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Field Report

Diving bradycardia of elderly Korean women divers, haenyeo, in cold seawater: a field report

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Abstract: The purpose of the present field study was to explore diving patterns and heart rate of elderly Korean women divers (haenyeo) while breath-hold diving in cold seawater. We hypothesized that the decreasing rate in heart rate of elderly haenyeos during breath-hold diving was greater and total diving time was shorter than those of young haenyeos from previous studies. Nine haenyeos participated in a field study [68 ± 10 yr in age, ranged from 56 to 83 yr] at a seawater temperature of 10 to 13 °C. Average total diving time including surface swimming time between dives was 253 ± 73 min (155–341 min). Total frequency of dives was 97 ± 28 times and they dived 23 ± 8 times per hour. All haenyeos showed diving bradycardia with a decreased rate of 20 ± 8% at the bottom time (101 ± 20 bpm) when compared to surface swimming time (125 ± 16 bpm) in the sea. Older haenyeos among the nine elderly haenyeos had shorter diving time, less diving frequencies, and lower heart rate at work (p<0.05). These reductions imply that haenyeos voluntarily adjust their workload along with advancing age and diminished cardiovascular functions.

Key words: Korean women divers, Breath-hold diving, Ageing, Heart rate, Cold water

Introduction

Since 18th century, Korean women divers, '*haenyeo*', have been known for breath-hold divers[1)] similar to '*ama*' in Japan, sponge divers in Greece, pearl divers in the South Pacific, and shell divers in Australia. However, most of those groups began to use self-contained underwater breathing apparatus (SCUBA), whereas women divers in Korea and Japan have continued to this day as commercial breath-hold divers.

Through classical studies on Australian aborigines, Kalahari Bushmen, Alacaluf Indians, Norwegian Lapps, channel swimmers, Gaspe fishermen, British fish-filleters, Eskimos, and Korean women divers, cold adaptation was classified into the following types: hypothermic habituation, insulative cold adaptation, and metabolic cold adaptation[2)]. In particular, Korean haenyeos were known to possess unique cold adaptive traits, which showed a higher basal metabolic rate[3)], lower shivering threshold[4)], and greater thermal insulation of tissues compared to control groups[5)]. In this regard, professor Hong and his colleagues' studies on Korean women divers remain as a monumental legacy in terms of thermoregulatory and cardiovascular adaptation of environmental physiology[6–11)]. However, such unique cold acclimatization disappeared over several years as wearing wet suits from the mid-1970s and later[7)]

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and interests in the thermal physiology of haenyeos gradually waned.

Cardiovascular functions of Korean haenyeos have become adapted to underwater environments through repetitive and chronic breath-hold diving in their daily lives. Haenyeos are classified into three groups according to the diving experience and skill. Class A is the most experienced group, who are able to dive deeper than about 16 m in depth, Class B dives about 13 m, and Class C dives shallower than 13 m[1]. It takes about 30 yr to reach Class A and haenyeos return to Class B or C with advancing ageing. It was reported that lung capacity was 12% greater for haenyeo (3.4 l) than non-diving women (3.1 l)[8]. Furthermore, inspiratory capacity of total lung capacity was 0.4 l greater for haenyeo than control[8]. This was regarded as an adaptation of the respiratory muscle to the underwater environment. Extreme breath-hold divers' total lung capacity (8.8 l) was 21% higher than non-diving controls (7.3 l)[12]. Bachman and Horvath had subjects train for 4-month-swimming or 4-month-wrestling, and found that increases in lung and inspiratory capacities were observed only in the group with the swimming training program[13]. The study indicates that improvements in lung and inspiratory capacities were not the result of long-term exercise only, but from underwater exercise where the lung is greatly exerted by water pressure.

