NAVAL MEDICAL RESEARCH INSTITUTE

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RESEARCH REPORT

MR 005.13-4001.06

Report No. 2

AN EXPERIMENT IN MAINTAINING HOMEOSTASIS IN A LONG DISTANCE UNDERWATER SWIMMER

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ABSTRACT

A record-holding long distance underwater swimmer served as the subject for investigations of conditions of prolonged submersion and exercise. The studies were performed while the swimmer was attempting to swim 110 miles along the Eastern Coast of Florida within a period of approximately 48 hours. The purpose of this experiment was to measure and attempt to replace his metabolic loss. The air was supplied from a self-contained underwater breathing apparatus (SCUBA). His nutritional needs were supplied by the every one-half hour feeding of 125 ml. of a nutrient formula taken down to the swimmer in a nursing bottle. This replacement diet consisted of 18 percent protein, 72 percent carbohydrate and 10 percent fat. The rate of sodium and potassium administration was 4 and 9 mEq. per hour, respectively. The estimates of his caloric requirement were made on the basis of a series of swimming pool trials and found to be approximately 150 kilocalories at a swimming speed of 0.9 mph. The caloric consumption during the ocean swim was calculated from the subject's air usage rate to be 264-280 kilocalories per hour at a swimming speed estimated to be 1.0-1.2 mph. Because his caloric replacement was at the rate of 187 kilocalories per hour, the subject had a calculated caloric deficit of 77-93 kilocalories per hour. His weight loss, however, was limited to 210 gm. Serum and urine changes which occurred during the ocean swim suggested a salt and water diuresis during submergence, followed by extreme water and salt conservation for at least 22 hours after the swim.

Failure of underwater lighting and shark activity necessitated termination of the experiment after one-fourth of the distance had been covered. However, the subject's response to the replacement regimen was most favorable. The operational procedures and data obtained are presented in a 16 mm., color, sound, motion picture.

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INTRODUCTION

The literature concerning exercise and caloric expenditure is vast. However, conspicuous by its dearth is literature concerning the concurrent replacement of calories as the exercise is in progress. The opportunity to study the effect of concurrent caloric replacement associated with exercise arose in connection with a long-distance underwater swimmer's attempt to set a new world record. This swimmer was a 39 year old white male who had held several world records for time and distance in underwater swimming. At the time this study was undertaken, he was to swim along the Eastern Coast of Florida with the Gulf Stream for a period of 48 hours, or for a distance of 110 miles. On his previous swims he had been fed a variety of foods, most of which were selected without regard to replacement value. It was deemed possible to effect a replacement program after his needs had been sufficiently evaluated. The following is a report on the methods used to study the subject, the results of those studies, the method by which the studies were applied to the contents of his replacement regimen and the results of such a replacement.

MATERIALS AND METHODS

1. *Physical Examination.* - The subject underwent a thorough physical evaluation to determine his fitness for the preliminary studies and the ocean swim. In addition, he was periodically examined throughout the period of study.

2. *Physical and Metabolic Studies.* - Prior to the actual ocean swim, a series of swimming pool trials were undertaken to assess several parameters of energy expenditure under differing swimming conditions. These data were then used as the basis of a caloric replacement program during the ocean swim.

a. *Speed and kick rate.* - A swimming pool of measured length was used for the preliminary trials. The swimming speed in miles per hour was calculated by measuring the time necessary to travel a given number of pool lengths. Studies were also performed to determine his mode of varying speed. One method used to vary speed was by changing only the rate of kick. The other method of varying speed was by changing the force of kick while maintaining a constant rate. The rhythm for various kick rates was supplied by striking a metal pole emerging from the water. In addition, the subject's caloric requirement was determined for various kick rates and related to his swimming speed.

b. *Caloric consumption.* - The subject's caloric requirement under these various conditions was measured using the method of Weir (1) which enables the calculation of caloric requirement using the caloric value of the percent expired O_2 reduced to dry air at Standard Temperature and Pressure (STP). The expired air volume was measured through a gasometer, collected in a Douglas Bag and the percent O_2 determined in a Pauling Oxygen Meter. The percent CO_2 was also determined in the expired tidal air by the use of a Dwyer CO_2 Analyzer. Gas collections were made at approximately 15-minute intervals while the subject was submerged and holding onto the pool ladder, maintaining a known kick rate and/or force of kick. When gas collections were not being made he swam back and forth in the pool at the established kick rate or force of kick.

