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LOSS OF BODY FLUID AFTER OPEN-WATER DIVES CONDUCTED AT NIGHT IN WARM WATER

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and Development Command
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Naval Medical Command
Washington, DC 20372-5210

NOTICES

TECHNICAL REVIEW AND APPROVAL

NMRI 92-003

The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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Changes in body weight were recorded in 9 divers after nighttime dives in 26 °C (78 °F) water [l]asting 2-5 hours. A total of 34 manned dives were made during March-April 1991 as part of operator [t]raining for a SEAL Delivery Vehicle (SDV). Loss of body fluid was estimated directly from changes in [b]ody weight (1 liter fluid per kg body weight).

Dive duration averaged 195 ± 10 min. The average loss of body weight, from pre- to post-dive, [w]as 1.31 ± 0.12 kg. This translated to an estimated loss of body fluid of 1315 ± 115 ml, or an hourly [r]ate of loss of 440 ± 44 ml per hour of dive.

The magnitude of the loss in body weight or body fluid did not correlate with the duration of the [d]ive. This can be explained largely by the facts that the dives all lasted more than 2 hours, and that

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immersion diuresis will peak within the first 2 hours of the dive. A significant negative correlation was noted for loss of fluid per hour of dive versus dive duration. This correlation is more artificial than real since the major portion of fluid available for loss can be excreted within the first 2 hours of the dive; longer dive times will result in lower apparent rates of loss for the same amount of fluid.

The magnitude of the estimated loss of body fluid during these night dives was greater than that reported in laboratory studies conducting nighttime immersions. Fluid losses actually approximated values reported for daytime laboratory immersions. This finding would suggest that divers performing repeated nighttime dives may shift their circadian rhythm towards a daytime pattern of urine flow. Thus, estimates of fluid loss during night operational dives would more closely compare to laboratory findings obtained from daytime immersions.

Exercise heart rate obtained from a 5-minute step test was about 10% higher in the post-dive period than the pre-dive test. The magnitude of this increase in exercise heart rate (12 ± 2 beats/min) did not correlate with dive duration or change in body weight. The post-dive increase in exercise heart rate supports the conclusion that a loss of body fluid as little as 2% of body weight will have a negative effect on the ability to perform work.

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INTRODUCTION

Laboratory studies have shown that immersion results in an increased urine production on the order of 200-300% greater than under dry conditions (6,8,12,13,15,16). In the absence of fluid intake during immersion, urine flow rates will peak within 60-120 minutes after the start of immersion and decline subsequently during the remainder of the exposure (5,12,15).

Urine production is normally lower at night than during the day, due to diurnal variations. Thus, total amounts of urine produced during nighttime immersions will be less than corresponding exposures conducted during the daytime (6,10,14). Nonetheless, the magnitude of the increase in urine flow is the same for day and night exposures when compared to the temporally matched non-immersed condition.

Since immersion diuresis results in loss of body fluid akin to other forms of dehydration, it is not surprising that physical performance declines in proportion to the amount of fluid lost. For example, exercise heart rates increased 10-19% during 6-hour cold water dives where plasma volume decreased by 17% (7).

The aforementioned laboratory studies were done under controlled conditions. In operational situations it is often not possible to control factors such as pre-dive diet, exercise, or work conditions. The question arises, therefore, whether changes in hydration status during open-water operational dives would be comparable to laboratory results. Accordingly, the purpose of this study was to measure changes in body weight as an estimate of hydration status, after prolonged dives in warm water. A favorable agreement of data collected under operational conditions with laboratory results would validate research approaches to mission-relevant questions.

METHODS

Nine U.S. Navy SEALs volunteered to participate in the study after signing informed consent. The study was approved by the NMRI Committee for Protection of Human Subjects. The divers were undergoing advanced operator training in SEAL Delivery Vehicles (SDV) from January-May 1991. The study measurements were obtained in March and April of this period; subjects were, therefore, considered acclimated to warm weather conditions. Divers had commenced nighttime diving operations about one week prior to the start of the study. Night operations were conducted 4 out of each 7-day period; the 5th day involved no diving, but subjects continued to follow their nighttime activity/rest pattern. Subjects performed their normal daily activities during this period and were not restricted with respect to dietary or exercise patterns.

The physical characteristics of the subjects are presented in Table 1. Skinfold thickness was measured at 12 sites: triceps, subscapula, anterolateral chest, axilla, abdomen, suprailiac, anterior thigh, biceps, forearm, lower back, posterior thigh, and calf. The first seven sites were used to calculate percent body fat according to the method of Jackson and Pollack (9).

