

## Daily diving pattern of Korean and Japanese breath-hold divers (ama)

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Hong SK, Henderson J, Olszowka A, Hurford WE, Falke KJ, Qvist J, Radermacher P, Shiraki K, Mohri M, Takeuchi H, Zapol WJ, Ahn DW, Choi JK, Park YS. Daily diving pattern of Korean and Japanese breath-hold divers (ama). *Undersea Biomed Res* 1991; 18(5-6):433-443.—Daily diving patterns and thoracic skin and sea-water temperatures were recorded during the entire work shift of Korean female unassisted (cachido) and Japanese male unassisted and partly assisted (funado) divers using Underwater Physiological Data Loggers developed in Buffalo and Japan. All 3 groups of divers were studied during the summer of 1989 and 1990. Additional studies were conducted during the winter of 1991 on Korean female divers who, unlike Japanese divers, dive all year round. The water temperature of the diving grounds in summer was 24°C in both Korea and Japan, and 10°C during winter in Korea. 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 · day<sup>-1</sup>, of which only 52-63 min were spent diving submerged, and the remaining time at the water surface. These diving patterns were not different between female and male cachido divers. Compared with Japanese male divers, Korean female divers dived to a shallower depth (3.7 vs. 6.9 m) with shorter dive time (29 vs. 37 s) and shorter bottom time (14 vs. 18 s). Velocities of descent (0.72 vs. 0.47 m · s<sup>-1</sup>) and ascent (0.77 vs. 0.56 m · s<sup>-1</sup>) were also slower in female divers than in male divers. The diving pattern of Korean female divers was similar in both summer and winter. Although all cachido divers wore wet suits and thus were protected from severe cold stress, thoracic skin temperature decreased during a work shift by 7°C in winter (vs. 1°C in summer) in Korean divers. Compared with Japanese male cachido divers, Japanese male funado divers stayed in the diving ground (including time in the boat) longer (201 vs. 305 min · day<sup>-1</sup>) but performed only 23 dives per day. The average diving depth (9.7 m), duration (69 s), and bottom time for each dive (45 s), however, were significantly greater in funados. The velocity of vertical descent (1.0 m · s<sup>-1</sup>) was also significantly greater in funados because they descend with a weight (8-12 kg). The rate of ascent was not different.

Korean women divers	funado
Japanese male divers	wet suit diving
cachido	breath-hold diving
Underwater Physiological Data Logger	

Professional breath-hold divers of Korea and Japan, known in the scientific literature as "ama," have been in existence for more than 2000 yr. They are engaged in daily diving activity while breath holding and subject themselves to cyclical changes of the hydrostatic pressure surrounding their body. Many physiologic studies have been conducted on these divers during the last 3–4 decades (1–7). These studies include examination of cardiorespiratory and thermoregulatory function, with special emphasis on the nature of their adaptation to many years of breath-hold diving. Although several investigators have attempted to determine the exact daily diving pattern, there were many technical difficulties. Thus, our current knowledge of their daily diving pattern is based on limited measurement made under surveillance during short intervals and often during unnatural circumstances. Since these divers stay in the sea water for as long as 2–5 h a day while engaged in repetitive diving, we believed it was important to determine their complete daily diving pattern so that one can quantify their diving work rate.

The present study was designed to monitor and record continuously their diving pattern and change of heart rate, skin temperature, and the water temperature while diving by using dive recorders recently designed and constructed in Buffalo by Henderson et al. (8) and by Vine Bionic System (Tokyo, Japan). These data were analyzed to determine gender differences, the effect of sea water temperature, and the difference in diving method (cachido/unassisted vs. funado/assisted) on the daily diving pattern and skin temperature changes accompanying diving.

## METHODS

Two types of dive data loggers, one developed by Henderson et al. (8) and the other developed by Vine Bionic Systems, were used simultaneously. Both loggers have the same operational characteristics and recorded every second the depth (0–50 m range with precision of  $\pm 2\%$ ) of an individual dive, thoracic skin and sea water temperatures (10–40°C range with precision of  $\pm 1\%$ ), and heart rate (24–300 beats  $\cdot$  min<sup>-1</sup> range with precision of  $\pm 0.5\%$ ) for a period up to 8 h.