However, a newly identified issue is that the haenyeo population has abruptly diminished (14,143 haenyeos in 1970 and 4,507 haenyeos in 2013). Since young Korean women avoid being haenyeos and over 80% of haenyeos at present are in their sixties or older[7], it is predicted that breath-hold diving of haenyeos will cease to exist in a couple of decades. As most studies reported by professor Hong and his colleagues were on young haenyeos in their thirties to forties, there is very little known about elderly haenyeos' thermal and cardiovascular changes.

In particular, oxygen consumption of diving animals while diving is minimized by selective blood circulation which flows to the brain, heart, and other necessary tissues along with blocking the flow to the intestines, kidney, or muscles through the autonomic reflex[9, 14]. The autonomic reflex results in reducing heart rate and cardiac output, which is able to extend diving time. Hong and his colleagues reported that haenyeos' heart rate decreased from 101 bpm at rest to 60 bpm at 40 s after water immersion[9]. However, as aforementioned, most observations were obtained from young haenyeos and no study reported on elderly Korean haenyeos' heart rate while naturally breath-hold diving in cold seawater. Therefore, the present study aimed to explore the pattern of heart rate during natural diving work in cold seawater and examine relationships between ageing and diving patterns. We hypothesized that the decreasing rate in heart rate of elderly haenyeos during breath-hold diving was greater and total diving time including surface swimming time was shorter than those of young haenyeos from previous studies.

Methods

Participants

Initially, thirteen Korean women divers participated in the monitoring survey but four were excluded because of incomplete data. Finally, nine were analysed for this study [mean ± SD: 68.4 ± 9.7 yr in age, 59.7 ± 4.0 kg in body mass, 154.1 ± 5.6 cm in height, 1.57 ± 0.84 m^2 in body surface area, 24.3 ± 3.8% in body fat, and 51 ± 10 yr in diving career]. The oldest haenyeo was 83 yr old with a 65 yr-diving career Body fat (%) was estimated by a body composition analyzer (Model Karada Scan HBF-370, Omron, Japan). Eight of nine were from Hadori town in Jeju Island and one was from Jongdalri town in Jeju Island. All haenyeos used to be part of the elite class (Class A), called 'Sang-Gun' in Korean, and wore cotton swimsuits in their youth. None of them smoked. A full explanation of procedures, discomforts, and risks were given prior to obtaining informed consent. All procedures were approved by the Institutional Review Boards of Seoul National University.

Monitoring procedure

The anthropometric survey and interview were carried out on Jan 23 and 24, 2014. Field tests using heart rate monitoring devices were conducted for three days (Jan 24 and 25, and Apr 8, 2014). Haenyeos arrived at a preparatory house located near the coast before 8 am. Thereafter, they were equipped with heart rate monitoring devices (a chest belt and a wrist watch) (Model RS400 or RS800, Polar Electro, Finland) and donned wet suits with 4 mm or 5 mm thickness. More detailed description on the wet suit was presented in Lee and Lee[1]. We began to record heart rate at 5-s interval as soon as they began walking to the coast, and averaged the heart rate as 1-min interval for analysis. Haenyeos wore T-shirts, briefs, socks and/or tights inside the wet suits. We recorded air temperature and air humidity (LT 8A, Gram Corporation, Japan), globe temperature (a black globe thermometer with 150 mm in diameter), and air flow (Velocicalc Air velocity Meter 8345, TSI, USA) on the coast at 10-min intervals. Sea surface temperatures during the field test were used from

Korea Oceanographic Data Centre. Seawater temperature becomes lower as it gets deeper, but is almost uniform between 0–250 m in depth. Because haenyeos usually dive up to 5 m and to maximum 20 m in depth, we used the sea surface temperature from Korea Oceanographic Data Centre[15]. Individual time of entering the seawater and coming out from the seawater were recorded. Haenyeos collected abalone, turban shell, sea urchins, sea cucumber, octopus, or seaweed from the sea and they carried the seafood using their individual net bag on their back or using a pickup truck for transport to the preparatory house (Fig. 1). We ended heart rate recordings the moment they doffed their wet suits in the preparatory house.