Data were collected before and after 17 nighttime SDV dives made between the hours of 1900 and 0500 on 8 dates (34 man-dives). Subjects performed 3-5 dives each during this period; a minimum of 48 h elapsed between dives for any particular subject. Diver subjects alternated duties as pilot and navigator of the SDV on each dive.

Divers wore a closed-circuit underwater breathing apparatus (MK-15) and full face mask. A 3-mm neoprene wet suit was worn beneath canvas coveralls. Surface water temperature was 25.6 °C (78 °F) and air temperature was 25.6-26.7 °C (78-80 °F). The maximum depth of any dive was 40 fsw (12.2 m); average depth was 20 fsw (6.1 m). For purposes of this study, dive time was measured from the time the divers entered the water until they exited the water. Dive times ranged from 2-5 h.

Body weights, measured to the nearest 0.11 kg (0.25 lb), were obtained within one hour before the start of each dive. No fluids or food were consumed thereafter in the pre-dive period. Post-dive weights were obtained within 30 min after exiting the water. Body fluid loss was estimated from the assumption that each kg loss of weight corresponded to a loss of 1 ℓ of fluid. Volume of urine produced (in ml) was calculated from change in body weight (in gm) by (2):

$$VOL_{urine} = 0.964 \text{ (change } WT_{body}) - 31$$

Exercise heart rate was measured before and after 8 dives (n=16) to assess the correlation between changes in body weight and cardiovascular reserve. The exercise test consisted of a 5-minute step test (step height = 42 cm, stepping rate = 30/min, alternating legs on the step-up). Pulse rate was manually counted for the first 15 seconds immediately following cessation of exercise and converted to heart rate in beats/min.

Decreases in body weight from pre- to post-dive were converted to loss of body fluid and expressed as milliliter of fluid lost per hour of dive time. The change in exercise heart rate from pre- to post-dive was used as an index of the cardiovascular stress. One-way analysis of variance (ANOVA) was used to test for statistical significance between pre- and post- dive values for body weight and heart rate. Two-way ANOVAs were applied to these variables to assess whether the order of each subject's dives influenced the measurements. Least squares regression techniques were applied to the data sets to test for correlations between experimental variables and dive time. Significance limits were set at $p < 0.05$ and grouped data are presented as the mean ± SEM.

RESULTS

Dive times averaged 195 ± 10 min (n=34, range: 120-300 min). No diver reported a sensation of being cold, nor was observable shivering noted. Diver activity was constrained to the operation of the SDV; no extravehicular activities occurred. No injuries were reported during the course of these dives.

Table 2 presents data for pre- and post-dive values for body weight and step-test heart rate. Body weight was significantly lower post-dive than pre-dive. The average loss in body weight was 1.31 ± 0.12 kg (n=34, range: 0.34-2.72 kg). This represented ~2% reduction in total body weight. Dives conducted between 1900-2300 hours had similar reductions in body weight (1.32 ± 0.14 kg, n=16) as those conducted from 2300-0500 hours (1.31 ± 0.18 kg, n=18). Reductions in body weight translated to an estimated net loss of body fluid of 1315 ± 115 ml. Body fluid loss expressed per hour of dive time averaged 440 ± 44 ml/h. The portion of fluid loss attributable to urine was 1236 ± 80 ml.

Figure 1 illustrates the individual losses of body weight versus dive time. No significant correlation existed between change in weight vs time ($R=-0.017$, $F=0.11$, $p>0.2$). Similarly, no correlation was noted between individual changes in body weight and dive test day. On the other hand, Figure 2 depicts a significant negative correlation between the rate of fluid loss per hour and dive time ($R=-0.469$, $F=10.75$, $p<0.01$).

Post-dive exercise heart rate at the end of the step test was 12 ± 2 beats/min higher than corresponding pre-dive values ($n=16$, $p<0.01$), an increase of approximately 10%. Figure 3 indicates that the change in heart rate from pre- to post-dive did not correlate significantly with dive time ($R=0.082$, $F=0.88$, $p>0.4$). Likewise, there was no correlation between change in heart rate and change in body weight ($R=-0.458$, $F=3.45$, $p>0.05$).