A comparative study of the accuracy of the respiratory minute volume measured through the gasometer and that calculated from the compressed air usage rate was made. This was done in order that respiratory minute volumes on the ocean swim might be calculated from the compressed air usage rather than measured through the gasometer. This was necessary should the latter method prove impractical during the ocean swim, as subsequently occurred. The calculated respiratory minute volume was derived from the known initial and final pressure of the compressed air bottles, the air temperature and the time necessary to consume the bottle. By reducing this air volume to STP, the respiratory minute volume is easily calculated. Although tested at a number of swim speeds, kick rates, and forces of kick in the pool trials, the greatest number of determinations were made at the same kick rate and speed expected to be used on the ocean swim. The water temperature ranged from 26° to 30° C. in the pool trials and from 27° to 29° C. in the ocean swim. The swimmer wore a 3/16-inch neoprene wet suit.

c. *Other studies.* - Blood and urine specimens were obtained both before and after the swimming pool trials and the ocean swim.

3. *Nutrition and Ventilation.* - Air on both the pool swim and the ocean swim was supplied by a self-contained underwater breathing apparatus (SCUBA), the compressed air bottles being replaced every 40 minutes. The caloric data obtained from the pool trials were used in estimating the nutritional requirements for the ocean swim. The swimmer's nutritional needs on the ocean swim were supplied by the intermittent feeding of 125 ml. of a nutrient formula taken down to him at his swimming depth of 15 feet every one-half hour in a Playtex* nursing bottle. The formula was prepared by diluting Sego** with tap water to twice its original volume and reconstituting the caloric content to the original 0.75 Kcal/ml. by using Dextri-Maltose.*** This replacement diet consisted of 18 percent protein, 72 percent carbohydrate and 10 percent fat. The rate of sodium and potassium administration was 4 and 9 mEq. per hour, respectively. Twenty-four hours prior to the swim, his nutritional intake was 2400 ml. of the undiluted Sego** with water *ad libitum*. He was not fed during the trial swims in the pool.

RESULTS

1. *Physical Examination.* - The subject had enjoyed prior good health and had no serious illness at the time of examination. The only significant finding was a mild early hypertension with resting blood pressures ranging from 120/88 to 158/100, the majority being approximately 138/90. A blood pressure of 124/80 immediately after the ocean swim was the lowest recorded during any of the examinations. Fifteen hours after the ocean swim his blood pressure had returned to the preswim levels. There were no sustained blood pressure changes associated with the swimming pool trials. Weight loss of 210 gm., measured shortly after the ocean swim, included approximately 100-150 ml. of emesis lost following emergence from the water. This emesis was deemed secondary to seasickness, resulting from the rough seas at that time.

2. *Physical and Metabolic Studies.*

a. *Speed and kick rate.* - Figure 1 shows the speeds attained by the swimmer in the swimming pool when varying his speed by the two previously mentioned methods. While maintaining a constant force of kick, his speed varied directly with the rate of kick until approximately 55 kicks per minute and 1.35 miles

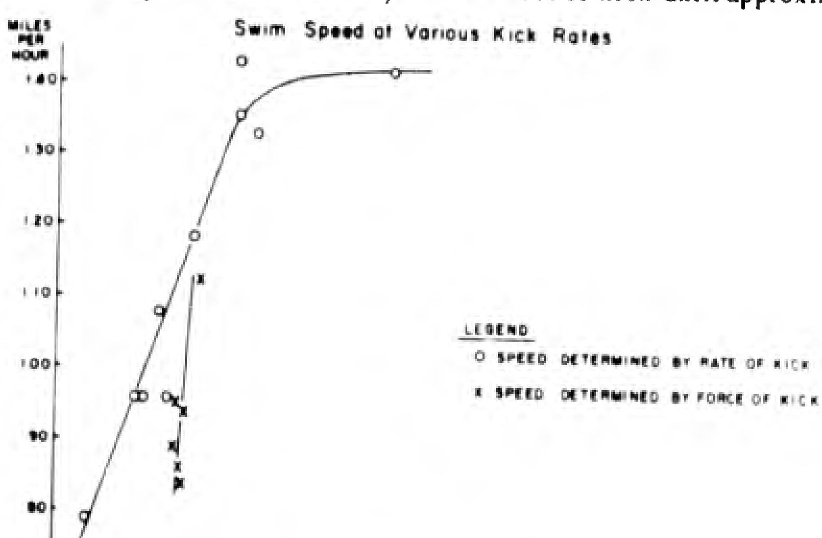

Figure 1. - The relationship between the rate of kick and the speed attained is shown from the swimming pool trials. At approximately 55 kicks per minute and 135 miles per hour the efficiency declines markedly. The range of speeds attained are much less when the kick rate remains constant and only the force of kick is varied. Each symbol represents the mean of at least three determinations.

