (Park and Hong, 1991). Park et al. reported that wearing wetsuit diminished cold acclimatization (Park et al., 1983).

However, haenyeos still work inthe severe cold while they dive in the sea water even though they wear wetsuit. The work place where they spend a couple of hours per day on average is underwater. The heat conductivity of water is 24 times that of the air so the heat loss induced during the work must be more considerable than working on the ground. Indeed, haenyeos reported that they feel cold on their hands, feet and face which were excluded from the protection of wetsuits (Lee et al., 2015).

2.2 Physiological aging

2.2.1 Definition

The word 'aging' is very familiar but its cause and definition still have been on debate. Its definition varies depending on the research field. In physiology, aging is defined as physiological changes because of the decrease in the function of various organ system with age. In other words, the aging is the processes in an organism that increase the mortality risk as a function of time (Thor, 2011). Aging can affect nervous, cardiovascular, musclular, and many other systems.

2.2.2 The older in heat stress

The older could be in danger exposed to heat stress since their effectors cannot respond to the heat because of the functional decrease. Age-related functional declines in several physiological functions of sweat gland function, skin blood flow, cardiac output, blood flow redistribution, etc. (Kenny and Munce, 2003).

Not only peripheral effectors, afferent nervous system could be affected by aging. There are gradual decrease on thermal sensitivity since the middle age (Levy, 1994). Aging also has impacts on the decrease of thermal pain threshold and perception of thermal stimuli. Chao et al. suggested the process of declining thermosensing. The density of peripheral nerves and epidermal innervation decrease with age. In addition, age-related changes might occur from neurotransmitter synthesis to action in brain and spinal cord. These changes could be the reason of alteration in the thermal sensitivity, further, in pain (Chao et al., 2007). As a result, clear reduction of thermal sensitivity might occur in the older. This could be led to the risk of heat injuries (Tochihara et al., 1993).

Loss of muscle elasticity is very critical factor which makes the older weak in the heat stress. In the older subjects, local sweating rates could be lower compared to the young subjects. It is smaller output per activated sweat gland which might contribute to the lower sweat secretion in the older subjects, not density of activated sweat glands. Numerous research reported that the weakening of skeletal muscle function correlates with the sweat glands decline. It was also reported that there was a reduction of the sweating responses in the older, as well as an elevated sweating threshold in body temperature (Foster et al., 1976). Blood vessels also lose their elasticity so that vasodilation which should occur in hot environment diminishes. Reduced vasodilation results in the decrease of skin blood flow. As a result, the old might not dissipate their body heat outside in heat stress, which means they have a risk of heat shock under hot environment.

2.2.3 Aging vs. acclimation and fitness

Despite it has been accepted that reduction of heat tolerance could be induced by aging, there had been research which investigated the heat tolerance of the old, who were physically active fit. Those researches suggested that aerobic fitness might be the important factor which affects the thermoregulatory response (Pandolf, 2007). Inoue et al. (1999) reported that the older who were highly fit in an aerobic capacity showed the same level at the total sweat rate. But the heat acclimation was less effective to the older than the young.

2.3 Cross-adaptation

2.3.1 Concept of cross-adaptation

The long-term exposure to a certain environment, whether continuous or intermittent, not only increases tolerance to a particularly given environment but also affect tolerance to other adverse factors. These factors could be what one never experiences before. This concept is called ‘cross-adaptation’. If a tolerance on a certain exposure to a stimulation develops, physiologic decrease of other stimulation is called crossed sensitization or negative cross-adaptation, and physiologic increased responses induced from the exposure is crossed resistance or positive cross-adaptation (Hale, 1969).

2.3.2 Cross-adaptation in other species

There had been a great deal of previous research that investigated cross-adaptation in many species, such as plants or animals. Rats which were exposed to the three-hour immobilization stress showed an enhanced capacity of non-shivering thermogenesis through increasing brown adipose tissue (BAT) and mitochondria density in BAT (Kuroshima, 1984). Puma rye (Secale cereale) showed the accumulation of heat stable proteins, simple sugars and long chain carbohydrate polymers, which indicates the adaptation to heat shock, during cold acclimation process. Many other research also found cross-adaptation responses and the 'Cross-adaptation' could be interesting research area since acclimation to the test environment can affect the tolerances of stresses which seems 'irrelevant' at a glance.

2.3.3 Cross-adaptation in human

There were also evidences which showed cross-adaptation in human. The heat acclimation through five consecutive days at 55°C ambient temperature for one hour per day lowered threshold of shivering and sweating responses which indicates cross-adaptation could be produced between heat and cold stresses (Hessemer et al., 1986). Lunt et al. reported generic autonomic cross-adaptive effect between cold adaptation and acute hypoxia-exposure in humans. The subjects who had been exposed to the cold water showed lower level of catecholamine concentration in hypoxic exposure (Lunt et al., 2010).

Chapter 3 Methods

3.1 Subjects

Twenty eight subjects (10 older haenyeos; 8 older females; 10 young females) participated in the study. The anthropometric characteristics of three groups were summarized in Table 3.1.

The experimental content, purpose of the study, and potential risks of the experiment were informed to the subjects before participating in an experiment. After an explanation of the study, written informed consent was obtained.

The experimental trials was conducted in Seoul National University, Korea, from August to late September. The older haenyeos, who lived in Jeju island, Korea, were brought from Jeju to Seoul after approving to participate in the study. Since the young female subjects were premenopausal, their experimental trials were scheduled within 10 days before ovulatory phase in the menstrual cycle of each subject.

This study was approved by the Institutional Review Board of Seoul National University (IRB Number: 1502/001-011).

Table 3.1 The anthropometric characteristics of the subjects (Mean±SE).

Group(N)	Young females(10)	Older females(8)	Haenyeos (10)	*P*-value
Age(yr)	23.4±1.9	70.8±3.8	75.1±3.5	<0.001
Height(cm)	163.0±4.4	152.6±5.0	154.5±5.4	0.001
Body weight(kg)	58.7±8.2	53.2±7.0	59.1±6.8	0.18
BSA(m^2)	1.63±0.13	1.50±0.11	1.57±0.10	<0.001

BSA: body surface area

3.2 Experimental procedure

The subjects were given 300 mL of water after arriving at the laboratory. Then, they changed their clothes to provided undershorts, a brassiere, shorts and a round T-shirt. To measure specific gravity of urine (PAL-10S, ATAGO, Japan), a small amount of urine was obtained in a small paper cup. Their body weight were measured with a body scale (ID2, Mettler-Toledo, Germany) before the experimental trial to estimate total sweat rate. After self-inserting of rectal probe, which was provided to subjects with lubricant (Silgreen cream, SEONG KWANG pharmacy, Korea), thermal probes were attached on 7 sites (the forehead, chest, forearm, dorsal hand, thigh, calf, and dorsal foot; all probes were on left side) and the heart rate sensing belt was worn on the chest.

The blood pressure cuffs was worn on the right upper arm. Local sweat rate probes were attached on the forehead, back (on latissimus dorsi) and right forearm.

Ten minutes of stabilization period was undertaken in the climate chamber maintained at an air temperature 28℃ and relative humidity 50%. They sat on a stool and subjective perceptions were asked on the 7^{th} min of the stabilization period. After the stabilization period, their legs under knees were immersed in the hot−water (42℃) tub (LH−300, LIMHO Industry Co., Korea) for an hour. Subjective perceptions were asked on every 10 min and activated sweat glands density was measured on the forehead, back, and forearm on every 20 min during immersion.

After immersion period, their body weight were measured again. All probes were detached and urine was obtained again to measure the difference between specific gravity of urine before and after the experimental trial.