DISCUSSION

It is reasonable to conclude that most of the body fluid loss in this study, estimated from changes in weight, was a result of urinary excretion. Behn et al. (2) determined that urine volume represented about 96% of the change in body weight after 8-hour thermoneutral immersions. Divers in the present study wore minimal thermal protection in 26 °C water. It is unlikely that excessive sweating occurred at this water temperature. Respiratory water loss under the present conditions would be expected to contribute only a small portion to fluid loss.

The present data indicate that approximately 1.3 ℓ of body fluid will be lost during open-water dives lasting 2-5 h. Absence of a correlation between fluid loss and dive time may be explained by the timeframe of immersions. All dives lasted at least 2 h; 59% of them (20 of 34) lasted more than 3 h. It has been shown that diuresis peaks within 30-120 min after the onset of immersion (5,12,13,15). Thus, the major portion of the diuresis would have occurred in all the current dives. Consequently, further losses of body fluid may represent a smaller fraction of the total, resulting in little temporal effect over the 2-5 h dives.

An increase in intrathoracic blood volume, secondary to immersion, is the stimulus for diuresis. Previous data from our laboratory noted a pre-immersion basal urine flow rate of 1.6 ml/min, and average flow rates of 5.1-5.9 ml/min occurred during 3-hour head-out immersions where no fluid was consumed (5). Converting flow to volume, the difference between immersed and basal volumes is 680-774 ml, the volume excreted in response to the immersion stimulus (increased intrathoracic blood volume). Using the same basal flow, 192-480 ml of urine would be excreted in 2-5 h of the present study. Subtracting this value from the total volume (1236 ml) yields 756-1044 ml excreted due to the immersion stimulus, and is close to our previous lab results. This similarity would suggest that head-out immersion and submersion result in equivalent renal responses.

Interestingly, the above-mentioned excreted volumes are numerically similar to the volume of blood reported to be translocated to thoracic vessels (~710 ml in 74.5 kg subjects) upon immersion (1). However, since urine normally contains no blood cells, the excreted volume is actually about twice the blood volume translocated to the thorax (assuming a hematocrit of 50%). Thus, the immersion diuresis likely excretes more fluid than just the amount due to central volume expansion. Extravascular fluid compartments may be involved in the overall immersion response.

The negative correlation between fluid loss, expressed as ml/h, and dive time is more artificial than real. Since there was no significant change in the magnitude of fluid loss with time, essentially the same volume loss measured over a longer time period will result in an apparent decrease in the *rate* of fluid loss.

Post-dive increases in exercise heart rate did not correlate with either dive time or change in body weight. Since body weight or estimated fluid loss did not vary with dive time among subjects, the absence of a temporal correlation with heart rate is not unexpected. It is known that exercise heart rate will increase proportionately with fluid loss (7). The data from this study would infer that hydration status, and hence heart rate, were similar among dives of 2-5 h in duration. In addition, the results indicate that loss of body fluid equivalent to a 2% reduction in body weight will increase exercise heart rate by 10%. This conclusion is consonant with a longstanding axiom that heart rate will increase 10 beats/min for every 1.5% decrease in body weight (3).

Fluid loss in the current night open-water dives are compared to literature values for AM and PM laboratory immersions in Table 3. Inspection of the table indicates that, generally, the nighttime fluid loss reported here more closely approximate values obtained during daytime laboratory immersions. Data from the present study is consistently higher than PM laboratory immersions.

The reason for the nocturnal difference between open-water and laboratory studies is not apparent. Differences may relate to operational effects on stimulation of circadian pacemakers. Laboratory studies usually involve single or periodic night exposures. Divers in the present study began night operations about one week before the start of the study and conducted night activities 4 days/week during the study period. Artificial lighting was always used in the course of preparation for all dives. Entrainment or resetting of circadian pacemakers is influenced both by rest-activity cycles (11) and light-dark cycles (4). In the course of conducting repeated night operations the divers in this study may have shifted their circadian pattern to more of a "daytime" cycle. If such an effect occurred, this could account for somewhat higher estimates of fluid loss in the present study; normally, urine flows are higher during the day than during the night. No doubt this is an area of potential operational relevance where additional studies are warranted to confirm this hypothesis.

LAY LANGUAGE SUMMARY

Nine Navy SEALS performed open-water dives at night in a SEAL Delivery Vehicle (SDV). Water temperature was 78 °F; the average depth of the dives was 20 fsw. A total of 34 man-dives were conducted between the hours of 1900 and 0500.