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* Playtex Nurser, International Latex Corporation, Dover, Delaware.
** Sego, Pet Milk Company, St. Louis, Missouri.
***Dextri-Maltose, Mead Johnson and Company, Evansville, Indiana.

per hour when his efficiency declined markedly. The range of attainable speeds was much less when a constant kick rate was maintained and only the force of kick was changed. A direct relationship between the kick rate and caloric consumption was established as seen in figure 2.

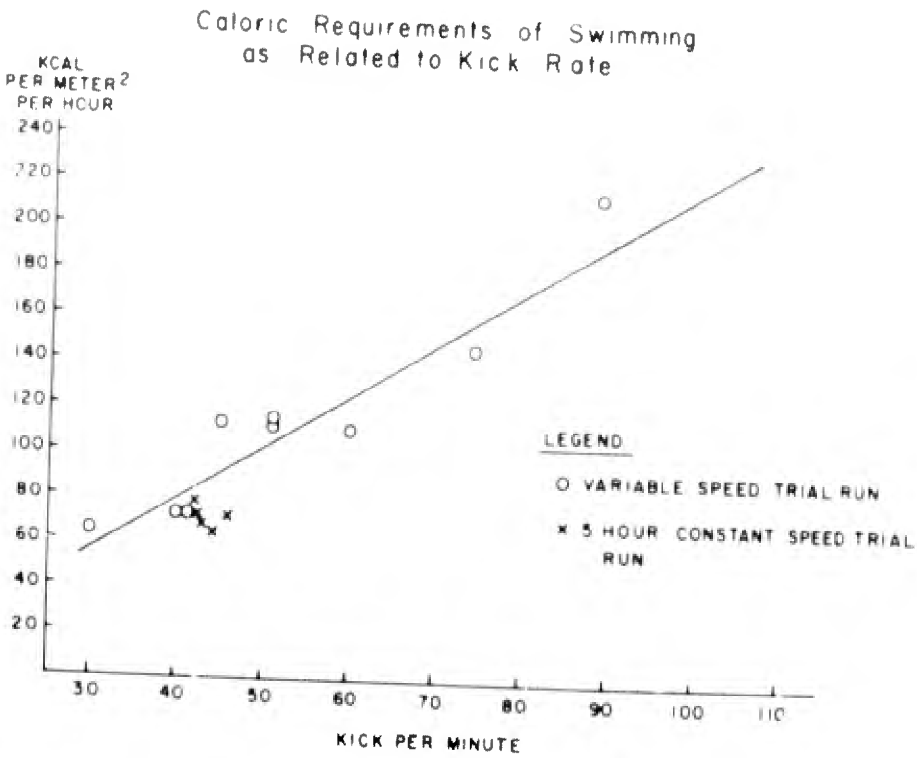

Figure 2. - The caloric consumption as determined in the swimming pool trials using the gasometer-Douglas Bag method varies directly with the kick rate. This relationship enables the use of the kick rate to estimate the caloric consumption while swimming. The greatest number of determinations were performed within the range of kick rates expected to be used in the ocean swim. Each symbol represents a mean of at least three determinations.

b. *Caloric consumption.* - A definite relationship exists between the respiratory minute volume measured through the gasometer and the caloric consumption as calculated from the percent remaining O_2 in the expired air. This relationship is seen for the swimming pool trials in figure 3. Thus, the swimmer's caloric consumption may be obtained by measuring his respiratory volume and referring to such a graph.