Field studies were conducted in August 1989, September 1990, and February 1991 on Korean female divers, and in August 1989 and September 1990 on Japanese male divers. The number of subjects as well as their physical characteristics in each group are provided in Table 1. Studies on Korean female divers were conducted at Hae Un Dai, Pusan, Korea, in both the summer (1989 and 1990) and winter (February 1991). These women are unassisted (cachido) divers who dive year round and wear wet suits and fins. They walk into the sea from the shore and swim to the diving grounds. Japanese male divers were studied in the summer of 1989 (August) and 1990 (September). The 1989 studies were conducted at the villages of Matsuwa and Nagai located on the Miura Peninsula; they were on 4 unassisted divers (cachido) who wore wet suits and used swim fins. The 1990 studies were conducted in the village of Chikura located on the Chiba Peninsula, on 9 partially assisted divers (funado) who descended from a boat with an 8–12 kg weight but ascended without assistance. After each dive,

**TABLE 1**  
AGE AND PHYSICAL CHARACTERISTICS OF VARIOUS SUBJECT GROUPS<sup>a</sup>

Diver Group (n)	Age, year	Height, cm	Weight, kg	Period of Diving, yr
Korean female cachidos (11), 1989 summer	49.0 ± 1.8	154.6 ± 1.8	54.5 ± 1.8	33.7 ± 0.6
Korean female cachidos (6), <sup>b</sup> 1990 summer	51.7 ± 3.4	152.7 ± 2.6	53.2 ± 1.1	34.7 ± 1.3
Korean female cachidos (9), <sup>b</sup> 1991 winter	50.9 ± 2.5	153.0 ± 2.3	57.4 ± 3.2	34.2 ± 2.0
Japanese male cachidos (4), 1989 summer	46.5 ± 4.4	165.0 ± 3.4	61.6 ± 4.9	19.0 ± 2.3
Japanese male funados (9) 1990 summer	52.3 ± 1.9	163.0 ± 3.8	67.1 ± 3.5	25.4 ± 2.4

<sup>a</sup>Mean ± SE; <sup>b</sup>all of these divers also participated in 1989 summer studies.

cachido divers stayed in the water whereas funado divers returned to the boat for rewarming with a propane stove deployed in the middle of the boat. These funado divers are not allowed by union rules to wear wet suits and hence wear only short neoprene pants. Moreover, Japanese divers (both cachido and funado) are allowed to dive only during the warm season (from May 1 through September 5). Both groups of Japanese male divers leave the shore by a motor boat, and it takes 5–10 min to reach the diving grounds.

Means and standard errors were computed for each variable for each diver group. Statistical comparisons were made between groups by nonpaired Student's *t* tests. A difference was considered significant if  $P \leq 0.05$ .

## RESULTS

A typical record displaying a depth-time profile, heart rate, thoracic skin temperature, and sea-water temperature during a 10-min segment of a diving shift is shown in Fig. 1. The total number of dives per day, their duration and the depth, the rates

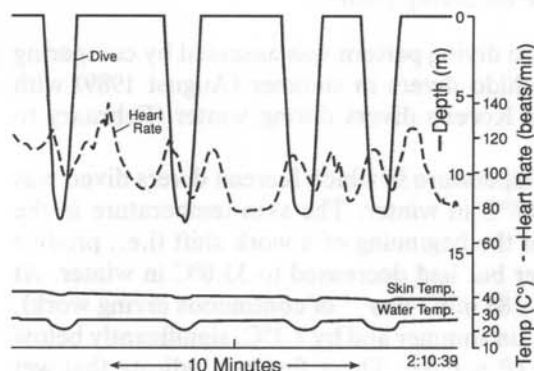


Fig. 1. A typical record obtained over a 10-min period from a Japanese male cachido diver showing the change in depth (m), heart rate (beats · min<sup>-1</sup>), thoracic skin temperature (°C), and sea water temperature (°C).

of descent and ascent (Table 2), the pattern of changes of heart rate, and the changes in both thoracic skin and sea-water temperatures in relation to diving activity may be determined from similar records taken throughout the entire daily work shift. In this communication, major emphasis is placed on an analysis of daily diving pattern and thoracic skin temperature variation. Heart rate data will be reported separately.

### Comparison of diving pattern among different groups of divers

#### *Comparison between male and female cachido divers*

Depth-time data obtained from Korean female and Japanese male cachido divers during August 1989 were analyzed for gender differences in diving pattern. Studies of Korean female cachido divers were conducted during the summers of 1989 (August) and 1990 (September); the various parameters of diving were not different between the two summers (Table 2). However, we examined the data obtained from the 1989 studies when comparing diving patterns between male and female cachido divers because there were more subjects studied in 1989. Both Korean female and Japanese male cachido divers wore similar wet suits (4–5-mm thick) and fins. The surface temperature of the sea water was comparable at around 24°C.