Dive times ranged from 2 to 5 h and averaged 195 ± 10 min. Post-dive body weight averaged 2.92 ± 0.25 lbs (1.31 ± 0.12 kg) less than the pre-dive weight; the range in weight loss was 1-6 lbs. This represented ~2% of their total body weight. Based on weight loss, the estimated loss of body fluid was 45 ± 4 fl oz (1.4 ± 0.1 qts). More than 96% of this fluid loss was probably in the form of urine.

The magnitude of the weight loss did not vary as a function of dive time in these 2-5 h dives. This finding may be explained by the fact that all dives lasted at least 2 h, and it is known that the greatest portion of urine losses occur during the first two hours of immersion. Thus, within the dive times of 2-5 h, the length of time in the water will not appreciably affect loss of body weight; nearly a 3-lb loss will occur in this range of times.

The magnitude of fluid loss in these night dives closely approximated fluid losses measured in daytime laboratory studies. It was greater than fluid losses measured during night time laboratory immersions. This may be due to a shift in the divers' circadian rhythm because they were continuously operating at night. Thus, estimates of fluid loss during night open-water dives can be derived from daytime lab values.

An exercise step test was administered before and after 16 man-dives. The post-dive exercise heart rate was 12 ± 2 beats per min higher than pre-dive values. Post-dive values did not depend on the length of the dive. These results indicate that a loss of body weight on the order of 2% will result in about a 10% increase in exercise heart rate.

CONCLUSIONS AND RECOMMENDATIONS

1. For planning purposes, estimate that divers will lose an average of 3 lbs in body weight, or about 1.5 qts of body fluid, during 2-5 h dives. The magnitude of the loss will be about the same for 2-hour dives as for 5-hour dives.

2. Loss of body fluid will represent about 2% of a diver's total body weight (before the dive).

3. Based on loss of body fluid, drinking fluid while in-water would have to occur a rate of 14 fl oz (0.4 qt) per hour. After the dive, divers should consume 1.5 qts of fluid within the first two hours.

4. If repetitive or continuous night operations are planned, estimates of fluid loss can be based on laboratory studies conducted in the daytime hours. See reference (8) in this report for fluid guidelines.

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TABLE 1

PHYSICAL CHARACTERISTICS OF SUBJECTS (n=9)

SUBJECT	AGE (yr)	HEIGHT (cm)	WEIGHT (kg)	SKINFOLD* (mm)	% BODY@ FAT	# DIVES
A	24	183	78.02	89.0	7.8	4
B	28	175	75.75	75.0	7.2	5
C	23	175	80.74	81.0	7.0	3
D	21	183	77.57	80.5	7.3	5
E	23	180	76.20	83.0	8.1	3
F	25	175	75.30	80.0	8.4	4
G	21	180	81.19	86.5	8.1	3
H	24	183	79.38	67.0	5.8	4
I	21	173	72.58	82.5	7.6	3
Mean	**23**	**179**	**77.41**	**80.5**	**7.5**	
SD	**2**	**4**	**2.78**	**6.4**	**0.8**	
SEM	**1**	**1**	**0.93**	**2.1**	**0.3**	

* Sum of 12 skinfold sites

@ Calculated from 7 skinfold sites

TABLE 2

PRE and POST-DIVE BODY WEIGHT and EXERCISE HEART RATE

(Mean ± SEM)

	PRE-DIVE	POST-DIVE
WEIGHT (kg) (n = 34)	77.43 ± 0.39	76.11 ± 0.36*
range:	71.67 - 82.10	71.22 - 80.74
HEART RATE (bpm) (n = 16)	126 ± 2	139 ± 3*
range:	108 - 144	124 - 160

* $p < 0.01$ from corresponding pre-dive variable

TABLE 3

URINE VOLUME AND FLOW RATE FOR AM & PM IMMERSIONS

	WATER T ° (°C)	DURATION (min)	URINE VOLUME (ml)	FLOW RATE (ml/min)	REF
AM IMMERSIONS	5	360	1260		4.16
	25	180	1062	5.9	5
	35	180	918	5.1	
	35	240	784	3.3	10[a]
	35	180	252	1.4	14
	35	180	925	5.1	12
	34	180	1337	7.4	16
	24	240	1098	4.6	13[b]
	29	240	922	3.8	
	35	240	322	1.3	
PM IMMERSIONS	5	360	930	3.0	6
	35	180	150	0.8	14
	35	240	442	1.8	10[a]
	26	**195**	**1236[c]**	**6.3**	**THIS STUDY**

