

Korean Women Divers ‘*Haenyeo*’: Bathing Suits and Acclimatization to Cold

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Abstract

During the 1960~80s Korean breath-hold women divers (*haenyeo*) received attention from environmental physiologists, especially Professor Suk-Ki Hong and colleagues, due to their unique ability to resist cold water wearing only a thin cotton bathing suit (*so-jung-ee*). Eventually, *Haenyeos* began to wear wetsuits to avoid severe cold stress instead of the cotton bathing suit from the mid 1970's. With advancing social industrialization, the number of *haenyeos* rapidly decreased and a total of 4,507 *haenyeos* works as of 2013. The average age of *haenyeos* is 70 years old and the oldest *haenyeos* currently diving is 92 years old. Today, some senior *haenyeos* over fifty years old share the diving experiences of their youth by wearing the classic cotton bathing suits. At present it is predicted that the tradition of *haenyeos* could cease to exist in 10-15 years because of their aging. At this point in time, it is worth reviewing the history of *haenyeos*' diving practices and acclimatization/deacclimatization to cold. The present review described the diving practices and physiology of *haenyeos* related to cotton bathing suits and wetsuits. Finally, we suggest interdisciplinary research on *haenyeos* from the viewpoint of social-environmental physiology and intangible cultural heritage.

Keywords: *haenyeo*, cotton bathing suits (*so-jung-ee*), wetsuits, cold adaptation, body temperature

1. Introduction

The world's breath-hold women divers, used mainly to collect seafood, exist mainly in Korea (*haenyeo*) and Japan (*ama*). *Haenyeos* in Korea originated from the Korean provinces of Jeju. The first historical records of breath-hold male divers in Jeju were found in 503 AD. Evidence of Jeju women divers, or *haenyeos*, was first found in the 17th century literature (Chwa et al., 2005). Japanese women divers are called ‘*ama*’. Both ‘*ama* [あま]’ in Japanese and ‘*haenyeo* [해녀]’ in Korean, literally mean: ‘sea women [海女]’. Until the 18th century, diving in Jeju was mostly done by men. Women took over the diving work, because of heavy taxes imposed on males, and thus became the breadwinner. As a result, during the 19th century 22% of the entire female population in Jeju was *haenyeos*. In 1903, a group of skilled *haenyeos* went over to Japan and by 1937 the number of *haenyeos* diving in Japan amounted to 1,601 persons (Chwa et al., 2005). In those days *haenyeos* were known as being more tolerable to cold water than Japanese female *ama*, which is related to differences in

sea water temperatures and work practices between Korea and Japan. Sea water temperatures in winter were lower in Korea than in Japan: on average of 3.4°C around the middle area of Korea and 13.6°C at the Jeju island, but on average over 14.0°C around both Tokyo and Fukuoka in winter (Seatemperature.org, 2014). Furthermore, *haenyeos* dived even in the middle of winter wearing only thin cotton bathing suits called ‘*so-jung-ee*’ (literally translated as ‘something precious’).

Classic articles on *haenyeos* published in the 1960-80's by professor Suk-Ki Hong and his colleagues remain as a monumental legacy in environmental physiology today. They reported that the cold adaptive properties of *haenyeos* disappeared as *haenyeos* began to wear new wetsuits instead of wearing traditional cotton bathing suits in the mid-1970s (Park et al., 1983b). Since the 1990's, interests in the environmental adaptation of *haenyeos* have gradually waned. At this moment it is important to note that about 98% of *haenyeos* are over fifty and over 80% are in their sixties or older (Jeju province, 2014). Most who are in their

sixties or seventies share the diving experiences of wearing the cotton bathing suits from their youth. Even though they wear wetsuits, the face, hands, and feet of *haenyeos* are exposed to cold water for much longer work shift than those times wearing cotton suits. As most active *haenyeos* in Korea are in their seventies and are getting older (Table 1), it is predicted that *haenyeos* in Korea would cease to exist in the near future.

As the world becomes increasingly industrialized and modernized, there are only a few ethnic groups remaining who are regularly exposed to severe cold. Because of this population difference, research investigating heat acclimatization (e.g., tropical indigenes) is more common than acclimatization to cold stress. Many of the ethnic groups who live in cold climates have developed specialized clothing, shelters, and heating units that keep them well insulated against the cold. For instance, the world's coldest city is Yakutsk, Russia, with temperatures averaging only -26.6°C from October to March. It was found that Yakutsk people wore very warm clothing and in extremely cold weather stayed indoors in warm housing (Donaldson et al., 1998). The Arctic area is the coldest region on earth habitable by man, but chronic whole body exposure to cold is almost absent in the Eskimo culture, modern polar explorers, and North Atlantic fishermen due to the use of protective clothing and heated shelters and housing. Intermittent and short exposures to cold may not be adequate to develop full acclimatization to cold (Burton and Edholm, 1955).