As shown in Table 2, the duration of the work shift ( $\sim 200 \text{ min} \cdot \text{day}^{-1}$ ) and the number of dives ( $\sim 110 \cdot \text{day}^{-1}$ ) were comparable in both groups of divers. On the average, cachido divers spent only  $\sim 60 \text{ min} \cdot \text{day}^{-1}$  in actual diving. Thus, cumulative surface time was  $\sim 140 \text{ min} \cdot \text{day}^{-1}$  in both groups. However, male cachido divers made deeper, longer dives with greater velocity of descent and ascent compared with female cachido divers. Japanese male cachido divers dived to an average depth of 6.9 m compared with 3.73 m for Korean female divers ( $P \leq 0.05$ ). The average maximal depth reached by these divers on the study day was 12.9 m for Japanese male divers and 6.0 m for Korean female divers ( $P \leq 0.05$ ). The average duration of a dive was longer in male divers ( $37.0 \pm 0.4 \text{ s}$ ) than female divers ( $28.9 \pm 0.3 \text{ s}$ ) ( $P \leq 0.05$ ). The longest dive observed was also longer in male ( $51.7 \pm 4.1 \text{ s}$ ) than in female ( $39.5 \pm 3.4 \text{ s}$ ) cachido divers ( $P \leq 0.05$ ). The velocity of both descent and ascent were greater in male ( $\sim 0.7 \text{ m} \cdot \text{s}^{-1}$ ) than female ( $\sim 0.5 \text{ m} \cdot \text{s}^{-1}$ ) divers ( $P \leq 0.05$ ).

#### *Effect of sea-water surface temperature on diving pattern*

The effect of dive water temperature on diving pattern was assessed by comparing data obtained from Korean women cachido divers in summer (August 1989) with those obtained from the same group of Korean divers during winter (February to March 1991).

As shown in Table 3, the sea-water temperature in which Korean divers dived was 23.4°C in summer, but decreased to 10.8°C in winter. The skin temperature in the chest region underneath the wet suits at the beginning of a work shift (i.e., pre-dive period) was as high as 36.1°C in summer but had decreased to 33.0°C in winter. At the end of a shift (i.e., at the end of  $170\text{--}188 \text{ min} \cdot \text{day}^{-1}$  of continuous diving work), skin temperature had decreased by 1.3°C in summer and by 7.1°C, significantly below the starting skin temperature, in winter ( $P \leq 0.05$ ). These findings indicate that wet

TABLE 2  
AVERAGE DIVE CHARACTERISTICS IN GROUPS OF MALE AND FEMALE KOREAN AND JAPANESE<sup>a</sup>

Parameter of Dive	1989 Summer, n = 11	Korean Female Diver (Cachido) 1990 Summer, n = 6 <sup>b</sup>	1991 Winter, n = 9 <sup>b</sup>	Japanese Male Diver (Cachido) 1989 Summer, n = 4	Japanese Male Diver (Funado) 1990 Summer, n = 9
Total time in water (shift), min · day <sup>-1</sup>	188 ± 6	179 ± 4 <sup>c</sup>	170 ± 2	201 ± 10	305 ± 5
Total diving time, min · day <sup>-1</sup>	52 ± 2	54 ± 9 <sup>c</sup>	57 ± 3	63 ± 12	26 ± 2
Total surface time, min · day <sup>-1</sup>	136 ± 7	125 ± 5 <sup>c</sup>	113 ± 3	138 ± 8	279 ± 6
Total number of dives per day	115 ± 9	129 ± 23 <sup>c</sup>	129 ± 12	109 ± 29	(on boat) 23 ± 1
Average depth of single dive, m	3.7 ± 0.03	3.6 ± 0.04	3.6 ± 0.4	6.9 ± 0.1	9.7 ± 0.5
Average deepest dive, m	6.0 ± 0.4	6.1 ± 0.6	5.8 ± 0.6	12.9 ± 1.8	11.9 ± 1.9
Average single dive time, s	28.9 ± 0.3	26.8 ± 0.3	28.2 ± 2.5	37.0 ± 0.4	68.5 ± 4.3
Average longest dive, s	39.5 ± 3.4	40.0 ± 6.1	37.7 ± 3.0	51.7 ± 4.1	79.8 ± 12.2
Descent velocity, m · s <sup>-1</sup>	0.47 ± 0.002	0.49 ± 0.003	0.40 ± 0.02	0.72 ± 0.005	0.97 ± 0.07
Ascent velocity, m · s <sup>-1</sup>	0.56 ± 0.003	0.60 ± 0.005	0.70 ± 0.03	0.77 ± 0.007	0.72 ± 0.03
Descent time <sup>d</sup> , s	7.9	7.3	9.6	9.8	10.0
Ascent time <sup>d</sup> , s	6.7	6.0	5.4	8.9	13.5
Bottom time per dive <sup>d</sup> , s	14.3	13.5	13.2	18.3	45.0
Bottom time per day <sup>d</sup> , s/min	1644/27.4	1741/29.0	1630/27.2	1921/37.0	1035/17.2