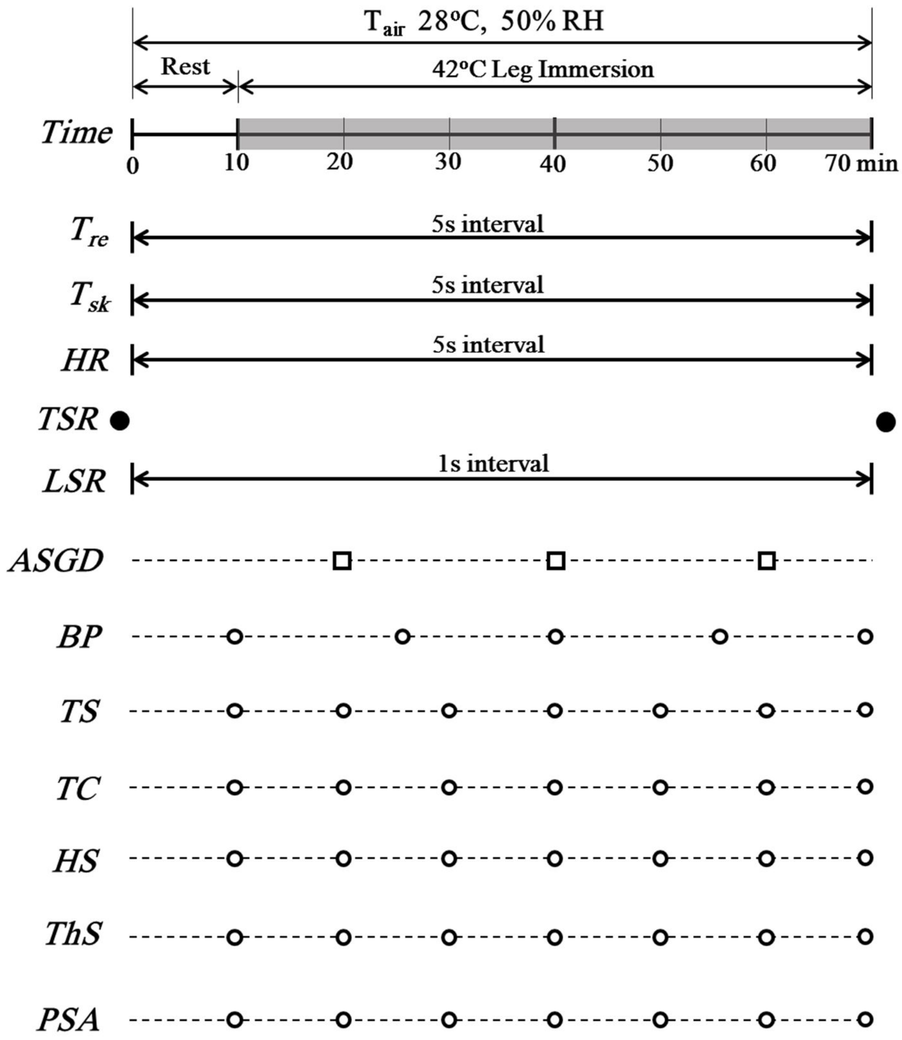

Figure 3.1 The time course of an experiment and measurements. T_{re}: rectal temperature, T_{sk}: skin temperatures, HR: heart rate, TSR: total sweat rate, LSR: local sweat rate, ASGD: activated sweat gland density, BP: blood pressure, TS: thermal sensation, TC: thermal comfort, HS: humidity sensation, ThS: thirsty sensation, PSA: perceptive sweated area.

3.3 Measurements

To compare heat tolerance among three groups, thermal, cardiovascular, perspiratory responses and subjective perceptions were measured during the experiments (Figure 3.2).

As a body temperature, skin temperatures (T_{sk}) and rectal temperature (T_{re}) were measured on every 5 s. T_{sk} were measured on seven areas: the forehead, chest, upper arm, dorsal hand, thigh, calf, dorsal foot. All probes were on left side of the body. T_{re} was measured with a rectal probe inserted in 16 cm depth from the anal sphincter. The data logger (LT−8A, GRAM corps., Japan) automatically recorded the temperatures from thermal probes on every 5 s. Mean skin temperature ($\bar{T}_{sk}$) was calculated (Hardy and DuBois, 1937) by the DuBois' mean skin temperature equation (Eq. 3.1).

$$\bar{T}_{sk} = 0.07 \cdot T_{forehead} + 0.35 \cdot T_{chest} + 0.14 \cdot T_{forearm} + 0.05 \cdot T_{hand} + 0.19 \cdot T_{thigh} + 0.13 \cdot T_{calf} + 0.07 \cdot T_{foot} \quad .... \quad \text{[Eq. 3.1]}$$

Heart rate (*HR*) and blood pressure (*BP*) were measured as cardiovascular responses. The watch−type data receiver (RC3GPS, Polar, Finland) recorded the HR on every 5 s. *BP* (HEM−7200, OMRON, Japan) was measured on every 10 min during the experiments. As *BP* could be affected by a small motions or cough, the measurements of *BP* were repeated three times and averaged. Systolic and diastolic *BP* were determined to mean arterial pressure (MAP) with Eq. 3.2.

$$\textbf{Mean arterial pressure (MAP)} = (P_{sys})/3 + 2(P_{dia})/3 \quad \text{[Eq. 3.2]}$$

Total sweat rate (*TSR*), local sweat rate (*LSR*) and activated sweat glands density (*ASGD*) were selected as parameters that could represent the thermal state of subjects in passive heat stress. *TSR* was estimated from the difference of body weight of the subjects before and after the experimental trial. The *LSR* were measured (SKN-2000 & SKD-2000, SKINOS, Japan) during the trial on every second. The sampling area of the *LSR* probe was 0.98 cm^2 and the *LSR* on the forehead, back and forearm were divided with the area to obtain *LSR* on unit area.

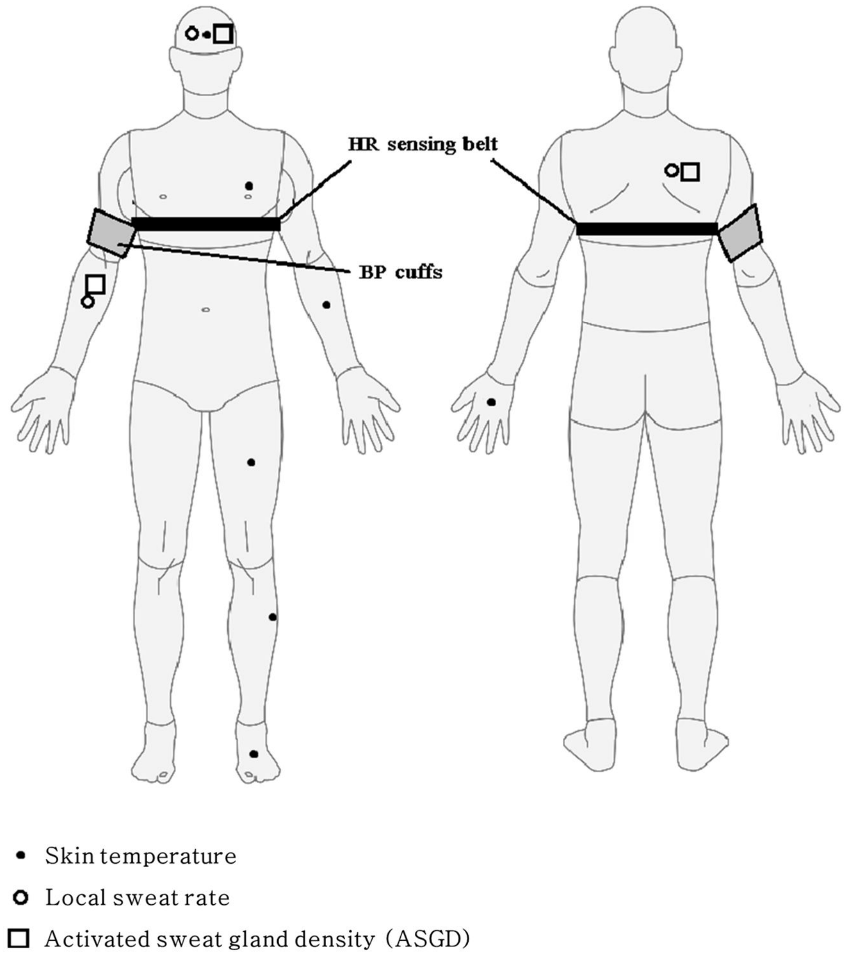

Figure 3.2 A diagram of measurement sites where skin temperatures, local sweat rates, activated sweat gland density (*ASGD*), heart rate (*HR*) and blood pressure (*BP*) were measured.

The activated sweat glands density (*ASGD*) was measured by the iodine−impregnated paper method (Inoue, 1996). The cotton paper which was not sized nor coated was cut into $3*3cm^2$ and left in desiccator with solid iodine for 24 h. The color of the paper pieces was turn into dark brown color after 24 h. When the paper piece contacted with sweating skin, small purple dots appear where the sweat glands were activated by iodine−starch reaction. Iodine−impregnated papers with dots were scanned immediately after the termination of trial. Counting the number of sweat glands was conducted with these scanned images. The counting was conducted after drawing a $1*1cm^2$ square on the scanned image.

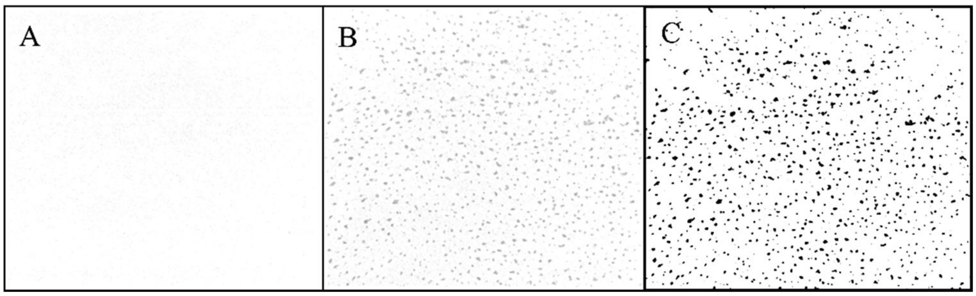

Figure 3.3 Analyzing activated sweat gland density by iodine impregnated paper method. A: The iodine paper, B: The iodine paper after contact with sweating skin, C: The modified image of B.

3.4. Statistical analysis

Statistical analysis were perform with IBM SPSS v. 21.0 to compare physiological responses during passive heat−exposure among three groups. A one−way ANOVA was used to find out if there were differences among parameters of subjects groups with Duncan's *post−hoc* test. All data were expressed in mean±SE and statistical significance was acceptable when the *P*−value was smaller than 0.05.