Senior *haenyeos* were exposed to severe cold stress until the 1970's and since then they have been exposed to a more mild cold stress while wearing wetsuits. While deacclimatization to cold in metabolic and thermal responses was reported since they wore wetsuits (Park et al., 1983b), the face, hands, and feet have been continuously exposed to cold water even with the use of wetsuits. It could be modulated that the mode of cold adaptation has switched from the whole body to local body adaptation with the switch from cotton bathing suits to wetsuits. Also, while deacclimatization to cold in terms of physiological responses of *haenyeos* were mainly explored, whole or local body responses in terms of thermal perceptions triggering behavioral responses in cold have not been explored enough. Furthermore, an interesting topic to explore is the interactions between ageing and cold adaptation. About 70% of current-professional *haenyeos* in Korea are in their seventies (Table 1), which indicate that they have dived more than 50 years.

For all these reasons, *haenyeos'* practices, representation, knowledge, skills, instruments, and objects are recently being re-considered as an intangible cultural heritage. In this regard, it is timely and worth revisiting the history of *haenyeos* from the viewpoint of

social-environmental physiology. The present review introduced the work practices, cotton and wet bathing suits of *haenyeos*, and discussed acclimatization and deacclimatization to cold of *haenyeos* and other ethnic groups based on classic studies.

2. Korean breath-hold women divers

Anthropometric and physical characteristics of haenyeo

Since the 1980's, the number of *haenyeos* has decreased because of changing occupational preferences with the industrialization of Jeju. The official number of Jeju *haenyeos* was 26,248 in 1962 but only 4,507 in 2013 (Fig. 1). According to an anthropometric report in 2012, *haenyeos* consisted of 78% of fishery workers in Jeju, which indicates that most fishery work was conducted by *haenyeos*. The age distribution of Jeju *haenyeos* in the 1970's for less than 30 years old, 30-49 and over 50 were 31%, 55% and 14%, respectively (Table 1). Presently, about 98% of all *haenyeos* are over 50 due to the increased avoidance of young women becoming *haenyeos* since the 1980's (Table 1). As of 2014, the oldest actual field *haenyeos* is Jung-Hyun Lee (92 years old, 71-year diving career, Jeju) (Jeju province, 2014).

According to a classic anthropometric survey with 100 *haenyeos* in Jeju (Kang, 1953), the hip size of 100 *haenyeos* was larger than those of non-diver females in

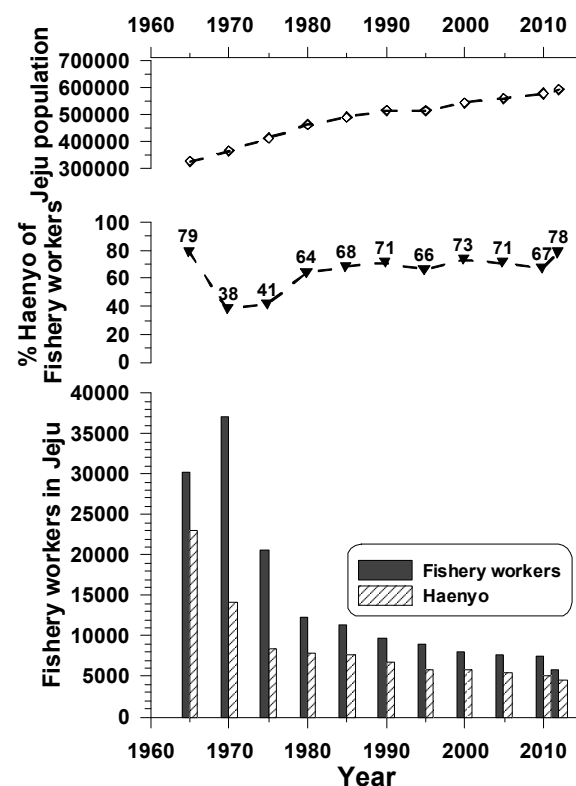


Fig. 1 Number of fishery workers and *haenyeos* in Jeju, Korea from 1965 to 2012 (Modified from data in Jeju province (2014)).

Table 1 Number of *haenyeos* in Jeju by age from 1970 to 2014

Year	Under 30 years old (person)	30~49 years old (person)	Upper 50 years old (person)			Total number of Haenyeo (person)
1970	4,426	7,765	1,952			14,143
1980	764	4,737	2,303			7,804
1990	294	3,017	3,516			6,827
1995	35	1,967	3,885			5,886
2000	3	1,282	4,504			5,789
2005	0	718	4,827			5,545
2010	0	125	4,870			4,995
			50~59	60~69	Upper 70	
2011	0	132	826	1,658	2,265	4,881
2012	0	87	755	1,580	2,152	4,574
2013	0	66	696	1,448	2,297	4,507

Modified from the statistics in Jeju province (2014).

Jeju, which was attributed to the heavy labor on the back imposed by carrying seafood from the shore to the gathering place and daily diving works in cold water which began in their mid-teenage years. From a physiological viewpoint, people living in colder climates generally have a noticeably wider body breadth compared to their tropical counterparts, which suggests that breadth rather than stature is the more important factor for thermoregulation (Lambert et al., 2008). There is a study reporting that menarcheal age was an average of 17.5 years for 395 *haenyeos* in Jeju, whereas 613 other females in the main land of Korea showed an average menarcheal age of 16.9 years (Kang, 1962). It is known that the menarcheal age varies according to ethnicity and climate, and is delayed in women who live in colder regions when compared to the women in warmer regions even in an identical ethnic group. In consideration of that the Jeju island is warmer than the main land, the delayed menarcheal age of *haenyeos* was ascribed to *haenyeos*'s cold water diving starting from their mid-teens.