<sup>a</sup>Mean ± SE; <sup>b</sup>these subjects were also studied in 1989; <sup>c</sup>n = 4; <sup>d</sup>based on appropriate group average value.

TABLE 3  
THORACIC SKIN TEMPERATURE (Ts) AT THE BEGINNING AND END OF EACH DAILY DIVING WORKSHIFT<sup>a</sup>

Subject Groups	Ts (°C) at Water Surface		Workshift Duration, min · day <sup>-1</sup>	Sea Water Temp at Surface, °C
	Predive (air)	End of Shift		
Korean female cachido				
1989 summer	36.1 ± 0.9	34.8 ± 1.4	188 ± 6	23.4 ± 0.04
1990 summer	34.3 ± 0.2	32.5 ± 0.7	179 ± 4	22.2 ± 0.04
1991 winter	33.0 ± 0.6	25.9 ± 0.8	170 ± 2	10.8 ± 0.1
Japanese male (summer)				
1989 cachido	38.3 ± 0.6	36.6 ± 1.5	201 ± 10	24.8 ± 0.03
1990 funado	34.8 ± 0.3	31.4 ± 0.6	305 ± 5 <sup>b</sup>	29.7 ± 0.2

<sup>a</sup>Mean ± SE. <sup>b</sup>Since divers in this group remained on the boat during surface time, the number represents the sum of the daily total diving time and the total time on the boat. In contrast, all cachido divers stayed in water during surface time, except for about 15–30 min taken by Japanese male cachido divers for lunch on the boat.



suits do provide reasonably adequate thermal protection in winter when the water temperature is as low as  $\sim 10^{\circ}\text{C}$ .

Despite this difference in the level of seasonal cold-water exposure, the daily diving pattern was remarkably similar in both summer and winter (Table 2). For instance, the total diving time, total number of dives per day, average depth, and duration of dive as well as the descent rate did not differ between summer and winter. On the other hand, the total time in water and the total surface time were slightly reduced in winter ( $P \leq 0.05$ ) whereas the ascent velocity was slightly higher in winter ( $0.7 \text{ m} \cdot \text{s}^{-1}$ ) compared with summer ( $0.56 \text{ m} \cdot \text{s}^{-1}$ ) ( $P \leq 0.05$ ). The bottom time (both the average per dive as well as the daily total) was not different between summer and winter (Table 2).

#### *Comparison between cachido and funado divers*

Funados dived far less frequently than cachidos ( $P \leq 0.05$ ) although they spent nearly 100 min more in the diving grounds than cachidos. The funado diver spent nearly 5 h in the sea, significantly more than the cachido diver ( $P \leq 0.05$ ) (Table 2), but spent only 26 min actually diving, making about 23 dives per day, significantly less than the cachido diver ( $P \leq 0.05$ ). In contrast, Japanese male cachido divers spent  $201 \text{ min} \cdot \text{day}^{-1}$  in the sea, of which 63 min ( $109 \text{ dives} \cdot \text{day}^{-1}$ ) were actually spent diving. The average depth of dive was significantly greater in funados ( $9.7 \pm 0.5 \text{ m}$ ) than in cachidos ( $6.9 \pm 0.14 \text{ m}$ ) ( $P \leq 0.05$ ). The deepest dive observed on the study day was not significantly different between the 2 groups (12 m). Although funados made only 23 dives a day (compared with 109 dives a day in the cachido), the average single dive time was nearly twice as long in the funado ( $68.5 \pm 1.9 \text{ s}$ ) compared with cachido diver ( $37.0 \pm 0.4 \text{ s}$ ) ( $P \leq 0.05$ ); the longest dive each type of diver performed during the study day was 80 s by the funado and 51.7 s by the cachido ( $P \leq 0.05$ ). As expected, the rate of descent was much greater in the funado ( $0.97 \pm 0.07 \text{ m} \cdot \text{s}^{-1}$ ) than in the cachido diver, probably due to the weight-assisted descent of the funado. On the other hand, the rate of ascent was comparable in both groups. In general, a funado diver dived much less frequently but dived deeper and longer than the cachido with longer bottom time.