Chapter 4. Results

4.1 Total sweat rate

Total sweat rate (*TSR*) and total sweat rate per body surface area (*TSR*/*BSA*) were calculated from the difference of body weight after passive heat exposure. The haenyeos showed the highest TSA (196.6±24.5 g·hr^{-1}) among three groups, which is significantly higher (*P* = 0.010) than the older females (111.8±9.1 g·hr^{-1}). There was no significant difference in *TSR*/*BSA*, but haenyeos showed a tendency to have higher *TSR*/*BSA* (*P* = 0.064) than other two groups (89.2±5.7 g·hr^{-1} and 80.3±10.0 g·hr^{-1} for the younger females and older females, respectively).

Table 4.1 Total sweat rate (*TSR*) and total sweat rate per body surface area (*TSR*/*BSA*) of young females, older females and haenyeos during the hot water-leg immersion (Mean±SE).

	Young females	Older females	Haenyeos	*P*-value
TSR (g·hr^{-1})	144.3±8.2	111.8±9.1	196.6±24.5	0.010
TSR/BSA (g·hr^{-1}·m^{-2})	89.2±5.7	80.3±10.0	127.0±17.0	0.064

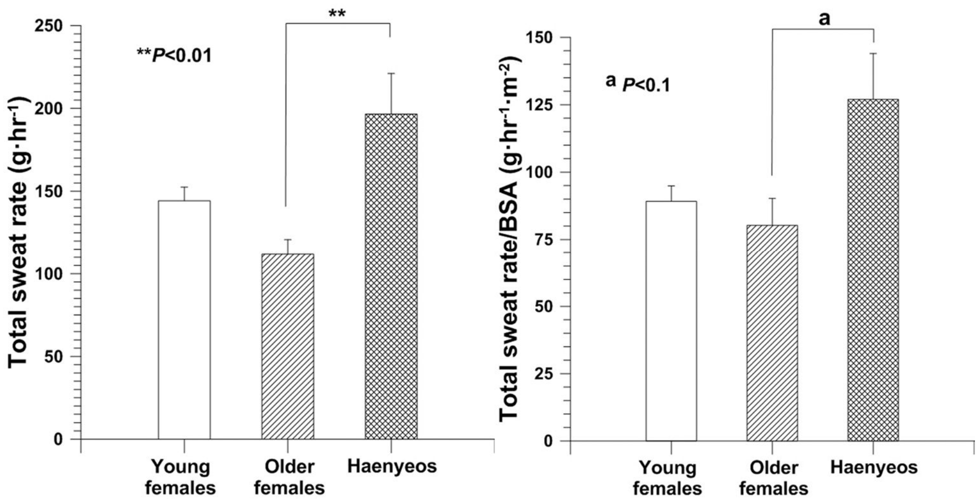

Figure 4.1 Total sweat rate (*TSR*) and total sweat rate per body surface area (*TSR/BSA*) of young females, older females and haenyeos during the hot water−leg immersion (Mean±SE).

4.2 Local sweat rate

LSR measured on the forehead, back and ventral forearm were showed in Figure 4.2, 4.3 and 4.4.

LSR showed no significant difference among three groups, however haenyeos showed tendency to have highest *LSR* on the forehead and back. The younger females also showed tendency to have highest *LSR* on the forearm.

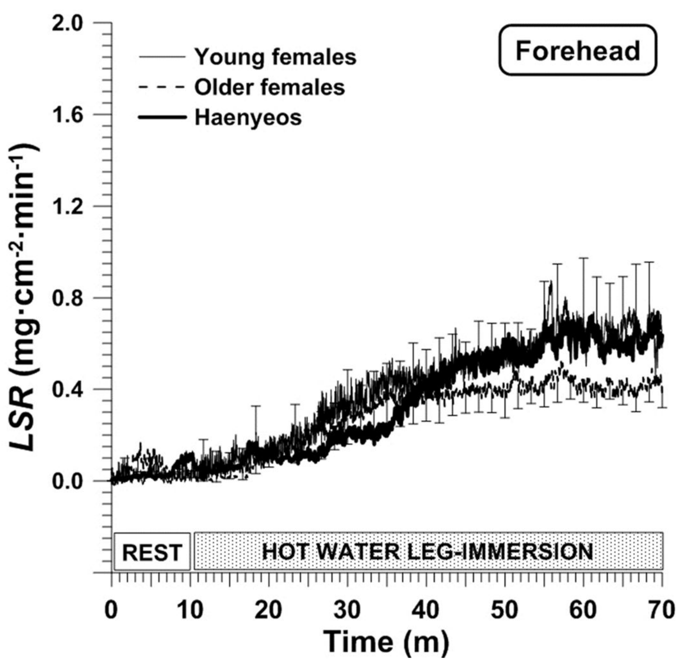

Figure 4.2 Local sweat rates (*LSR*) on the forehead of young females, older females and haenyeos during passive heat stress (Mean±SE).

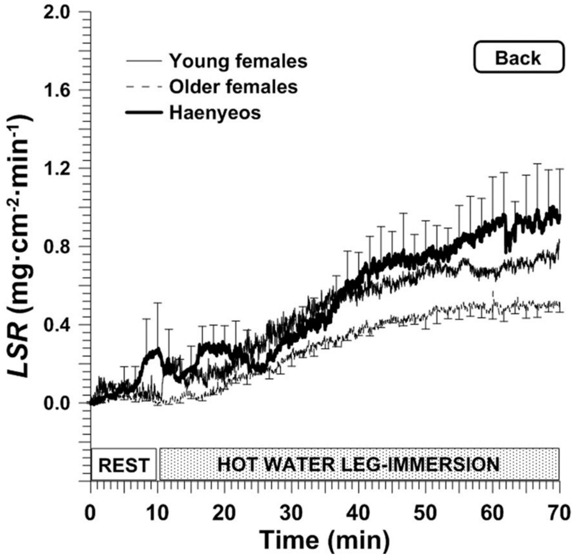

Figure 4.3 Local sweat rates (*LSR*) on the back of young females, older females and haenyeos during passive heat stress (Mean±SE).

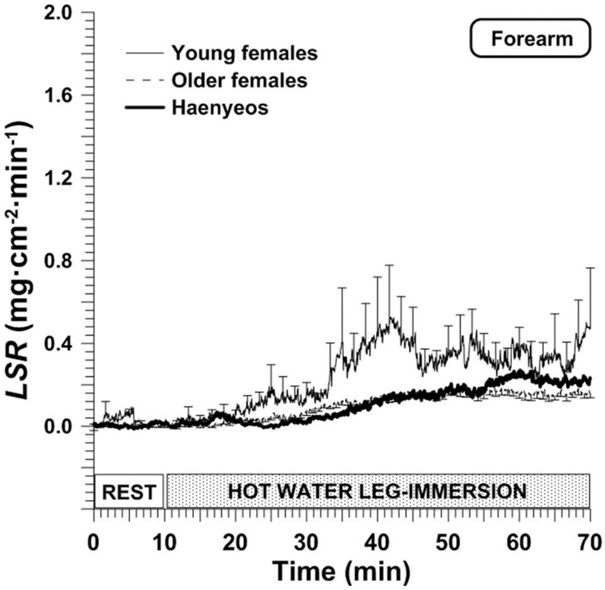

Figure 4.4 Local sweat rates (*LSR*) on the forearm of young females, older females and haenyeos during passive heat stress (Mean±SE).

Table 4.2 Local sweat rates on the forehead, back and forearm of young females, older females and haenyeos at last 5 min of hot water−leg immersion (Mean±SE).

Local sweat rate ($mg \cdot cm^{-2} \cdot min^{-1}$)		Younger females	Older females	Haenyeos	*P−value*
Forehead	0~10th	0.02±0.01	0.06±0.03	0.02±0.01	0.439
	65~70th	0.67±0.21	0.42±0.08	0.62±0.08	0.422
Back	0~10th	0.07±0.03	0.17±0.01	0.03±0.04	0.385
	65~70th	0.74±0.13	0.49±0.06	0.91±0.25	0.140
Forearm	0~10th	0.02±0.01	0.00±0.01	0.00±0.01	0.515
	65~70th	0.36±0.18	0.16±0.02	0.21±0.04	0.555

*The time expressed as 00th meant the time from the beginning of the experimental trial which included the stabilization period.

4.3 Activated sweat gland density

ASGD of haenyeos showed significant difference only on the forehead on the 50^{th} min of immersion (P = 0.006). Haenyeos also showed regional difference (P = 0.016) at the 10^{th} min of the immersion, however, the other groups did not. From the 30^{th} min of the immersion, all three groups showed regional differences.

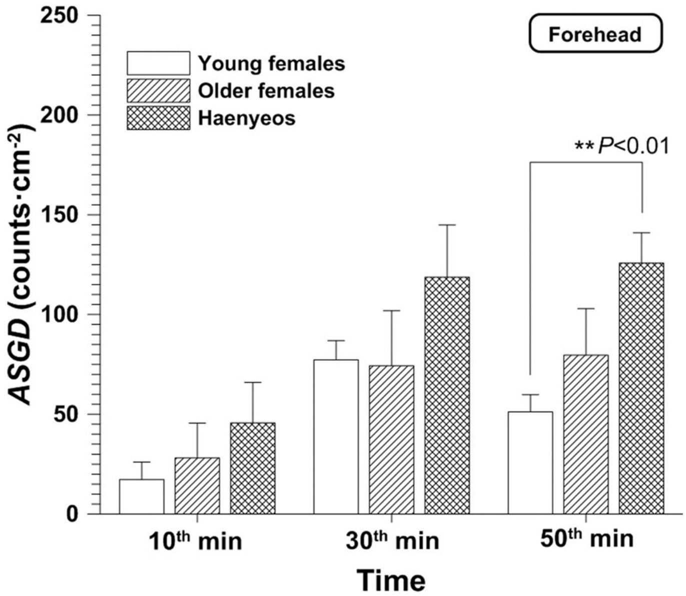

Figure 4.5 Activated sweat gland density (*ASGD*) on the forehead of young females, older females and haenyeos during passive heat stress (Mean±SE).