Dive practices

Most *haenyeos* begin diving at the approximate age of 8 to 15 and continue to dive over their seventies. According to the diving skill, *haenyeos* are classified into three groups: [Class 1], [Class 2], and [Class 3]. Class 1 is able to dive deeper than about 16 m in depth with 2 min-breath-holding (Chaw et al., 2005), Class 2 is about 13 m in depth, and Class 3 dive shallower than 13 m. It takes about 30 years for a diver to reach Class 1 (Chun, 2010). When *haenyeos* want to dive as deep as 20 m, they need a heavy ballast belt and are attached to another weight of up to 30 kg, depending on their own body weight. While Korean *haenyeos* are all unassisted divers, Japanese *ama* are divided into two groups: Cachido (unassisted) and Funado (assisted). Funados generally dive deeper than Cachidos (10-20m vs. < 10m) (Shiraki et al., 2002).

Haenyeos engage in diving for periods of 1 to 5

hours daily depending on seasons and tide time. Hong et al. (1991) reported that both Korean female and Japanese male Cachido divers made 113-138 dives a day and stayed in the water a total of 170-200 min a day, of which only 52-63 min were spent diving submerged, and the remaining time at the water surface. Another study reported that Japanese *ama* spent 250-280 min a day on the sea at their diving locations and the actual diving time was 100-120 min (Mohri et al., 1995). In winter, a typical dive lasted about 60 s and consisted of a 30-sec dive followed by a 30-sec rest interval.

Most *haenyeos* dive during menstrual periods as well (Chaw et al., 2005) and dive even up to the day of delivery if pregnant (Chun, 2010). They worked an average of 28 days a month from March to August while during the winter season worked about 15 days a month when wearing the traditional cotton bathing suit (Fig. 2). In winter, the in-water-working time in wearing so-jung-ee (traditional cotton swim suit) did not exceed an hour. As water temperature of the sea varies by season, the total time spent submerged for divers wearing the cotton suit was about 30 min for January, February, October, November, and December, while about 40 min to 1 hour from Spring to early

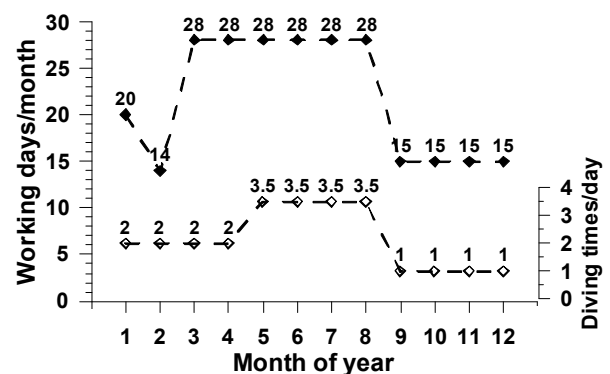


Fig. 2 Working days per month and diving times for a day when wearing the traditional cotton bathing suit, *so-jung-ee* (Redrawn from Chaw et al. (2005)).

Autumn (Chaw et al., 2005). When wearing cotton bathing suits, even Class 1 *haenyeos* hardly worked over 40 min during the winter and only dived about 20 min during the winter (Chun, 2010). However, the dissemination of wetsuits in the mid-1970's enabled them to dive much longer than before. Park et al. (1983b) found the prolongation of the diving shifts due to the wetsuits increased from 70 min to 180 min in summer and 10 to 120 min in winter compared to when wearing the cotton suits.

Cotton and wet bathing suits

Jeju *haenyeos* wore a bathing suit made of cotton-broadcloth in white or black (100% cotton with 30 counts, about 0.5 mm thick, and 8.5% water absorption at a dry condition) until wetsuits were supplied. Before the broad cotton cloth was imported from Japan, the bathing suit was originally made of muslin (thin cotton cloth). *Haenyeos* preferred the broad cotton to the muslin bathing suit because the broad cotton was relatively thicker and stronger in salty water than the muslin cloth. The traditional cotton suit consisted of 'so-jung-ee (bathing suit)', 'juck-sam (upper)', and 'mul-su-gun (hood)' without any goggles (Fig. 3). In winter, *haenyeos* wore the juck-sam over the so-jung-ee.