#### **Comparison of bottom time**

The average single dive time and depth, the actual time spent in descent and ascent, and the average bottom time for a single dive for different groups of divers are shown in Table 2. The average bottom time for a single dive was 14–18 s for all groups of divers except the Japanese male funado diver whose bottom time was nearly 3 times longer (45 s). However, funados made fewer dives per day ( $23 \pm 1$ ) (Table 2) compared with other groups who made more than 100 dives per day. Thus, the cumulative bottom time per day in funados was only 1030 s (or 17.2 min), approximately one-half that of other groups of divers.

#### **Comparison of the typical depth-time profile**

Figure 2 depicts the average dive profile of the 3 different groups of divers. In general, cachido divers were engaged in shallower, shorter dives with a higher frequency than the funado divers.

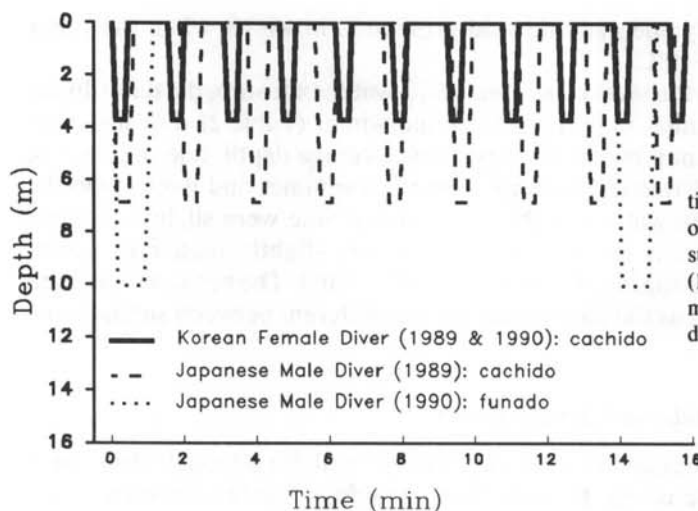


Fig. 2. Average diving depth-time profiles obtained from groups of Korean female cachido (1989 summer), Japanese male cachido (1989 summer), and the Japanese male funado (1990 summer) divers, respectively.

## DISCUSSION

Although many studies have been conducted on Korean and Japanese ama divers to examine the physiology of breath-hold diving (1-7), their daily diving pattern was not concomitantly documented. Recently, a computer-assisted diving data logger developed in Buffalo and Tokyo, Japan (8) has enabled diving frequency and the depth and duration of individual dives during an entire daily work shift to be collected. In addition, heart rate and thoracic skin and sea-water temperature were also recorded while a subject was engaged in work. Since there were no cable connections between the recorder and the investigator, the divers remained completely unconstrained to engage in normal diving activity.

Previous studies on the wet-suited Korean female diver showed that she dived on the average for ~32 s with an average surface interval of ~45 s and a total water time of 3 h (7). These figures agree with the present findings except for the surface interval, which we found was twice as long as previously measured. The rate of vertical descent and ascent was comparable between present and previous studies (6, 7).

A gender difference in diving pattern was investigated by comparing data obtained from groups of Korean female and Japanese male cachido divers during the summer of 1989. The mean age of the 2 groups of divers also was comparable, although the Korean female diver had been engaged in diving work on average 15 yr longer than the Japanese male diver (Table 1). Despite such a difference in diving experience, data shown in Table 2 clearly indicate that the total water time, total diving and surface time, and the total number of dives completed per day were identical in both groups. Other diving measurements demonstrated that male divers made deeper, longer, and faster (greater velocity) dives.