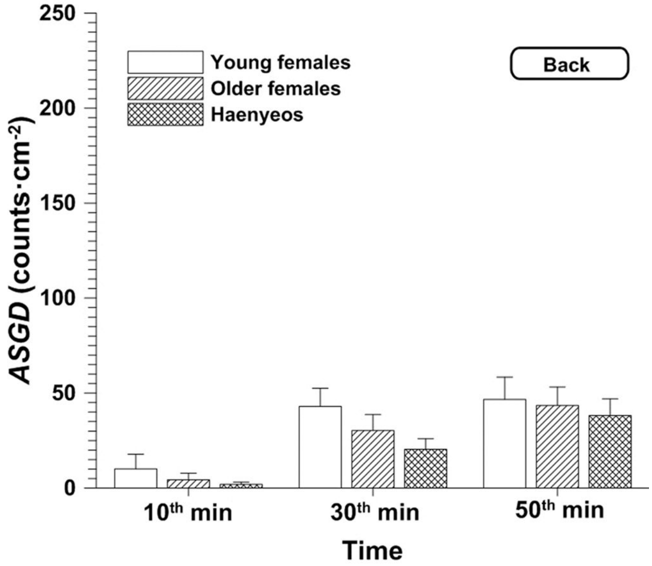

Figure 4.6 Activated sweat gland density (*ASGD*) on the back of young females, the older females and haenyeos during passive heat stress (Mean±SE).

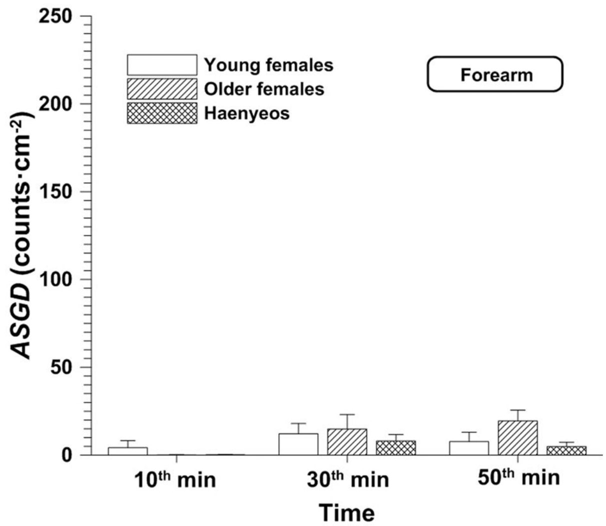

Figure 4.7 Activated sweat gland density (*ASGD*) on the forearm of young females, the older females and haenyeos during passive heat stress (Mean±SE).

Table 4.3 Activated sweat gland density (*ASGD*) of young females, older females and haenyeos (Mean±SE).

ASGD (counts/cm^2)		Younger females	Older females	Haenyeos	*P-value*
Forehead	10th min	17.3±8.8	28.1±17.5	45.6±9.5	0.459
	30th min	77.3±9.6	74.4±27.5	118.7±26.1	0.291
	50th min	51.2±8.6	49.6±23.3	125.7±15.2	0.006
Back	10th min	10.1±7.7	4.4±3.5	1.9±1.3	0.473
	30th min	43.0±9.5	30.3±8.5	20.4±5.6	0.126
	50th min	46.7±11.7	43.5±9.7	38.2±8.8	0.825
Forearm	10th min	4.2±4.1	0.1±0.1	0.2±0.2	0.410
	30th min	12.2±5.8	14.9±8.2	8.0±3.7	0.701
	50th min	7.7±5.3	19.4±6.3	4.9±2.4	0.100

*The time expressed as 00th meant the time from the beginning of the immersion which did not include the stabilization period.

4.4 Rectal temperature

The rectal temperature showed significant difference since the 45th min of the immersion (P = 0.050). The increase of rectal temperature during immersion also showed that the increase of haenyeo group was higher than those of young female group (P = 0.009).

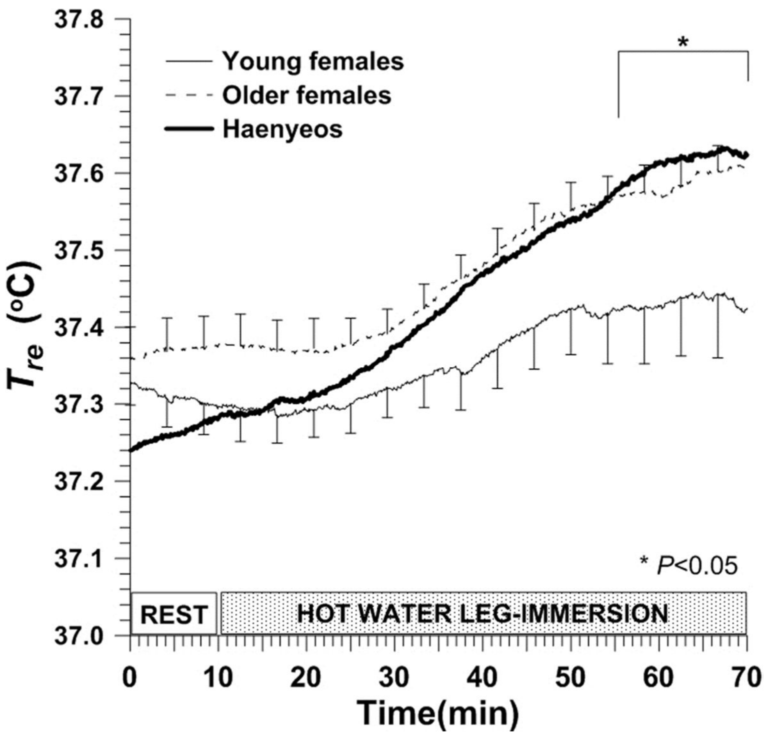

Figure 4.8 Rectal temperature (T_{re}) of young females, older females and haenyeos during passive heat stress (Mean±SE).

Table 4.4 Summary of rectal temperature of young females, older females and haenyeos during passive heat stress (Mean±SE).

T_{re} (°C)	Young females	Older females	Haenyeos	*P*−value
Before immersion	37.33±0.03	37.36±0.04	37.26±0.04	0.103
After immersion	37.44±0.08	37.59±0.03	37.62±0.03	0.050
ΔT_{re}	0.11±0.06	0.22±0.05	0.36±0.05	0.009

4.5 Mean skin temperature

There was significant difference among three groups in $\bar{T}_{sk}$ during stabilization period and first 15 min of the immersion. These differences disappeared as $\bar{T}_{sk}$ of young females increased until the end of the immersion. Haenyeos showed tendency to maintain their $\bar{T}_{sk}$ however the $\bar{T}_{sk}$ of older females decreased.

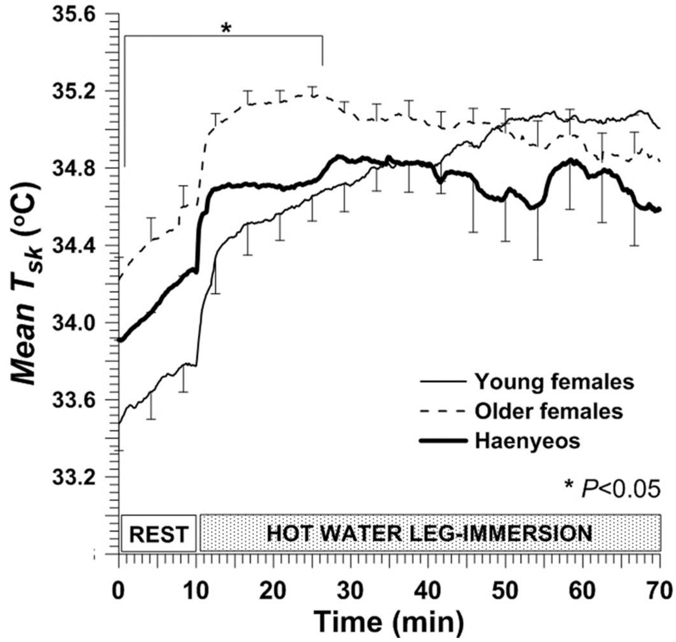

Figure 4.9 Mean skin temperatures (*Mean* T_{sk}) of young females, older females and haenyeos during passive heat stress (Mean±SE).

Table 4.5 Summary of mean skin temperature (Mean T_{sk}) of young females, older females and haenyeos during passive heat stress (Mean±SE).