Jeju *haenyeos* who went to Japan for diving work came back to Jeju bringing their own wetsuits from Japan in the early 1970's (Chwa et al., 2005). Figure 4 shows the wetsuits currently worn by *haenyeos* in Jeju. In those days, flippers were also supplied with the wetsuits. As a result of such change, *haenyeos* were no longer exposed to the severe cold water (Kang et al., 1983). Wetsuits certainly made the work of *haenyeos* more comfortable and productive but longer than before. Before wearing the wetsuits, daily-diving hours in the winter were rarely over 1 hr, whereas the daily-work hour increased more than 1 hr, regardless of season, after the introduction of the wetsuit, and diving days per month also increased about 5 days more than

before (Kim et al., 1986). Senior *haenyeos* put weight around the waist or the back to assist their diving power. In general, *haenyeos* use the weights corresponding to 10% of their own body weight (5-7 kg weights). At present, three thicknesses of wetsuits are supplied in Jeju by season: 4 mm in thickness for summer, 5 mm for spring and autumn, and 6-7 mm in winter (Chwa et al., 2005). Swimming goggles were supplied in the early 1900's and the goggles are called 'nun' in Korean, literally meaning 'eyes'. *Haenyeos* wore binoculars called 'jock-se-nun' in the past, but the 'big eyes' (*wang-nun*) have been used since 1950's. Due to the dissemination of swimming goggles, a noticeable progress in technology occurred. The visibility during diving work was originally about 2-3 m wide, but has been broadened up to 20 m. The eye fatigue of *haenyeos* was also diminished. Jeju *haenyeos* washed the inside of the swimming goggles with mugwort to prevent the glasses from steaming up under water (Chwa et al., 2005). An earplug made with cotton and oil or honey was also commonly used.

Symptoms and diseases related to breath-hold diving

Occupational related diseases of *haenyeos* are typically identified as follows: (1) headache, (2) hearing-impairment, (3) otitis media, (4) stomach disorder, (5) skin irritation, and (6) musculoskeletal symptoms. First of

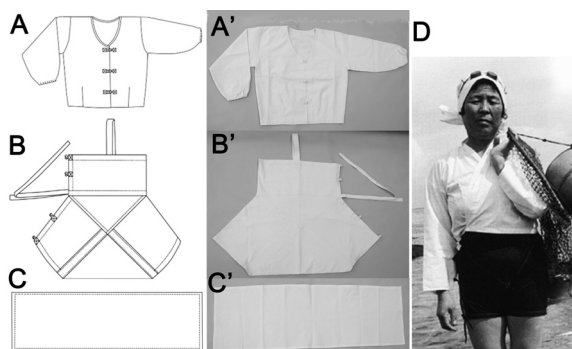


Fig. 3 Traditional cotton suit (so-jung-ee) worn by Jeju *haenyeo* until the 1970's (A. an outer (*juck-sam*); B. a bathing suit (*so-jung-ee*); C. a head cover (*mul-su-gun*); D. a photo of *haenyeo* in 1970's (By courtesy of the Jeju Haenyeo Museum).

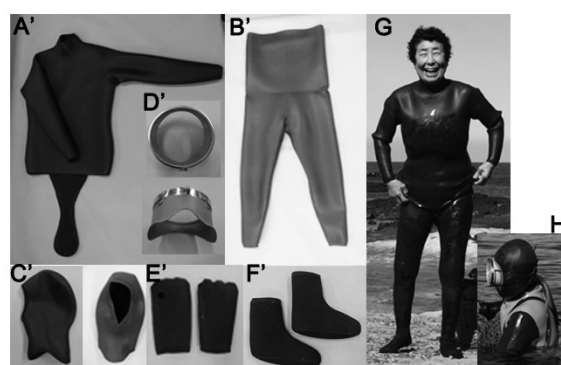
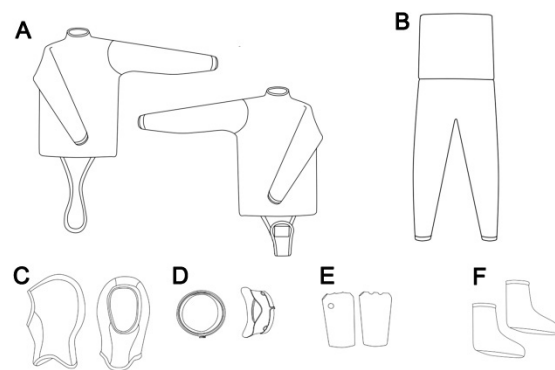


Fig. 4 Wet suit currently worn by Jeju *haenyeo*. A. an upper garment; B. a lower garment; C. a hood; D. swimming goggles (*wang-nun*); E. gloves without fingers; F. footwear; G. Jeju *haenyeo* in 2014; H. Jeju *haenyeo* working in 2014.

all, most *haenyeos* take headache pills called '*Neusun*' or antisickness pills called '*Easylong*' or '*Tosslong*' just before diving. Choi et al. (2008) reported that 71% of 911 *haenyeos* overused analgesics. Decompression sickness has been considered to be related to scuba diving than to breath-hold diving. However, several cases of decompression sickness after breath-hold diving have been reported (Stefanidou et al., 2013; Tamaki et al., 2010b). Tamaki et al. (2010b) reported on a Japanese male breath-hold diver (*ama*) who developed neurological disorders during repetitive dives to 22 meters of sea water. For the *ama*, each diving duration and surface interval was 40-80s and 20-30s, respectively. The male *ama* suffered from sensory numbness of the right cheek, hand and foot, and double vision. Greater depth, longer bottom time, quicker ascent rate and the short duration of surface intervals are considered to be the main factors precipitating decompression sickness after breath-hold diving (Stefanidou et al., 2013; Tamaki et al., 2010a).