Fig. 1. Donning wetsuits and equipment (A), walking to enter the sea and entering the seawater (B–E), swimming back to the coast (F), arriving to the coast (G), walking back to the haenyeos' resting house (H, I), and classifying seafood harvested (J). 'H' is from http://www.jejusg.co.kr.

Data analysis

Data were generally presented as mean with standard deviation (mean ± SD). Frequency of dives was calculated by the bottom points of diving cycles in heart rate. Diving time (duration) did not include the walking period to enter and walking time to come back from the seawater. Total diving time in the sea consisted of 'descending time, bottom time, ascending time, and surface swimming time (surface interval)'. Breath-hold diving time refers to descending, bottom time, and ascending time, but did not include surface swimming time. During surface swimming time, haenyeos did not hold their breath but rather breathe deeply making a sound called 'Sumbi' in Korean, which is possible because their head is out of the seawater and they rest on their buoy with their arms in the sea. The bottom time was defined as a duration that haenyeos search and collect seafood around the ground under the sea (the bottom), whereas the descending and ascending time were defined as periods of going down to the bottom and coming up from the bottom, respectively. Differences in variables between bottom and top points were tested by paired *t*-test using SPSS 20.0. Relationships between age and diving time, frequency of dives, or heart rate were tested by Pearson's correlation coefficients. Statistical significance was accepted for probabilities less than 0.05.

Results

Environments and diving patterns

Air temperature, air humidity, and globe temperature were 14.9 ± 1.0°C, 63 ± 4%RH, and 18.3 ± 1.5°C, respectively. Air flow on the coast was 3.4 ± 1.0 $m \cdot s^{-1}$. Sea surface temperatures during the field test were reported at 10–13°C[10]. All haenyeos began their daily diving work at about 9 am, but completion time varied according to the individual and weather. Six of nine haenyeos finished their work around 2–3 pm, but three completed their works around noon. The average total diving time including surface swimming time was 253 ± 73 min for a day with a range of 155 to 341 min (Table 1). Haenyeos swam out to a target spot to collect seafood and hang their buoy with a weight on the surface of the spot so that their mesh nets with the buoy are not swept away. Then, they did repetitive breath-hold diving around the surface area. Once they collected enough seafood at the spot, they moved to another spot with their buoy and mesh (net) bag. The total frequency of dives was 97 ± 28 times (56–134 times) and

Table 1. Total diving time and frequency of elderly haenyeos in cold seawater

	Haenyeos									Mean (SD)
	#1	#2	#3	#4	#5	#6	#7	#8	#9	
Age (yr)	78	73	67	56	58	57	74	70	83	68 (10)
Diving career (yr)	61	57	49	39	40	36	58	51	65	51 (11)
Total diving time (min)[a]	183	290	314	341	328	287	155	175	200	253 (73)
Frequency of dives (times)	82	100	>56	134	132	>85	92	n.c.[c]	n.c.	97 (28)
Frequency of dives (times·h^{-1})	27	21	11	24	24	18	36	-	-	23 (8)
Cycle of dive[b] (min)	2.2	2.9	5.6	2.5	2.5	3.4	1.7	-	-	3.0 (1.3)

[a, b]Including surface swimming time; [c]Not counted; Approximately 3–20 m in diving depth (Interview data base)

diving frequency per hour was 23 ± 8 times·h^{-1} (11–36 times). For two of nine haenyeos (subjects #8 and #9), the frequency of dives was not counted because their decreasing heart rate was not clear (Fig. 2). We could not judge whether the slight decrease in heart rate of subjects #8 and #9 was attributed to bottom diving or simple breath holding during surface diving.