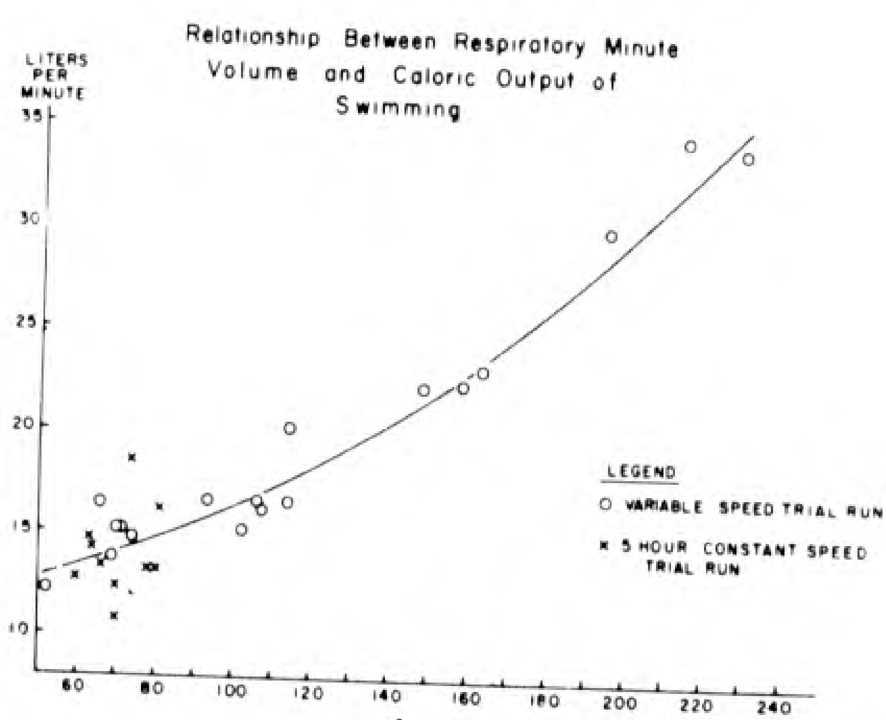

Figure 3. - The caloric consumption, as determined in the swimming pool trials using the gasometer-Douglas Bag method, has a definite relationship to the respiratory minute volume. This curve may be used to determine caloric consumption when only the respiratory minute volume of the swimmer is known. Each symbol represents a mean of at least three determinations.

The results of the comparative study between the gasometer-Douglas Bag method and compressed air usage methods of determining respiratory minute volume are seen in figure 4. It is noted that the respiratory minute volume as measured by these two methods agree closely and are, therefore, comparable.

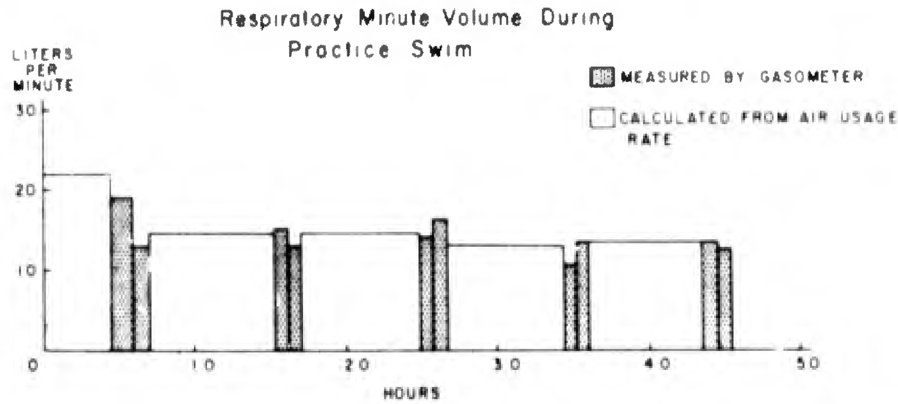

Figure 4. - Satisfactory agreement exists between the respiratory minute volume as measured directly through the gasometer and that indirectly determined from the compressed air usage.

The respiratory minute volumes from the ocean swim as calculated from the compressed air usage are seen in figure 5. With the exception of the first 40 minutes, while the swim was getting underway, the subject had a respiratory minute volume of approximately 20 liters per minute. When this is plotted on the graph derived from figure 3, it reveals that the caloric consumption was mainly between 132 and 140 Kcal/ M^2/hr. as seen in figure 6. Using a standard nomogram, the swimmer was found to have two square meters

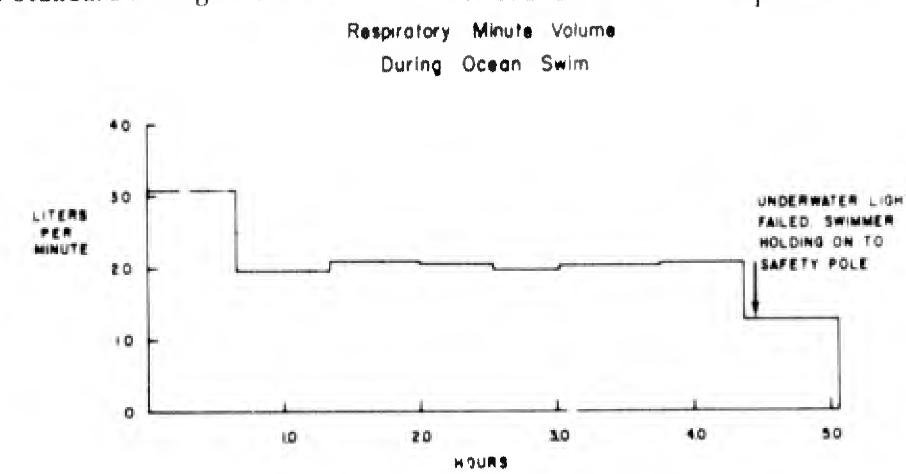

Figure 5. - After the initial high volumes, the swimmer's respiratory minute volume remained approximately 20 liters per minute as calculated from compressed air usage.