Mean T_{sk} (°C)	Young females	Older females	Haenyeos	*P*−value
0~5th min	33.6±0.1	34.3±0.1	34.0±0.3	0.015
5~10th min	33.7±0.1	34.5±0.1	34.2±0.3	0.014
10~15th min	34.3±0.2	35.0±0.1	34.6±0.3	0.037
15~20th min	34.5±0.2	35.1±0.1	34.7±0.3	0.041
20~25th min	34.6±0.1	35.2±0.1	34.7±0.3	0.046
25~30th min	34.7±0.1	35.1±0.1	34.8±0.3	0.138
30~35th min	34.8±0.1	35.1±0.1	34.8±0.3	0.487
35~40th min	34.8±0.1	35.1±0.1	34.8±0.3	0.565
40~45th min	34.9±0.2	35.0±0.1	34.8±0.3	0.669
45~50th min	35.0±0.2	35.0±0.1	34.7±0.3	0.457
50~55th min	35.1±0.2	34.9±0.1	34.6±0.3	0.377
55~60th min	35.1±0.2	35.0±0.1	34.8±0.3	0.657
60~65th min	35.0±0.2	35.0±0.2	34.8±0.3	0.406
65~70th min	35.1±0.2	34.9±0.2	34.6±0.2	0.413

*The time expressed as 00th meant the time from the beginning of the experimental trial which included the stabilization period.

4.6 Local skin temperature

The T_{sk} where perspiratory responses was measured, that is forehead, torso (chest) and ventral forearm, are shown. There was significant differences only in chest at the end of immersion (P = 0.008). The chest temperature of haenyeo and the older female groups decreased after immersing their legs, however, those of the younger female group increased until the end of the immersion. This tendency was also appeared on forearm temperature. The forehead temperature of haenyeo group increased after the immersion and the younger female group increased slightly but the older female group did not change.

There were significant differences in T_{sk} during stabilization period and early stage of the immersion on forearm, thigh and calf. These differences disappeared as the immersion proceeded.

Generally, local T_{sk} of young females had tendencies to increase continuously through the immersion. However those of the older females and haenyeo showed increases at early stage of the immersion but decreased soon rather than increase, despite of passive heat stress.

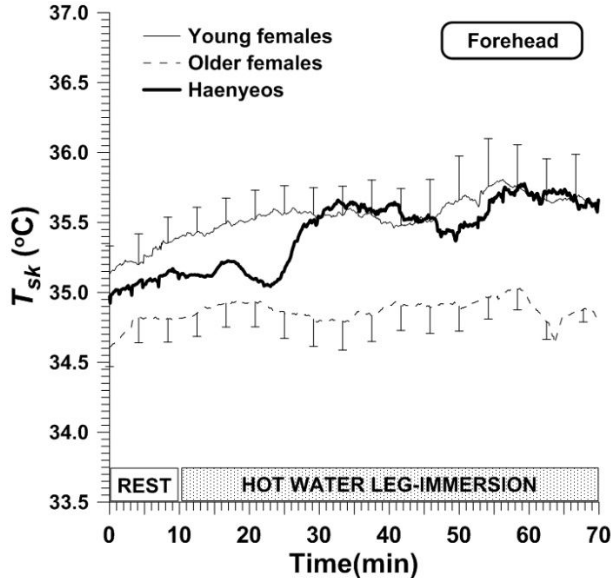

Figure 4.10 Local skin temperature (T_{sk}) on the forehead of young females, older females and haenyeos during passive heat stress (Mean±SE).

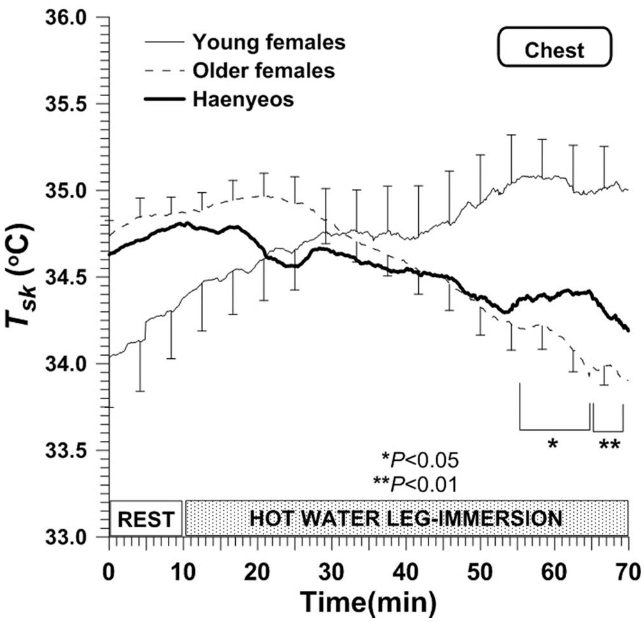

Figure 4.11 Local skin temperature (T_{sk}) on the chest of young females, older females and haenyeos during passive heat stress (Mean±SE).

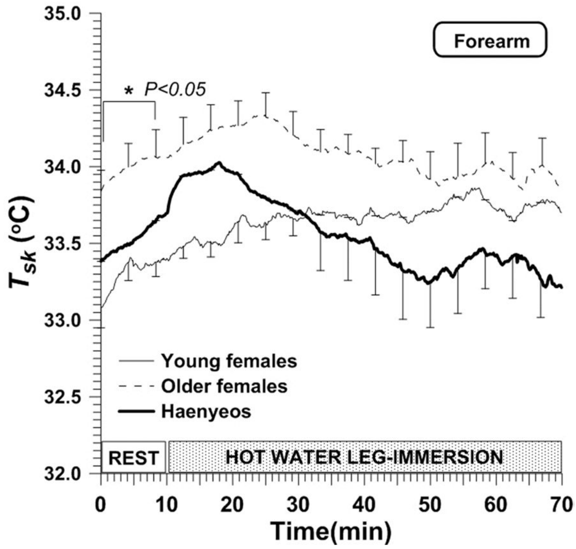

Figure 4.12 Local skin temperature (T_{sk}) on the forearm of young females, older females and haenyeos during passive heat stress (Mean±SE).

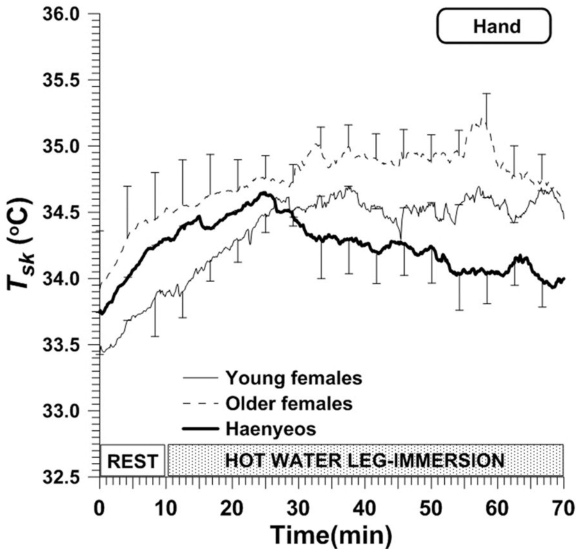

Figure 4.13 Local skin temperature (T_{sk}) on the hand of young females, older females and haenyeos during passive heat stress (Mean±SE).

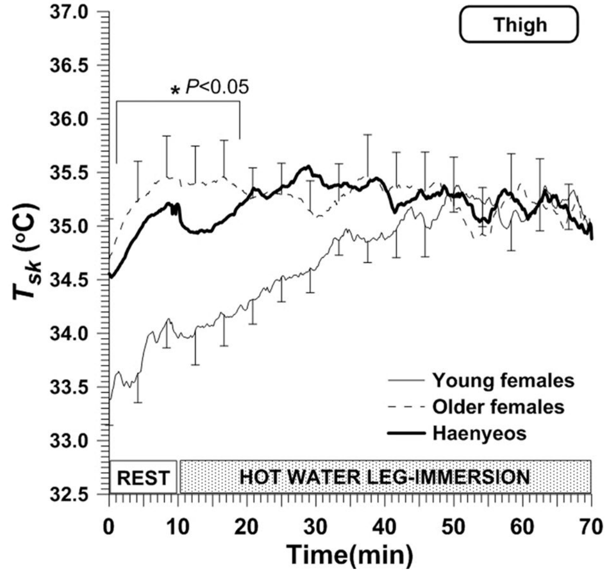

Figure 4.14 Local skin temperature (T_{sk}) on the thigh of young females, older females and haenyeos during passive heat stress (Mean±SE).

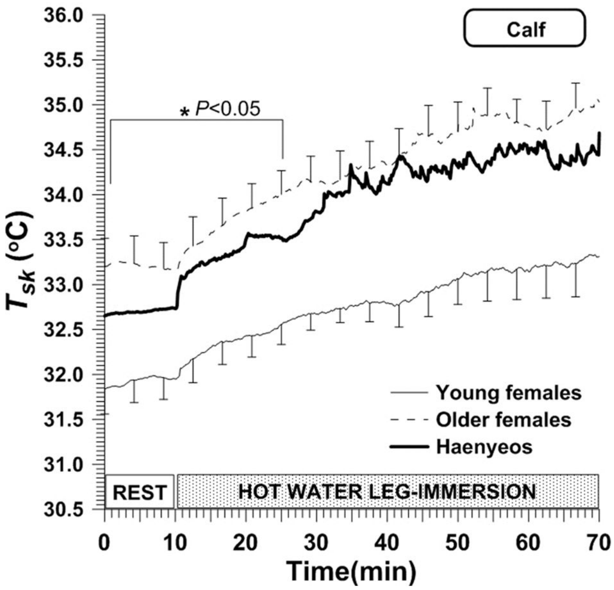

Figure 4.15 Local skin temperature (T_{sk}) on the calf of young females, older females and haenyeos during passive heat stress (Mean±SE).