Heart rates while diving in cold seawater

Heart rate at work had a mean of 111 ± 15 bpm with a range of 86 to 136 bpm (Table 2). Heart rate was 32 ± 18% greater while walking back with their heavy seafood collection from the seawater than while walking out to the sea in the morning (p<0.001). While they were breath-hold diving under the sea, heart rate was markedly reduced by 20 ± 8% (11–32%) when compared to heart rate during surface swimming in the sea (p<0.001). Interestingly, subject #7 only showed lower heart rate during diving in the sea than during walking on the earth, with no hyperventilation during surface swimming (Fig. 2). Negative relationships were found between age and diving time (r=−0.573, p<0.05), diving frequency (r=−0.510, p<0.05), and heart rate at work (r=−0.410, p<0.05) (Fig. 3).

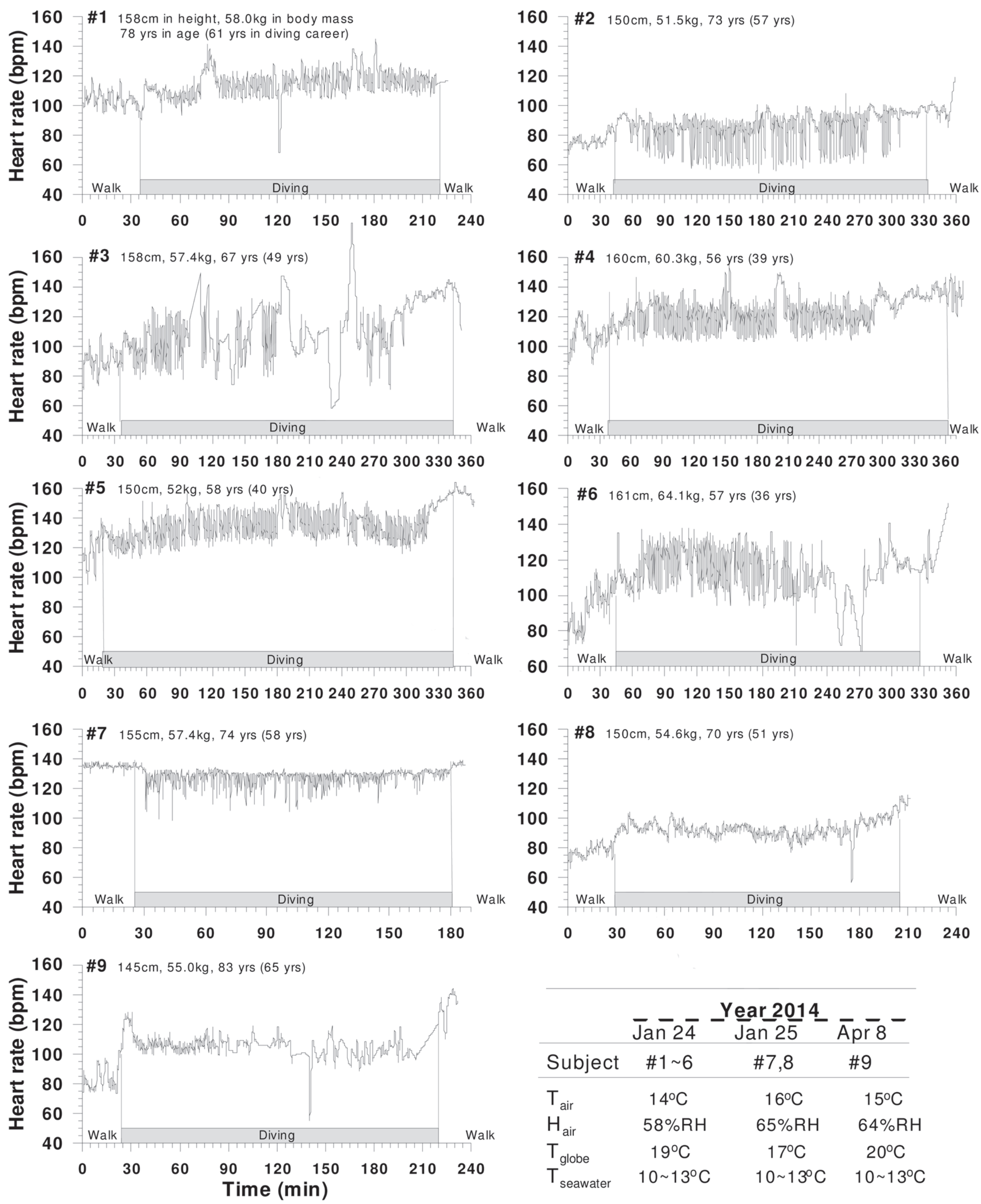
Discussion

To our knowledge, we are the first to study the heart rate of older women divers (56–83 yr in age) during commercial breath-hold diving in cold seawater. As expected, diving bradycardia due to apnea and immersion were apparent and the decreased rate was about 20% of the heart rate during surface swimming. Eight haenyeos, except one (subject #7), had a greater heart rate during surface swimming compared to walking. The older haenyeos showed shorter total diving time, less diving frequency, and lower heart rate at work. This suggests that elderly haenyeos adjust their workload according to the degeneration of cardiovascular functions with ageing. We discuss more about diving bradycardia along with the influences of ageing and cold water.

Diving bradycardia with advancing age

Diving bradycardia is a physiologically protective oxygen-conserving mechanism common in diving mammals and breath-hold divers[9, 14]. Landsberg reported a 35 beat-decrease while breath-hold diving in 25°C water for eight young males[16]. For elite young male breath-hold divers the decline of heart rate was 44 ± 10%[17], whereas heart rate reduction was approximately 21% for young non-divers[18]. Hong and his colleagues reported a 21% and 37%-decrease in heart rate during breath-hold diving for five young haenyeos (37 ± 5 yr) in summer and winter, respectively[9]. For middle-aged Korean haenyeos (50 ± 6 yr), heart rate showed a gradual