Hearing-impairment is also common for *haenyeos*. Because of wetsuits and flippers, *haenyeos* began diving deeper and longer compared to the days of wearing thin cotton swim suits without flippers, which resulted in injuries of the tympanic membrane and hearing-impairment. Otitis media is related to the deeper and longer diving patterns. Because of their impaired hearing, most *haenyeos* have a deeper voice. Also, *haenyeos* have suffered from stomach disorders, which is related to long hours diving under the sea. In general *haenyeos* skip their meal before diving so as to prevent them from throwing up the meal during their hand-standing-diving position and from defecating in the sea while working for several hours (Kang, 2013). Also, *haenyeos* experience skin irritation and muscular pain. They frequently walk on slippery basalt rocks while carrying collected seafood weighing ~70 kg. While gathering seafood under the sea or carrying the seafood from the shore to the collecting place, *haenyeos* experience pricking by the sea urchin, decaying fingerprints swollen in the sea water, blisters on the shoulder, and muscular pains (Kang, 2013). Bae et al. (2003) reported that the prolonged habitual cold-water immersion of *haenyeos* may induce a decrease in fiber size and an increase in capillarity in human skeletal muscles. It has been found that, splenic contraction and increased hematocrit occur during breath-hold diving in *haenyeos* (Hurford et al., 1990).

3. General responses to cold

Humans, who are a homeothermic animal, have four major physiological defenses against the cold: (1) the thermal cutaneous vasomotor response which results in cutaneous vasoconstriction induced by the cold, (2) shivering, (3) nonshivering thermogenesis, and (4)

piloerection.

During exposure to cold stress, the cold receptors in the skin are activated to initiate the reflexes involved in conserving heat. This is accomplished through a constriction of the subcutaneous blood vessels (vasoconstriction), which limits the flow of warm blood from the core to the outer body (shell). The fall in skin temperature on the extremities is much greater than that of the trunk. In a cold environment most of the venous return from arms and legs is through the deep venae comitantes that received heat from blood flowing through the arteries, thereby minimizing heat loss. When fingers and toes are exposed to extreme cold, their skin temperature falls at first sharply, but soon fluctuates at a certain level, rising and falling alternatively (*Cold-induced vasodilation*, CIVD). The reaction varies considerably among individuals and is the essential factor which determines the individual differences of local cold resistance.

The increase of heat production by metabolism as a defense against cold consists of '*shivering*' and '*non-shivering thermogenesis (NST)*' (Burton and Edholm, 1955). Shivering is a unique physiological function which is a coordinated movement of the voluntary skeletal musculature. All the energy in shivering is transformed into heat. The overall heat production due to shivering may amount to two or three times the resting level when measured over a period of one hour (Edholm, 1978).

An increase in metabolism without muscular movement is called NST, but it is difficult to separate experimentally nonshivering and shivering thermogenesis caused by cold since both may be active simultaneously during a cold exposure. NST is probably a more efficient mechanism than shivering for increasing heat production in the cold because the muscular tremor of shivering increases convective heat losses from the body surface. Noradrenaline and thyroxine are hormones that play significant roles in the development of NST (Frisancho, 1993). One particular mechanism for NST is that concerned with brown adipose tissue (BAT). In a number of animals, there is a distribution of BAT, mainly in the subcutaneous area between the scapulae. This fat has a rich nerve supply and when the animal is cooled there is a breakdown of the fat and the release of heat. Animals exposed to cold stress exhibit a marked increase in BAT. Fall in body temperature of animals exposed to -25°C for 3 h was inversely related to the weight of BAT (LeBlanc and Villemare, 1970). In recent years, a group of researchers has shown that BAT is present in human adults, showing the relation to NST (Lidell and Enerback, 2010; van der Lans et al., 2013). Furthermore, a 10-day cold acclimation protocol in humans increased BAT activity along with an increase in NST (van der Lans et al., 2013).

4. Acclimatization to cold

The term used to describe the physiological responses to chronic exposure to environmental stress is acclimatization (IUPS Thermal Commission, 2001). Proof of cold acclimatization in humans requires that one or more of the following criteria be satisfied: (a) increased resting or basal metabolic rate, i.e., metabolic acclimatization, (b) reduced heat loss at a given air temperature, i.e. insulative acclimatization, (c) decreased susceptibility to pain, numbness or cold injury in the extremities, i.e. vasomotor acclimatization, or (d) decreased cutaneous sensory threshold for cold thermogenesis, perceptual habituation.

The main feature of insulative acclimatization to cold is an enhanced lowering of skin temperature by which heat loss is decreased and metabolic rise is minimized. Insulative acclimatization to cold seems to be manifested in an increased tone of peripheral vasoconstrictor. Lower skin temperatures and decreased metabolic rates were found in a group of men who stayed in Antarctica for 1 year (Wyndham et al., 1964). An insulative type of adaptation appears to develop only in individuals who experience frequent and severe cold stress conditions which result in a reduction in body heat stores. Improved vasoconstrictor responses to cold and development of enhanced avenues of counter-current heat exchange in the limbs have been suggested as mechanisms for this type of adaptation (Young, 1988).