[a] values corrected for 800 ml water intake during immersion

[b] values for first 4 hours of 12-24 hour immersions

[c] estimated from: vol = 0.964 (wt loss) - 031

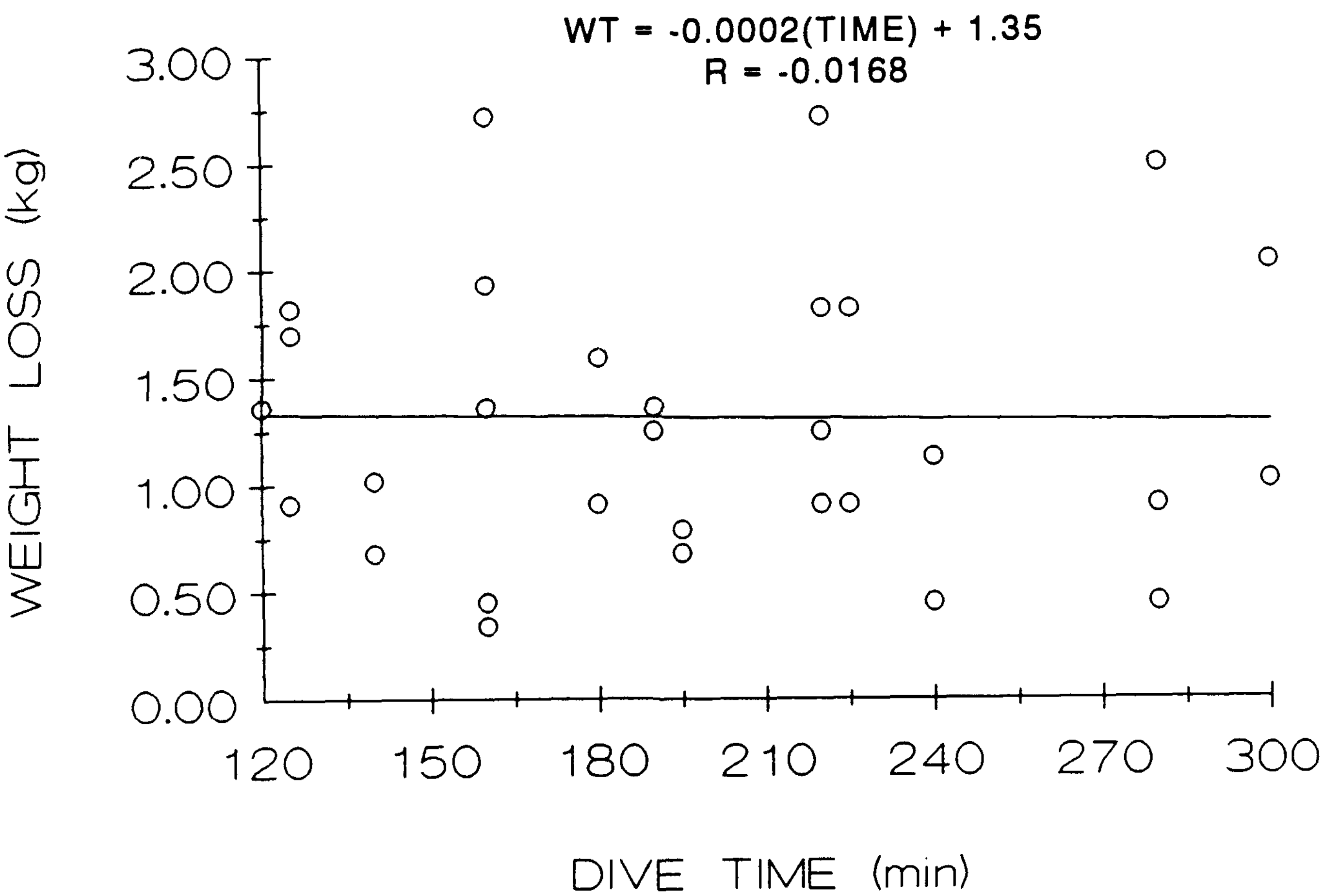
FIGURE LEGENDS

FIGURE 1. Post-dive weight loss in 9 divers versus time of dive. Weight loss did not correlate with dive time. Each symbol represents one dive (n=34); subjects performed 3-5 dives each.