bradycardia from 95 bpm to about 65 bpm during the dive (32% decreased)[19]. The present study showed that elderly haenyeos had diving bradycardia with about a 20% decrease rate (average 24 bpm decline), but the extent of decline was weaker than young haenyeos[9] or elite male divers[17] in previous studies. One may raise a question if such differences between the older divers in the present study and young divers in previous studies were not just from the differences in age, but from the differences in water temperature. We are not completely sure that ageing is the only factor for the attenuated diving bradycardia for the older divers. However, it is reasonable to consider that such differences in attenuated bradycardia would be the result of ageing effects, because Hong and his colleagues reported their results from young women divers in 10°C-seawater[9].

Furthermore, Holm and colleague supports the hypothesis[20]. They compared the cardiovascular functions of four groups (older male divers [54 ± 6 yr], older non-divers, young divers, and young non-divers) through face immersion in 15 °C water in an experimental test. The



	Year 2014		
	Jan 24	Jan 25	Apr 8
Subject	#1~6	#7,8	#9
T_{air}	14°C	16°C	15°C
H_{air}	58%RH	65%RH	64%RH
T_{globe}	19°C	17°C	20°C
$T_{seawater}$	10~13°C	10~13°C	10~13°C

Fig. 2. Time courses of heart rate for Korean women divers, haenyeo, while diving in cold water (T_{air} refers to air temperature; H_{air}, air humidity; T_{globe}, globe temperature).

heart rate of older divers was decreased by about 14%, while the heart rate of young divers was decreased by 35%. Older divers had more exceptional cardiovascular functions compared to older non-divers, but not as pronounced as the typical younger divers. Such age-dependent bradycardia has been reported before[21, 22]. Diving bradycardia appeared to be greater in 11–14 yr-olds than in adults[23]. Our results are in agreement with the previous studies, but most elderly haenyeos displayed both breath-hold diving bradycardia and swimming tachycardia, which suggests that their diving work is still actively progressed. Also, as it was reported previously, that the excretion of norepinephrine increased slightly in Korean haenyeos during winter, which is attributable to the reduction in resting