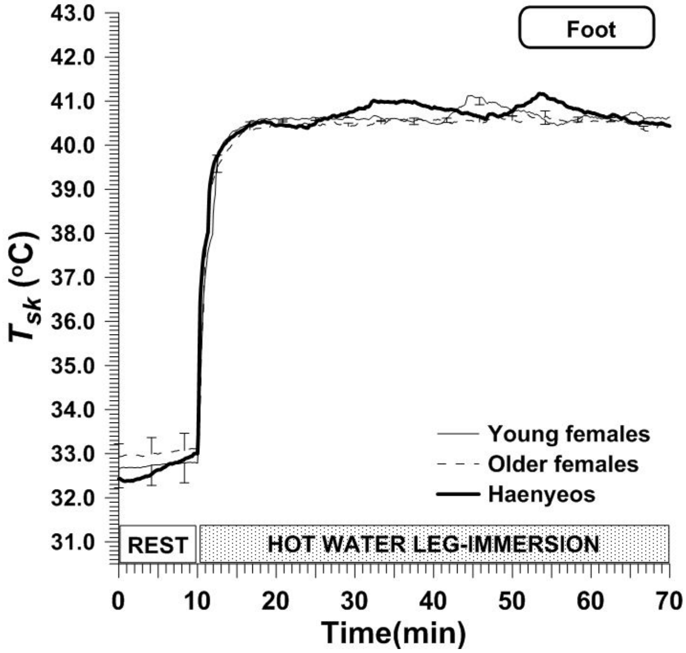

Figure 4.16 Local skin temperature (T_{sk}) on the foot of young females, older females and haenyeos during passive heat stress (Mean±SE).

4.7 Heart rate

Haenyeos showed the lowest *HR* among three groups during the whole immersion ($P < 0.05$). The increases of *HR* (differences of *HR* between stabilization and last 10 min of immersion) showed no significant difference ($P = 0.073$).

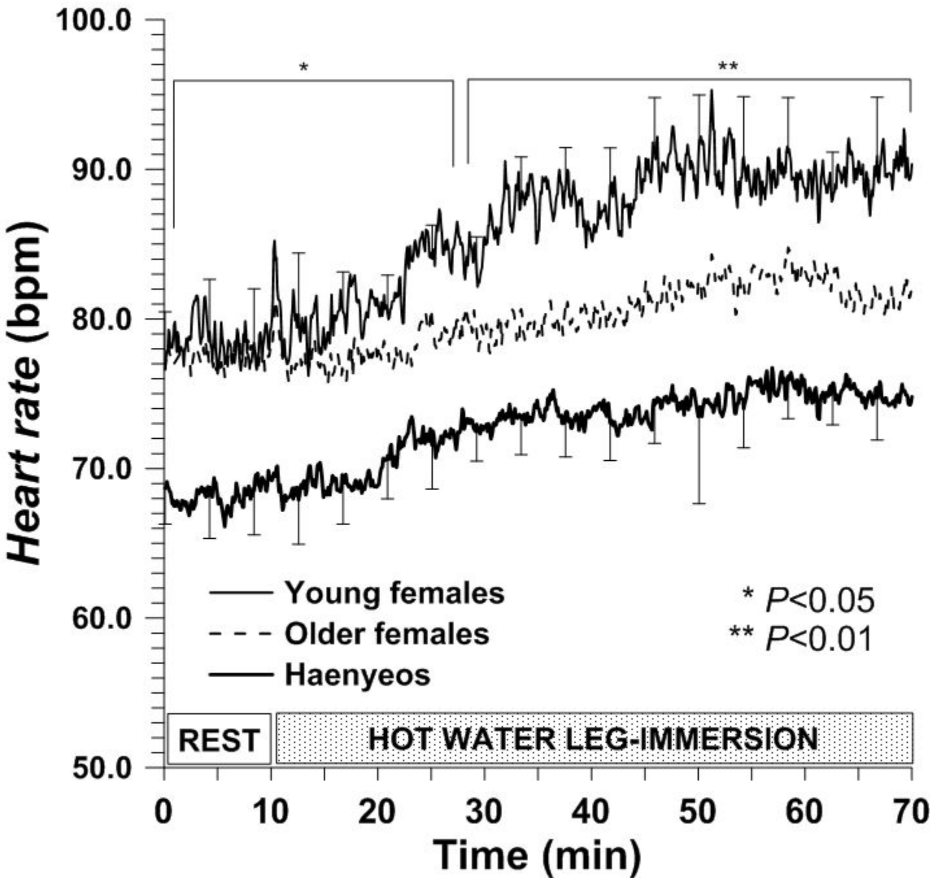

Figure 4.17 Heart rates of young females, the older females and haenyeos during passive heat stress (Mean±SE).

Table 4.6 Summary of heart rate(*HR*) of young females, older females and haenyeos during passive heat stress (Mean±SE).

HR (bpm)	Young females	Older females	Haenyeos	*P*–value
Before immersion	78.9±3.2	76.4±1.4	68.1±3.0	0.024
After immersion	89.9±3.4	81.3±2.1	74.7±2.8	0.004
⊿HR	11.2±2.3	4.8±2.0	6.7±1.3	0.074

4.8 Blood Pressure

The older females showed significantly higher *BP*, and *BP* of young females and haenyeos did not differ through whole experimental trial ($P<0.05$). Diastolic *BP* was not different among three groups. The summary of *BP* was presented in Table 4.7.

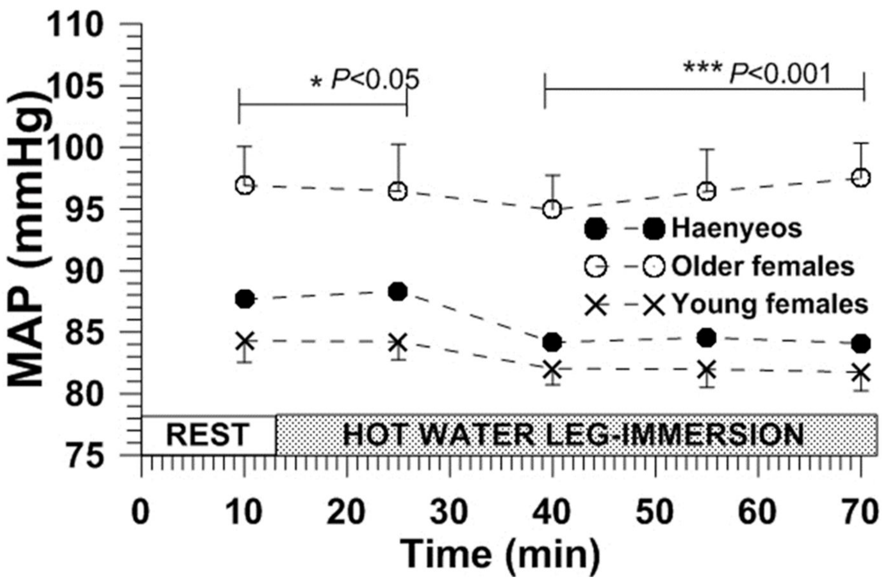

Figure 4.18 Mean arterial pressure (*MAP*) of young females, older females and haenyeos during passive heat stress. (Mean±SE).

Table 4.7 Summary of blood pressure (*BP*) of young females, the older females and haenyeos during passive heat stress.

BP (mmHg)		Young females	Older females	Haenyeos	*P*-value
Systolic pressure	10^{th}	108.6±1.6	131.5±5.6	117.4±4.1	0.002
	25^{th}	109.1±1.6	132.5±6.0	118.0±4.1	0.002
	40^{th}	107.6±1.3	130.8±5.2	113.2±3.9	0.001
	55^{th}	109.1±1.6	134.6±5.9	113.2±3.3	<0.001
	70^{th}	109.3±1.8	134.3±5.3	113.2±3.1	<0.001
Diastolic pressure	10^{th}	74.3±4.0	79.6±2.5	72.8±2.7	0.368
	25^{th}	74.7±3.7	78.4±3.8	73.5±2.0	0.565
	40^{th}	72.0±3.6	77.0±2.6	69.6±1.5	0.202
	55^{th}	71.3±3.8	77.3±3.1	70.2±1.8	0.253
	70^{th}	70.7±3.8	79.1±2.7	69.5±1.5	0.071
Mean arterial pressure (MAP)	10^{th}	84.3±1.7	96.9±3.1	87.7±2.9	0.001
	25^{th}	84.2±1.5	96.5±3.8	88.3±2.4	0.002
	40^{th}	82.0±1.3	95.0±2.8	84.2±2.1	<0.001
	55^{th}	82.0±1.5	94.4±3.4	84.5±2.1	<0.001
	70^{th}	81.7±1.5	97.5±2.9	84.1±1.7	<0.001

*The time expressed as 00^{th} meant the time from the beginning of the experimental trial which included the stabilization period.

4.9 Thermal sensation

The passive heat exposure of hot water–leg immersion induced continuous increases of thermal sensation among three groups. There was a significant difference only on the 30th min of the immersion. The young females showed tendency to express that they felt hotter than the older subjects.