Shiraki et al. (1) studied the daily diving pattern of the wet-suited Katsugi (male cachido) diver on Tsushima Island, Japan, located between the southern end of the Korean peninsula and Kyushu, Japan. This study also showed that the male diver stayed in the sea (27°C during summer) for 276 min a day (two shifts  $\cdot$ day $^{-1}$ ), nearly 80 min longer than the Japanese male cachido employed in the present study. In contrast, the single dive time of  $38.6 \pm 3.3$  s in the Katsugi is comparable with 37.0



TABLE 4  
VERTICAL VELOCITY ( $M \cdot S^{-1}$ ) OF DIVING BY VARIOUS GROUPS OF DIVERS

Subject Group (no. divers)	Rate of Descent	Rate of Ascent	Notes and References
Japanese female funado (n = 4)	1.21 (21) <sup>a</sup>	1.55 (21) <sup>a</sup>	subjects wearing cotton bathing suits (5)
Japanese male funado, partly assisted (n = 4)	1.00 (83)	0.67 (85)	subjects wearing short pants made of neoprene; present study
Japanese male cachido (n = 4)	0.68 (15)	0.50 (15)	shallow dives (<10-m depth); subjects wearing short cotton pants (1)
(n = 4)	0.80 (10)	0.68 (10)	deeper dives (>10-m depth); subjects wearing short cotton pants (1)
(n = 2)	0.63 (6)	0.27 <sup>b</sup> (6)	shallow dives (<10-m depth); subjects wearing wet suits and fins (1)
(n = 4)	1.12 (14)	0.77 (14)	deep dives (>10-m depth); subjects wearing wet suits and fins (1)
(n = 4)	0.72 (83)	0.77 (83)	subjects wearing wet suits and fins; present study
Korean female cachido (n = 3)	0.57 (8)	0.58 (12)	subjects wearing cotton bathing suits (6)
(n = 5)	0.54 (10)	0.84 (6)	subjects wearing wet suits and fins (7)
(n = 11)	0.47 (1235)	0.56 (1235)	subjects wearing wet suits and fins; present study summer (1989 study-August)
(n = 6)	0.49 (629)	0.60 (629)	subjects wearing wet suits and fins; present study summer (1990 study-September)
(n = 9)	0.40 (1164)	0.70 (1164)	subjects wearing wet suits and fins; present study winter (1991 study-February)

<sup>a</sup>(n) Number of dives performed by all divers in the group on the study day.

<sup>b</sup>This slow rate of ascent is attributed to the terrain of the sea bottom and does not reflect the typical rate.

$\pm 0.4$  s found in the male cachido employed in the present study. The rate of descent in the Katsugi divers was high ( $1.12 \text{ m} \cdot \text{s}^{-1}$ ) when they dived deeper ( $>10 \text{ m}$ ). This is more than twice as fast as that measured in the Korean female cachido (Table 2). It was noted that the Katsugi uses legs and fins more vigorously during descent than the female cachido of Korea. These findings on the Katsugi suggest that the male is a stronger and/or a more skillful diver than the female.

Although the sea-water temperature regularly decreases to  $\sim 10^\circ\text{C}$  in winter compared with  $23^\circ\text{C}$  in summer, Korean divers used to dive during the entire year until 1977 wearing only a cotton bathing suit, subjecting themselves to a severe cold-water stress (2, 3). Earlier studies conducted on these traditional, unprotected divers indicated that in winter they took only one brief winter work shift lasting 15–30 min, during which their rectal temperature decreased to  $\sim 35^\circ\text{C}$  (3). The duration of their work shift was directly proportional to the sea temperature (2). The introduction of the wet suit now seems to provide adequate thermal protection, as indicated by the remarkable increase in the duration of the work shift to 2–3 h  $\cdot$  day $^{-1}$  with little reduction of rectal temperature (4). The present study also suggests that the effect of the cold sea-water temperature on the diving pattern has been largely eliminated by wearing wet suits. However sufficient the relative thermal protection of the wet suit there remains a far greater net heat loss, indicated by a significant decrease in thoracic skin temperature during the diving shift in winter than in summer.

The diving pattern was markedly different between the male cachido and funado (Table 2). Compared with the cachido, the funado dived longer, deeper, and faster (greater velocity of diving). Although the bottom time for a single dive is longer (45 s), the daily total bottom time of the male funado diver (single bottom time  $\times$  no. of dives per day =  $45 \text{ s} \times 23 \text{ dives per day} = 1035 \text{ s}$  or 17.2 min) was only one-half that of the cachido diver (Table 2). It is also of interest that the rate of vertical descent for funado divers in the present study was as high as  $0.97 \text{ m} \cdot \text{s}^{-1}$ , a value considerably lower than the  $1.21 \text{ m} \cdot \text{s}^{-1}$  reported by Teruoka (5) for the Japanese female funado (Table 4) carrying a 15-kg weight for descent. Moreover, even the Japanese male cachido diver of Tsushima (Katsugi) descended at a faster rate ( $1.12 \text{ m} \cdot \text{s}^{-1}$ ) than the funado divers employed in the present study.

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