Table 2. Heart rate of elderly haenyeos while diving in cold seawater

Work phase	Haenyeos									Mean (SD)
	#S1	#S2	#S3	#S4	#S5	#S6	#S7	#S8	#S9	
Walking to enter the seawater (bpm)	104	76	91	105	119	93	135	78	82	98 (20)
Walking back from the seawater (bpm)	116	99	134	135	157	126	137	110	132	127 (17)
Surface peak point [S] (bpm)	123	93	123	131	145	128	131	n.c[b]	n.c	125 (16)
Bottom point [B] (bpm)	106	64	84	108	124	101	117	n.c	n.c	101 (20)
Rate of decrease[a] (%)	13.8	31.0	31.6	17.7	14.7	21.0	10.6	n.c	n.c	20.1 (8.3)
Whole duration HR (bpm)	113	86	109	122	136	111	129	91	104	111 (15)

[a](S-B) 100/S; [b]Not counted

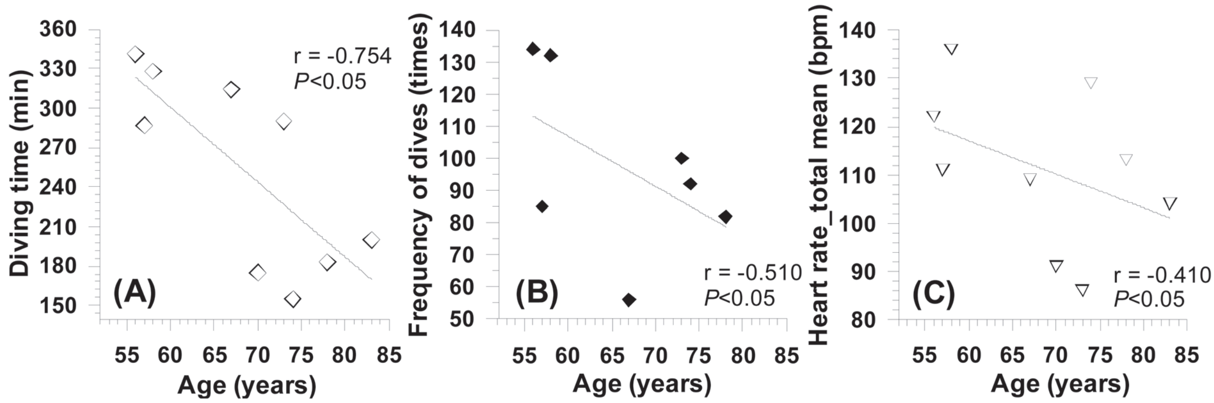


Fig. 3. Relationships between age and diving time (A), frequency of dives (B), and heart rate at work (C).

heart rate of Korean haenyeos[10], it will be of interest to compare the norepinephrine of elderly haenyeos to elderly non-divers with diving bradycardia in future.

An interesting finding is that a case of diving bradycardia with no swimming tachycardia was observed from subject #7 aged 74 yr old (Fig. 2). Commercial breath-hold diving usually involves swimming exercises. The combination of apneic submersion and swimming exercise results in both diving bradycardia and exercise tachycardia. For subject #7, however, it seems that diving bradycardia was dominant which caused no tachycardia during surface diving.

Time and frequency of dives

In this field study, average total diving time (253 ± 73 min for a day) which includes surface intervals was not shorter, but total frequency of dives (97 ± 28 times for a day, up to 134 times) was smaller than values in previous reports. Hong and his colleagues[11] reported a total diving time of 170 ± 2 min and a dive frequency of 129 ± 12 times for a day from nine middle-aged haenyeos (51 ± 3 yr) during the winter. In this study, a single diving time including a single surface swimming time was calculated to 3 min on average since diving frequency per hour was 23 ± 8 times·h^{-1} (Table 1). The present results demonstrate relatively longer single diving times (including descending, bottom, ascending, and surface swimming time) and less frequency of dives per hour when compared to previous reports on haenyeos.