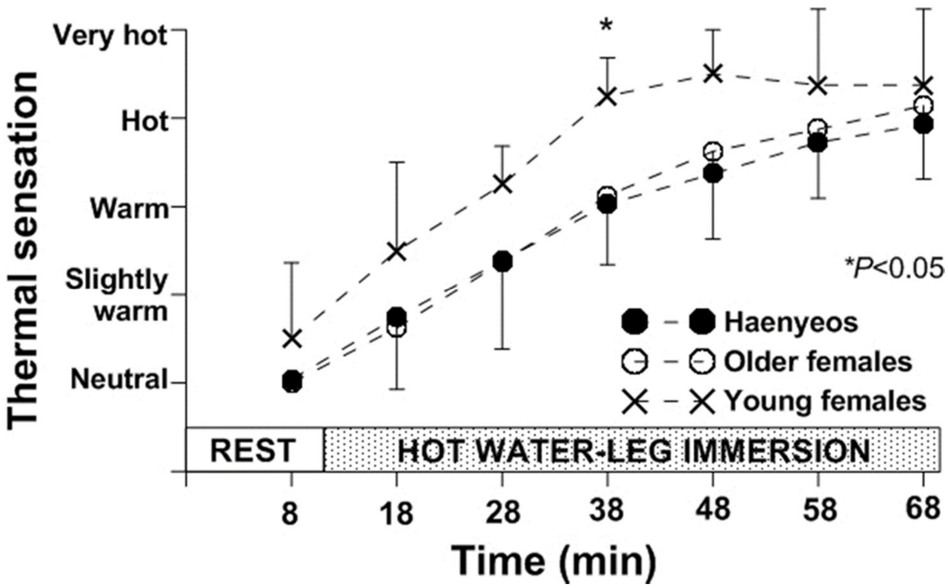

Figure 4.19 Thermal sensation of young females, older females and haenyeos during passive heat stress (Mean±SE).

4.10 Thermal comfort

The thermal comfort of three groups decreased through the passive heat exposure of hot water-leg. There was significant difference on the 20~40th min of the immersion. The thermal comfort of young females showed tendency to decrease faster than the older subjects. The older females did not feel discomfort from the passive heat stress.

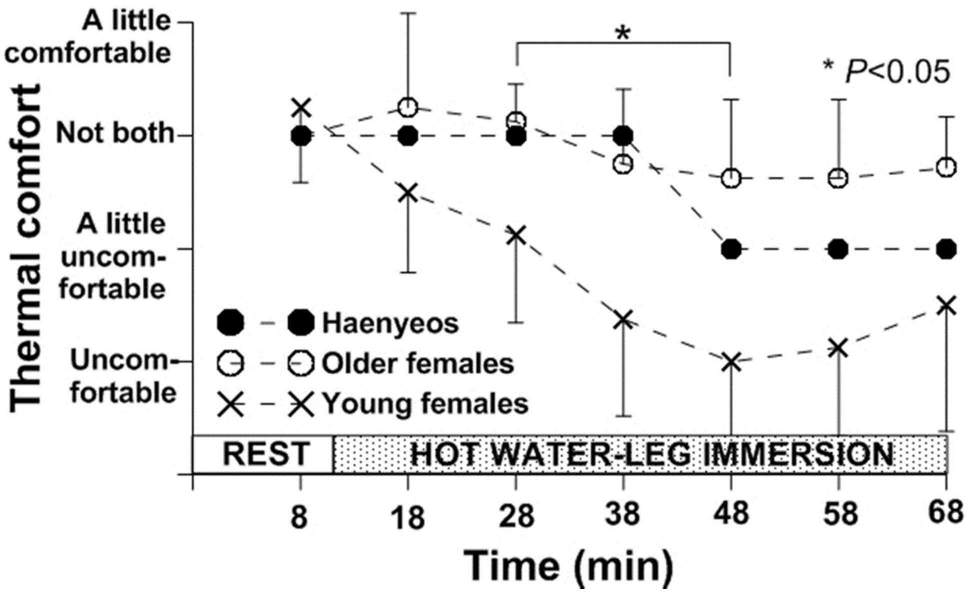

Figure 4.20 Thermal comfort of young females, older females and haenyeos during passive heat stress (Mean±SE).

4.11 Sweat sensation

There was no significant difference in sweat sensation among three groups during passive heat stress (Figure 4.20).

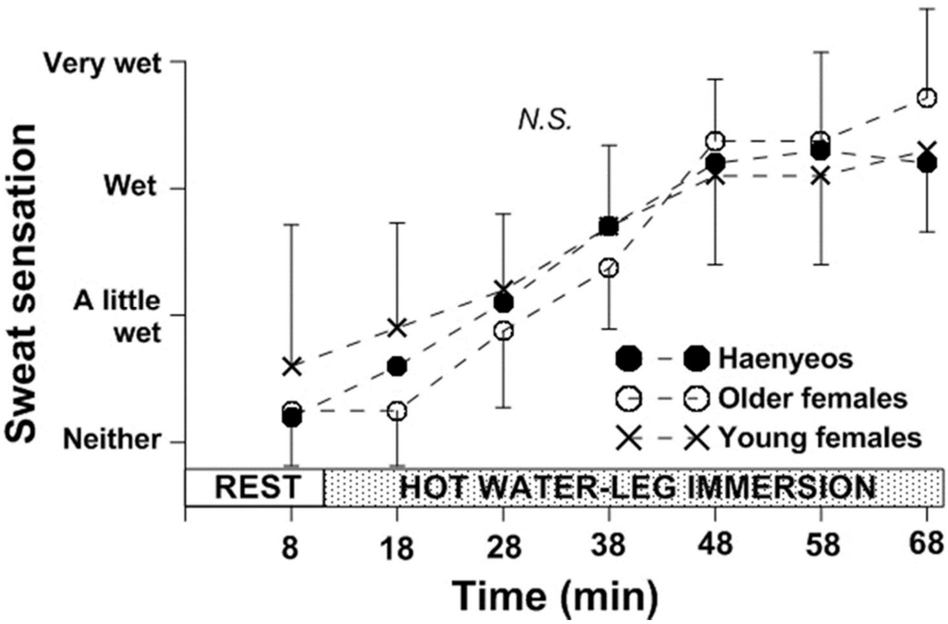

Figure 4.21 Sweat sensation of young females, older females and haenyeos during passive heat stress (Mean±SE).

4.12 Thirsty sensation

There was significant difference in thirsty sensation from the 40th min to the end of immersion ($P<0.05$). Thirsty sensation of young females was higher than the older groups.

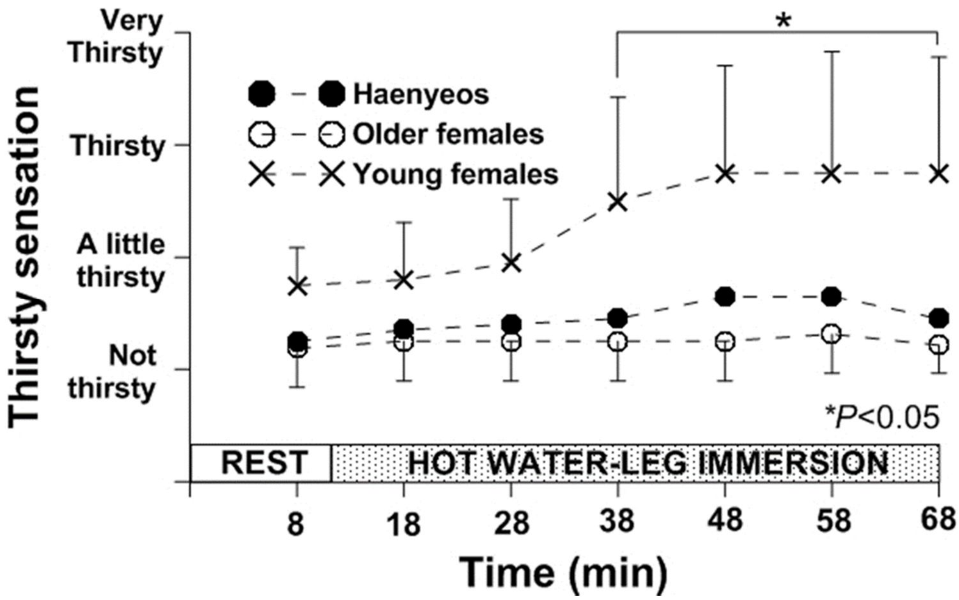

Figure 4.22 Thirsty sensation of young females, older females and haenyeos during passive heat stress (Mean±SE).

Table 4.8 The rank of physiological responses during passive heat stress.