From the 1940's to 1970's, many ethnic groups, such as Australian aborigines, Kalahari Bushmen, Alacaluf Indians, Andean Indians, Eskimos, Nomadic Lapps, Japanese and Korean women divers, have been explored in terms of acclimatization to cold. Among the ethnic groups, the Australian aborigines faced by the combined stress of cold and food shortage show a hypothermic-insulative response. Despite the cold stress, the aborigines were able to sleep comfortably without shivering. The aborigines compared to white subjects tolerated a greater lowering of the skin and rectal temperatures, resulting in a 30% reduction in heat conductance from core to shell even though mean skinfold thickness and percent body fat were considerably lower in the aborigines than in the whites (Hammel et al., 1959). Australian aborigines showed 30% smaller metabolism related to cold than that of the white subjects (Hammel et al., 1959; Hammel, 1964). The aborigines appear to resist cold stress by both increasing insulation of the outer body through vasoconstriction and by tolerating moderate hypothermia without metabolic compensation.

A metabolic cold acclimatization exists whereby a more pronounced increase in heat production is elicited by cold exposure. The possibility that a shift from NST accounts for this adaptation has been suggested. NST

is stimulated by noradrenaline in rodents. Humans have an increased sensitivity to noradrenaline after acclimatization to cold (Kang et al., 1970). In Davis's study (1961), 36 subjects dressed only in shorts were exposed for 4 weeks to daily 8-h periods of temperatures ranging from 5 to 11°C. In this experiment there was a decrease in shivering and an increase in NST and later initiation of shivering. The native Eskimo housing type, 'Igloo', is well-insulated. In most areas the Eskimo clothing consists of caribou fur in thickness of 1.5-3 inches, which provides insulation equivalent to 7 to 12 clo units (Scholander et al., 1950). There is certainly no evidence that the Eskimo has a core temperature any lower than the natives of the tropics (Burton and Edholm, 1955). Krogh and Krogh (1914) were the earliest to study metabolism in the Eskimo, and they reported a raised BMR. The Eskimo and white Europeans shiver at the same skin temperatures, but Eskimos generate 30% to 40 % more heat from NST than do Europeans not typically exposed to the cold (Gisolfi and Mora, 2000). However, this elevation in metabolism is attributed to the high-protein diet consumed by the Eskimo.

Local adaptation in fingers and toes to extreme cold is manifested in an acceleration of the hunting reaction which keeps extremities warmer. Yoshimura et al. (1960) evaluated CIVD in the toe of three groups (foot immersion to ice water daily 15 min for a month, daily 30 min immersion, and no immersion). The trained group showed significant acceleration of CIVD after a month while the changes in the control group were insignificant. Lapp shepherds from Norway have not developed formal housing and thus were continuously exposed to cold stress. The microclimate inside the clothing of the Lapps has been found to be warm (Scholander et al., 1957). Nomadic Lapps exhibited an earlier onset of CIVD and less pain than white controls when immersing their hands in ice water for 15 minutes (Krog et al., 1960; Krog et al., 1969). Also, the Inuit were better able to maintain the temperature of their extremities in response to localized cold stress, in comparison to oriental and Caucasian subjects from warmer climates (Livingston et al., 1978). Eskimos maintained higher hand temperatures and showed greater increase in blood flow, especially to the fingers, than the Europeans when their hands were immersed in 5-10°C water (Brown and Page, 1952; Gisolfi and Mora, 2000).

5. Cold acclimatization and deacclimatization of *haenyeos*

In the 1970's to 80's, professor Suk-Ki Hong and his colleagues studied extensively the thermal physiology of Korean women divers, *haenyeos*, who engaged in diving work in cold water 22-24°C in summer and 10°C in winter. They reported the pattern of cold

acclimatization of *haenyeos*, who wore thin cotton suits, in the 1970's. After *haenyeos* began to wear wet-suits in the mid-1970's to avoid severe cold water stress during diving work, Hong and his colleagues reported the time course of deacclimatization to the cold of *haenyeos*. In the following section, we discuss the acclimatization and deacclimatization to cold in *haenyeos*'s thermoregulatory responses in relation to the transition from cotton bathing suits to wetsuits.

Cotton-suit *haenyeos*: cold acclimatization

Studies of *haenyeos* provide conclusive evidence that chronic exposure to cold stress increases their metabolic rate. These findings were in marked contrast to those of Eskimo or Australian aborigines living in cold climates. The cause of these differences can be explained by the degree of cold stress experienced by each population. When sufficiently exposed to cold, all humans adapt to cold through increased metabolic rates and with an attendant increase in peripheral temperature. Kang et al. (1963) reported that *haenyeos*' basal metabolic rate (BMR) during the winter months, when they were diving in very cold water, was significantly elevated above values observed during warmer months. *Haenyeos* increased their BMR by ~35% during the winter, while BMR of non-divers was maintained at a normal level throughout the year (Kang et al., 1963) (Fig. 5). Daily urine samples indicated that excretion of nitrogen was the same in *haenyeos* and in control subjects. For this reason, Hong and his colleagues suggested that the increase in BMR in *haenyeos* in the cold season is a manifestation of a metabolic acclimatization to cold stress and cannot be caused by differences in diet. The 35% increase in BMR could be due to an increased utilization of thyroid hormones (Hong, 1973) and to a slight increase in sensitivity to norepinephrine (Kang et al., 1970). Thyroid hormones and norepinephrine both stimulate metabolism. The total diving heat loss during a work shift of *haenyeos* appeared to be 320 kcal in summer (60-min shift) and 480 kcal in winter (30-min shift). Since they took three shifts a day in summer and one or two shifts in winter, the average daily diving heat loss was estimated to be 1,000 kcal (Hong, 1973; Kang et al., 1965).