A diving time is dependent on the depth of diving and Korean haenyeos usually dive up to 5 m in depth, but the maximum depth is up to 20 m. For Japanese male Ama (56 ± 5 yr in age), diving depths were 8 to 20 m with dive numbers of 75 to 131 times and they reported that repetitive short surface intervals or long breath holding session may cause intravascular bubbles in ama divers[24]. In particular, breath-hold divers in Japan, who dive to depths of up to 22 m of seawater, suffered from sensory numbness after more than two hours of dives[25]. Water pressure at 10 m and 20 m depths are 2 atm and 3 atm, respectively. In general, class A-haenyeos can be more suffered by greater water pressure. In the present field study, however, none of nine haenyeos reported a deeper dive of 13–15 m in depth at the interview after works. Also, they did not perceive any difference in water temperature while diving under the sea according to the depths.

Park and his colleagues reported that for the up to 5 m depth diving a breath-hold diving time (including descending, bottom, and ascending time) was 32 s and surface swimming time was 46 s (a single diving time=78 s) with the frequency of dives at 46 times per hour[26]. As oxygen partial pressure in blood drops to a risky level when a diving time under water exceeds about 60 s, experienced haenyeos have maintained a diving time under water for about 30 s. It is difficult to compare the present results to previous reports because we did not record the diving depth of each diver. However, it is confirmed that the much older haenyeos in this study showed shorter diving time and smaller frequency of dives with lower mean heart rate (Fig. 3). If we observe longer surface swimming time and shorter breath-hold diving times from elderly haenyeos when compared to values for young haenyeos in further studies, it will be acceptable to suppose that the longer surface swimming time of older women divers can be a behavioural adjustment with advancing age to lessen workloads due to repetitive breath-hold diving.

Effects of cold water and wet suits on reduced heart rate

We found the decrease of 20 ± 8% in heart rate during breath-hold diving in cold seawater. The decreased rate can be explained by water immersion and compressed wet suits as well as apnea. Heart rate is lower in water than on land, which is related to gravity, compression, dive reflex, and temperature. As the human body is less affected by gravity in water, blood flows from below the heart back up to it with less effort, which results in a lowered heart rate. Also, water along with compressed wet suits can cause a smaller venous load to the heart than equivalent land exercise. In addition, when the face is submerged in water, a diving reflex lowers heart rate. Regarding the effect of cold stress, when coupled with cold stimulation and apnea, a greater reduction in heart rate was observed[22, 27].

Heart rate is higher at the same exercise intensities in hot conditions than in cold conditions and such increase under heat stress have been shown to be around 10 beats per min[28]. At colder temperatures, increases in cardiac output and stroke volume are observed because blood in the veins of the extremities is deviated from the superficial to deep veins due to the vasoconstriction of the skin blood vessels. Such increases in central blood volume and venous return induce the reduction in heart rate in cold water.

The extent of bradycardia during apneic maneuver was 20% greater in cold seawater (10°C) than in warm seawater (27°C)[9]. This is due to the initiation of the diving reflex primarily from stimulation of receptors on trigeminal afferent fibers, particularly cold receptors located in the forehead[18]. Wearing wet suits with 4 mm or 5 mm in thickness provide insulation to haenyeos but is not sufficient to insulate the whole body in 10–13°C seawater. In addition, half of the face and the hands is often exposed to cold water. It is worth noting that the elderly Korean women divers of this study have immersed themselves in 10–13°C cold seawater every winter for the last 50 yr (Table 1).

Conclusions

This study confirmed that older haenyeos had diving bradycardia during bottom time and tachycardia during surface swimming time in seawater. The decreased rate of 20 ± 8% at the bottom time was lower than decreased rates from previous reports on young haenyeos in cold seawater, which suggests that diminished cardiovascular functions and diving reflex with advancing age exist. For older haenyeos, shorter diving time and less frequency of dives suggest that haenyeos have voluntarily adjusted their workload along with their advancing age, which is regarded as a behaviroral adaptation to compensate for attenuated cardiovascular capacity due to ageing.

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