FIGURE 2. Fluid loss per hour of dive time, calculated from changes in body weight (n=34). Loss per hour negatively correlated with dive time. Each symbol represents one man-dive.

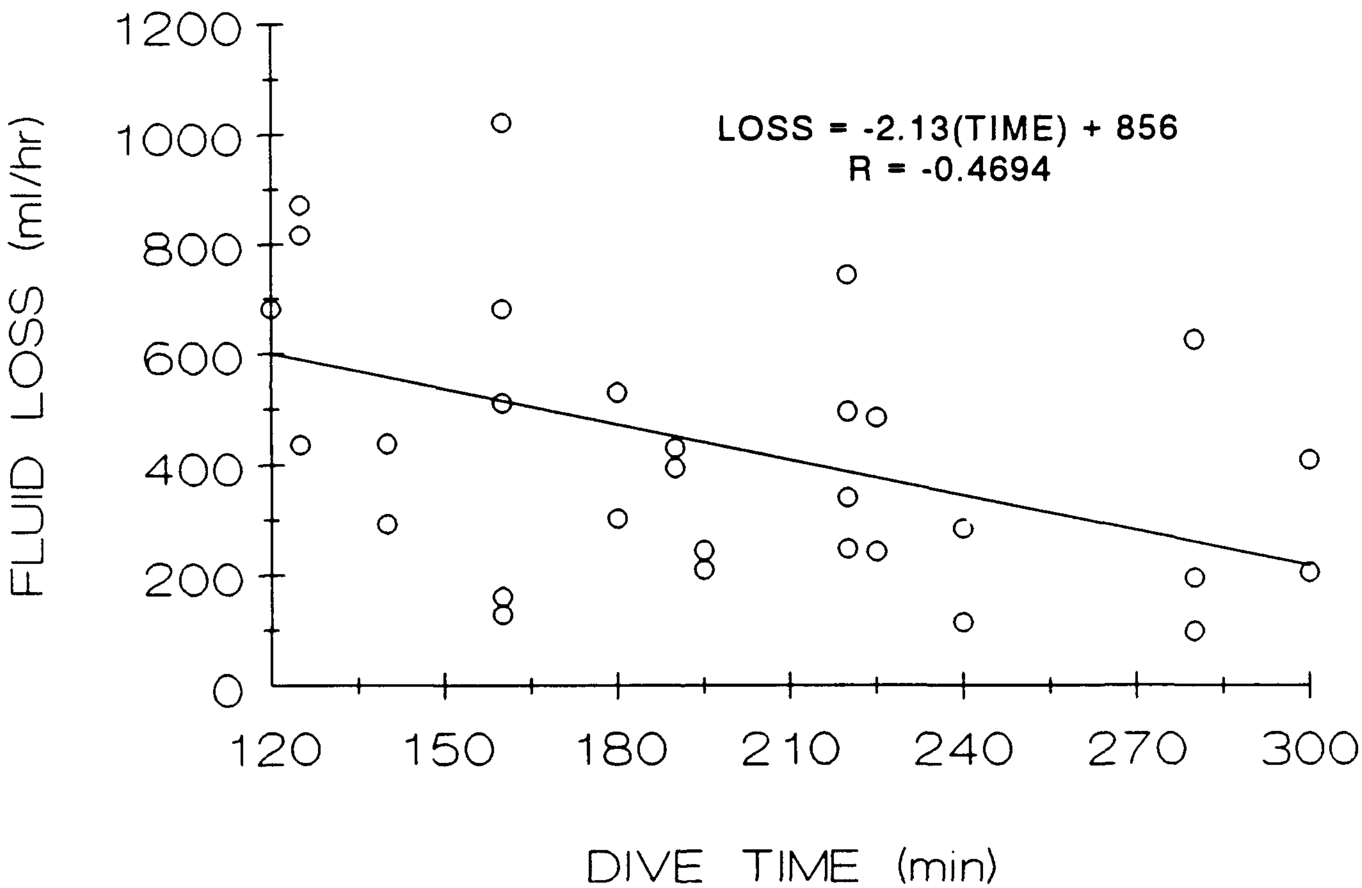
FIGURE 3. Change in step test exercise heart rate (post-dive minus pre-dive) versus dive time (n=16). Change in heart rate did not correlate with dive time. Each symbol represents one man-dive.