Another important adaptive mechanism of the *haenyeos* against the cold is increasing peripheral body insulation. When compared to other ethnic groups, *haenyeos*' tissue insulation is greater than those of Eskimos and Andean Indians (Webster, 1974). *Haenyeos* are relatively lean individuals and the amount of subcutaneous fat they possess is typically lower than that of non-divers in Korea. However, they lost less heat under the conditions of cold exposure than non-divers with the same thickness of subcutaneous fat. The answer to this relates to the control of peripheral

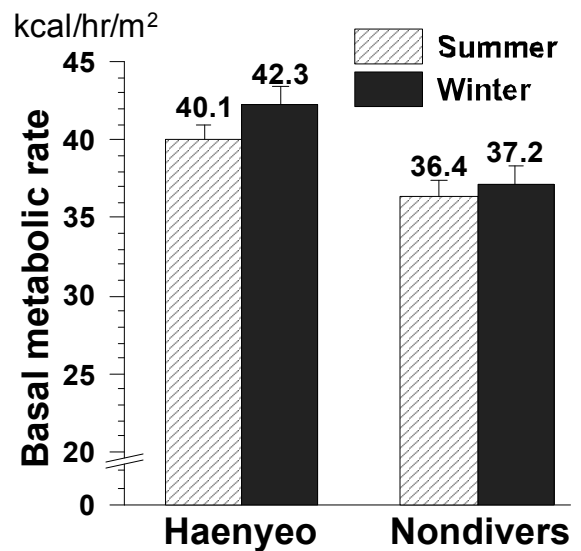


Fig. 5 Basal metabolic rate of Korean *haenyeos* in winter and summer (Modified from data in Kang et al. (1963)).

blood flow, especially, to the limbs. Also, *haenyeos* shivered at a significantly lower water temperature than non-divers. They defined a critical water temperature as the lowest water temperature one can tolerate for 3 h without shivering, which is synonymous with a shivering threshold. The water temperature at which 50% of the *haenyeos* shivered was 28.2°C, compared with 29.9°C for non-divers, and 31.1°C for Korean adult males (Hong, 1973). The greater insulative outer body of *haenyeos* was attributed to the suppression of shivering. Because Hong et al. (1969) also presented evidence for an increase in blood flow to the limbs of *haenyeos* with no increase in heat loss, it has been concluded that the greater insulation is due to a more efficient countercurrent heat exchange system (Hong et al., 1969; Hong, 1973; Kang et al., 1970). Such responses suggest an insulative type of acclimatization and the basic pattern of the insulative acclimatization is similar to that observed in Australian aborigines regardless of the mechanism (Hammel et al., 1959).

Kang et al. (1983) reported that the rectal temperature of *haenyeos* in sea water declined steadily to approximately 35°C after 30 min in winter and after 60 min during the summer when wearing the cotton suit, while the rectal temperature in wetsuit divers did not change appreciably over the 2 h work period. The total reduction of rectal temperature in 2 h was only 0.4°C in summer and 0.6°C in winter. The mean skin temperature was also maintained to some extent for the wetsuit divers, while the mean skin temperature dropped quickly from about 34°C to the level of water temperature for the cotton suit divers (Kang et al., 1983). Another feature of cold acclimatization was a strong vasoconstriction in the most distal part of the extremities during cold water immersion. Finger skin

temperature and blood flow during hand immersion in 6°C in the *haenyeos* were lower than those in non-divers (Paik et al., 1972). Contrary to the attenuation of finger vasoconstriction observed in arctic fishermen or Eskimos, the cotton suits wearing *haenyeos* showed greater vasoconstriction than non-divers. This response was attributed to the whole body cold exposure of the *haenyeos* compared with only local cold exposure experienced by Eskimos and arctic fishermen. Skin temperatures in the hands and arms were maintained higher than in non-divers without increasing total blood flow to the arms, because a relatively larger proportion of the total circulation returned through the veins directly under the skin.