		Young females	Older females	Haenyeos	*P*-value
TSR		2	3	1	<0.01
LSR	Forehead	1	3	1	N.S.
	Back	2	3	1	N.S.
	Forearm	1	2	2	N.S.
ASGD 50^{th} *min*	Forehead	3	2	1	<0.01
	Back	–	–	–	N.S.
	Forearm	–	–	–	N.S.
Tre	*Rest*	–	–	–	N.S
	⊿Tre	1	2	3	<0.01
Mean Tsk	*Rest*	1	3	2	<0.05
	⊿Tsk	3	1	1	<0.05
HR	*Rest*	2	2	1	<0.05
	⊿HR	3	1	2	N.S
BP	*Rest*	1	3	1	0.074
	⊿BP	–	–	–	N.S
TS		3	1	1	<0.05
TC		3	1	2	<0.05
SS		–	–	–	N.S
ThS		3	1	1	<0.05

* The parameters were ranked by the order of improved heat tolerance.
TSR: total sweat rate, *LSR*: Local sweat rate, *ASGD*: activated sweat gland density, T_{re}: rectal temperature, *Mean* T_{sk}: mean skin temperature, *HR*: heart rate, *BP*: blood pressure, *TS*: thermal sensation, *TC*: thermal comfort, *SS*: sweat sensation, *ThS*: thirsty sensation.

Chapter 5 Discussion

In the present study, the cross−adaptational effects of cold exposure and the effects of aging on heat tolerance of harnyeos during passive heat stress. Compared to the previous studies, the subjects were females, which was unique since most of studies had investigated the heat tolerance during passive heat from male subjects. The fact that the number of haenyeos has been decreased so that the occupation of haenyeo is in danger of distinction also gives a significance to the present study. The evaluations of heat tolerance of three groups from the results and the effects of aging and cross−adaptation would be discussed.

5.1 Heat−tolerance of hanyeos: Cross−Adaptation

The haenyeos has repeated diving into the sea water where the temperature is lower than body temperature since their adolescent. They had showed improved heat tolerance including higher level of BMR than twenties and same level of *LSR* as twenties when they wore the cotton−suit. The improvement of heat tolerance in the older males induced by repeated exercise and exposure to hot condition was reported (Inoue et al., 1994). The highly fit older males showed as same level of total sweat rate as twenties. However, the improvement of heat tolerance of haenyeo was a different case since haenyeos are the occupational group who have experienced frequent cold exposure.

Haenyeos changed their cotton-suit to wetsuit composed of neoprene. It was expected that they would gradually lose their cold tolerance because the insulation of neoprene-wetsuit was much higher than cotton suit (Lee and Lee, 2014). Despite of this increase of the insulation, haenyeos reported that they felt extremely cold on the face, hands and feet (Lee et al., 2015). Furthermore, the thermal conductivity of water is 24 times higher than air. The repetitive diving induces considerable heat loss even though when haenyeos wear the neoprene wetsuit. The suit do not cover the face, hands and feet of haenyeos, exposing the regions to severe cold stress directly. In regards to these facts, evaluating the cross-adaptational effect of cold exposure on heat tolerance is considerable.

When temperate natives were exposed to passive heat stress of leg immersion in hot water, they showed high level of *TSR* and *LSR*. They also presented high degree of *ASGD*. In addition, the skin temperatures were lowered because of the evaporative heat loss induced by higher sweat rates (Wijayanto et al., 2011; Matsumoto et al., 1997; Lee et al., 1997). In present study, haenyeos showed significantly higher *TSR* than the older females and young females. The forehead, most frequently exposed regions to cold stress during diving, showed significantly higher *ASGD* in the haenyeos than other groups and *LSR* of the haenyeos was same with the young females. These results suggested that the life-time cold exposure induced positive cross-adaptation of heat tolerance in haenyeos. In addition, the decreases in T_{sk} on the chest, forearm and hand indicated haenyeos showed temperate natives' heat adaptation.

On the other hand, the haenyeos showed the highest elevation in T_{re} (0.36±0.05℃). It could be interpreted that the heat tolerance of the haenyeos to be inferior to the other subject groups. The previous researche however reported the increase of T_{re} was over 0.5℃ in same passive heat stress protocol (Wijiyanto et al., 2011). The increase of T_{re} in present study was too smaller to evaluate the heat tolerance by T_{re} itself.

5.2 Heat−tolerance of hanyeos: Aging

There were the results showing that the heat tolerance of the haenyeos decreased by the effects of aging although they had improved heat tolerance affected by cross−adaptation. The haenyeos showed lowered *ASGD* and *LSR* in the forearm as same level as the older females. These results corresponded with the previous report that the aging affected from the extremities (Inoue and Shibasaki, 1996).

The haenyeos also showed less sensitive responses than the young females in subjective perception. The functional decreases in somatosensory system and thermal reception (Chao et al., 2007) could be responsible to the less sensitive respond in subjective perception. However, the empirical and cultural differences between the older subject groups (the haenyeos and older females) and young females should be in consideration. The older subject groups had spent most of their life time before the commercialization of an air−conditioner and a ferroconcrete building. They also spent long time outside because they were in agricultural society before the development of transportation. In short, they had been exposed directly to environmental changes so the passive heat stress might be relatively less stressful to the older subject groups than to the young females. When asked the *TS* or *TC*, many older subjects answered “it is bearable”, not ‘hot’ or ‘uncomfortable’.

To distinguish the effect of aging and the cultural factors, further studies such as a thermal threshold test of the skin would be necessary.

5.3 Heat-tolerance of hanyeos: Effects of life-time diving

The results of *HR* and *BP* showed that life-time diving of the haenyeos has influenced cardiovascular system. The haenyeos showed significantly lower *HR* than other groups and lower *BP* than the older females during the immersion.

Generally, it is agreed that well-trained person has lower *HR* in resting state because their improved cardiac output (Powers and Howley, 2012). Haenyeos perform underwater swimming up and downward from the surface of the sea to the sea-floor. They keep an intense exercise to overcome the gravity or buoyancy and collect sea foods, pulling water. The results that the haenyeos had the lower *HR* and *BP* indicated the positive effects of exercise to cardiovascular system in haenyeos.

It is well-known that high-level of physical fitness could improve the heat tolerance. When considering the haenyeos' daily work intensity, it could be possible that the improved heat tolerance was affected by their fitness, not by cross-adaptational effect of cold exposure. The highly fit older subjects showed as same level of *TSR* as the young subjects however the single sweat gland output was lower by the effect of aging (Inoue et al., 1999). A longitudinal study where mid-aged subjects participated also suggested that the function of sweat glands decreased although the subjects maintained their cardiorespiratory endurance (Inoue, 1996). The hanyeos, however, showed the highest *TSR* among three groups and the function of sweat glands such as *ASGD* and *LSR*, had not weakened. These results indicated that the improved heat tolerance of haenyeos was induced by not only physical fitness but also cross-adaptational effects of cold exposure.

5.4 Limitations

The measured sites of perspiratory responses and T_{sk} were not matched so that whether the cause of decrease of T_{sk} on the chest was evaporative heat loss or not was not certain. However, sweating patterns in torso were similar as reported in previous research (Machado et al., 2008) so the perspiratory responses on the chest could be estimated from the back.

ASGD and *LSR* were parameters which showed large deviations among individual subjects. As a result, there was no significant difference in those parameters. Because the *P*-values of the parameters, however, were close to 0.05, tendencies could be found on them.

Chapter 6 Summary and Conclusions

The present study compared the heat tolerance of haenyeos with the older and young females during passive heat stress of hot water-leg immersion to investigate the effects of aging and the cross-adaptation of cold exposure.

As results, the haenyeos showed improved heat tolerance by the effects of cross-adaptation even though there were partly decreased responses by aging. TSR of the haenyeos was the highest and LSR was the same level of the young females. Evaporative heat loss also could be found in decreased T_{sk} on haenyeos. The repetitive underwater diving had affected the cardiovascular system of the haenyeos. They showed significantly lower HR and BP than the older females and young females. The increase of HR and BP was lower in the older subject groups which meant the passive heat exposure was relatively less stressful in them than the young females.

These results confirmed that the cold exposure could affect heat tolerance by cross-adaptation especially on the function of sweat glands.

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초 록

본 연구는 해녀가 물질작업 중에 필연적으로 발생하는 추위노출과 연령에 따른 노화가 해녀의 내열성에 어떠한 영향을 미치는 지 알아보기 위해 하지온욕을 통한 수동적 서열환경에서 고령해녀와 일반고령여성 그리고 20대 여성의 내열성을 평가하였다. 해녀들은 총발한량이 세 그룹 중 가장 높게 나타났으며($P<0.05$) 국소발한량과 활성땀샘밀도가 20대보다 높거나 유사하게 나타나 온대인 유형으로 내열성이 증진된 모습을 보였다. 한 편, 전완에서는 국소발한량과 활성땀샘밀도가 일반고령여성과 같은 수준으로 나타나 말초부위부터 노화가 진행된다는 선행연구와 일치하는 결과를 보였다. 따라서 해녀는 노화의 영향으로 말초부위의 내열반응은 약화되었지만, 반복적으로 추위에 노출되며 교차적응의 영향을 받아 내열성이 증진되었음을 알 수 있었다. 또한, 반복적인 물질작업으로 고강도의 수영을 반복한 해녀들은 20대보다 낮은 심박수를 나타내고, 혈압은 70대보다 유의하게 낮았다 ($P<0.05$). 이는 물질작업이 심혈관계의 노화를 지연 혹은 방지하였음을 보이는 결과이다.

반복적으로 추위에 노출되는 직업군인 해녀들이 교차적응의 영향으로 내열성이 증진됨을 확인하였으며, 이러한 교차적응은 노화로 인해 발한반응이 약해지는 것을 방지하는 모습을 말초부위를 제외한 부위에서 확인할 수 있었다.

주요어: 해녀, 내열성, 교차적응, 노화, 하지온욕
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