FIGURE 1



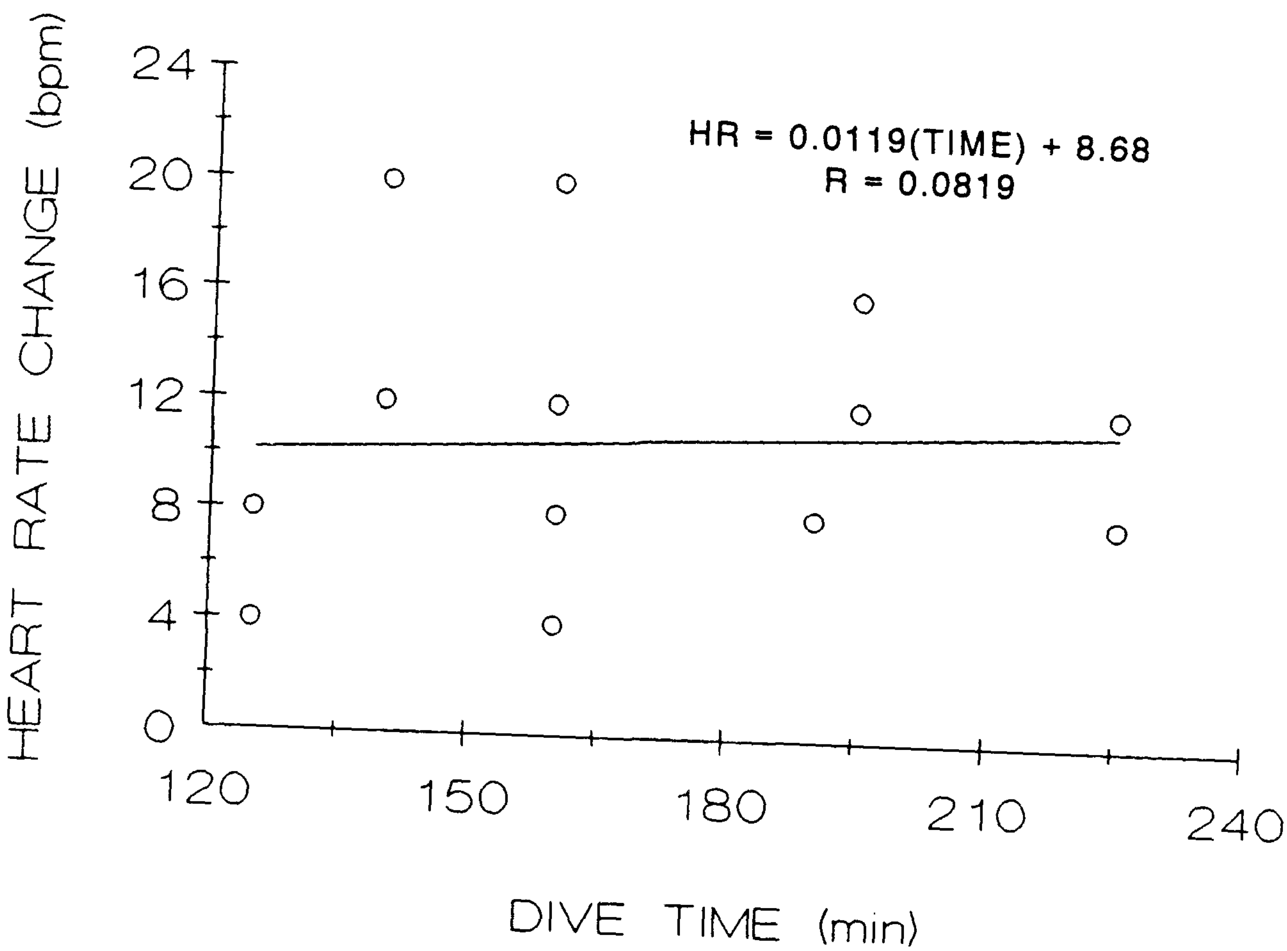
WT = -0.0002(TIME) + 1.35
R = -0.0168
WEIGHT LOSS (kg)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
120
150
180
210
240
270
300
DIVE TIME (min)

FIGURE 2



1200
1000
800
600
400
200
0
FLUID LOSS (ml/hr)
LOSS = -2.13(TIME) + 856
R = -0.4694
120
150
180
210
240
270
300
DIVE TIME (min)

FIGURE 3


HEART RATE CHANGE (bpm)
24
20
16
12
8
4
0
HR = 0.0119(TIME) + 8.68
R = 0.0819
120
150
180
210
240
DIVE TIME (min)