Wet-suit *haenyeos*: loss of cold acclimatization

Scholander and colleagues (1950) observed that birds walked around at temperatures of -40 to -50°C without frostbite, while a gull which was kept indoors at 20°C escaped into the snow at -20°C and the web of the feet froze hard within a minute with subsequent gangrene. This may be considered as an example of loss of cold acclimatization. *Haenyeos* began wearing wetsuits to avoid severe cold stress in the mid 1970's. Diving in wetsuits certainly made the work of *haenyeos* more comfortable and productive. Years later, as a result of the reduced cold stress, there was no seasonal change in metabolic rate and basal metabolism was no different in *haenyeos* compared with non-divers (Gisolfi and Mora, 2000). Rectal temperature fell only 0.6°C during a diving sequence in the winter, compared with a fall of 2.2°C when *haenyeos* wore a cotton bathing suit (Gisolfi and Mora, 2000). In a wet suit, mean skin temperature was as much as 10°C higher, and heat loss was reduced to only 37% of what it was when the *haenyeos* wore a cotton bathing suit (Gisolfi and Mora, 2000). The difference in critical water temperature between the *haenyeos* and non-divers in the 1960s was as much as 4°C, compared with only 1°C in 1981 and no difference in 1983.

The finger skin temperature and blood flow during hand immersion in 6°C among wet suit wearing *haenyeos* were similar to those of non-divers. This finding suggests that the local vascular acclimatization observed among the cold stressed *haenyeos* studied in the 1960s disappeared in wet suit *haenyeos*. Park and Hong (1991) supported the notion that the latter response was associated with whole-body cold exposure rather than cooling of the hands alone. That is, those results suggested that the low finger skin temperature observed in cotton suit wearing *haenyeos* was a result of generalized cold body stress rather than cold stress to the hands as it occurred with the Gaspe fishermen. The type of cold acclimatization of Gaspe fisherman (LeBlanc, 1962) and British fish-filleters (Nelms

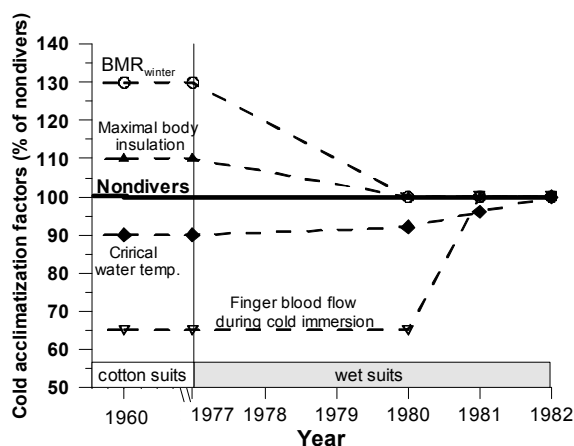


Fig. 6 Loss of cold acclimatization in various variables since the adoption of wetsuits in 1977 (Redrawn from Park et al. (1983b))

and Soper, 1962) is basically different from that of whole body cold exposure of cotton suit wearing *haenyeos*.

The greater vasoconstriction of finger blood vessels of cotton suit wearing *haenyeos* during cold water immersion of a hand were sustained until year 3 of wet suit diving, but disappeared during the subsequent 3 years (Park et al., 1983b). The adoption of wetsuits by the *haenyeos* in the mid-1970s led to a progressive deacclimatization to cold over the next 5 years (Fig. 6). The authors discussed that the insulative acclimatization of the peripheral tissue disappeared in wetsuits wearing *haenyeos* faster than the mechanism of shivering attenuation, which suggests that the elevation of the maximal body insulation is distinct from the elevation of the shivering threshold. Such return of thermoregulatory function to control levels after several years of diving in a protective garment provides evidence that the cold exposure experienced by cotton suit wearing *haenyeos* indeed produced cold acclimatization.

6. Revisiting Korean *haenyeo* and further research

Cold acclimatization in daily life is a reoccurring issue in Korea because of climate change and indoor energy saving issues during the winter. Since the 1990's, the research on the physiology of *haenyeos* have been fragmentary, but experimental instruments and research methodology in thermal physiology have progressed. Classic examination of human responses to prolonged exposure to cold, in a search for cold acclimatization, have included the following measurements: heat production, calorie intake, hormonal changes, body insulation, thickness of body fat, vasomotor control of superficial vasculature, subjective tolerance and performance, diminished or increased incidence of cold injury, and local acclimatization to cold. Furthermore, rare studies from psychophysiological viewpoints with

thermal sensitivity of *haenyeos* exist but relatively convenient methods and devices to examine cutaneous thermal thresholds of humans have been developed. During cold water immersion, *haenyeos* usually complained of internal chilling not external chilling, whereas non-divers complained of external chilling (Park et al., 1983a). This may imply that the sensitivity of cutaneous cold receptors may be suppressed in *haenyeos*.

As addressed before, the average age of *haenyeos* today are in the seventies. It is agreed that the tradition of *haenyeos* in Korea would cease within 10-15 years due to their ageing. In this regard, it would be an interesting issue to explore the interaction between ageing and cold adaptation. In addition, the relative contribution of genetic factors to prior cold-acclimatization remains unclear. Considering <20 genes in mammalian cells are affected by cold exposure (Sonna et al., 2002), it is reasonable to assume that more physiological and morphological characteristics may be attributed to genetic origins as more data from *haenyeos* becomes available. In a collective sense, topics on cutaneous thermal thresholds, the interactions between ageing and cold adaptation, and genetic factors to cold adaptation of *haenyeos* are recommended for future research.

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