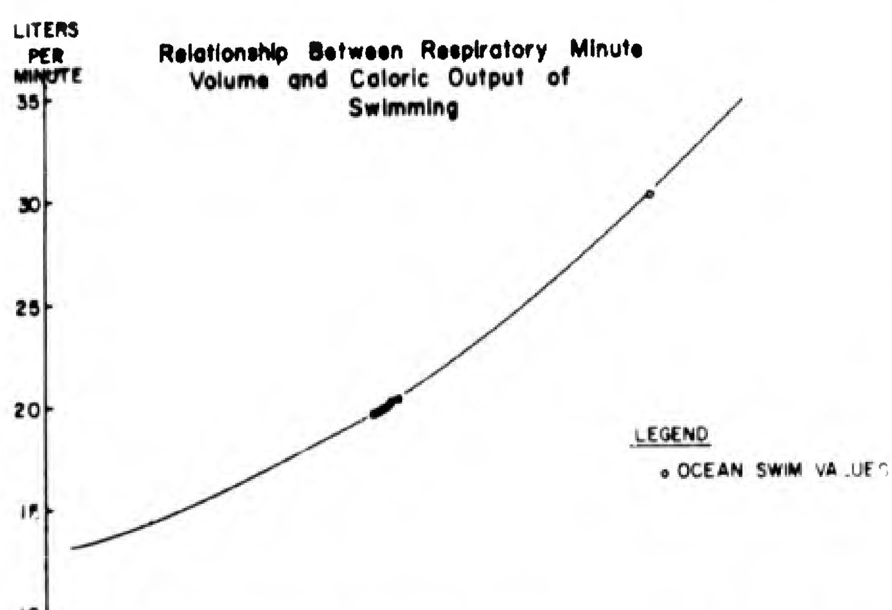

Figure 6. - By using the relationship shown in figure 3, the respiratory minute volumes from the ocean swim are plotted. These were derived from the compressed air usage. The respiratory minute volumes are considerably higher during the ocean swim than they were estimated to be on the basis of the swimming pool trials.

of body surface area: his caloric consumption, therefore should be 264 to 280 Kcal/hr. This was approximately one-half the 506 Kcal/hr. determined for an acute maximal effort of three minutes on a resistance bicycle. His speed during the ocean swim was estimated to be between 1.0 and 1.2 miles per hour. Consequently, a caloric deficit of 75 to 91 kilocalories per hour might be calculated since his feeding supplement supplied 189 Kcal/hr. The percent of CO_2 in the expired tidal air while swimming was between 3.4 and 3.8, approximately 1 percent higher than the percentages found in this laboratory in non-swimmers. This conforms to the observations of Lanphier (2), Goff and Bartlett (3) and also Schaefer (4) that experienced SCUBA divers adapt to a higher CO_2 percentage than non-swimmers.

3. *Other Studies.* - The following values were measured and were found to be within normal limits; hematocrit, eosinophile count, serum potassium, serum chloride, routine urinalysis. His leukocyte count doubled with a shift to the left during the ocean swim, returning to normal 22 hours afterward. There was a slight elevation in the serum creatinine from an initial value of 1.16 mgm. percent to 1.20 mgm. percent immediately after the swim to a value of 1.28 mgm percent 22 hours after the swim. However, creatinines on a normal diet and with no strenuous exercise were below 1.0 mgm percent. The serum specific gravity rose as a result of the ocean swim from 1.0267 initially to 1.0287 during the swim and continued to rise to 1.0290 as measured 22 hours after the swim. Urine volume increased from 34 ml/hr. for the 24-hour period prior to the swim to 60 ml/hr. for a timed urine specimen available during the swim and then decreased to 11 ml/hr. for the 22-hour observation period after the swim. The urine specific gravity increased from 1.017 at the end of the swim to 1.032 22 hours after the swim. The urine osmolarity increased from 714 mOsm during the corresponding times. While excreting 15 mEq. of sodium in a 2.23 hour timed-urine specimen during the ocean swim, he excreted only 15 mEq. of urinary sodium during the 22 hours following the swim. The subject was thirsty during these 22 hours after the swim, but reported no thirst, nausea, or other discomfort during the swim.

DISCUSSION

Among some of the more interesting findings during the ocean swim were the subject's increased rate of sodium and water excretion, followed after the ocean swim by thirst, rising serum creatinine, antidiuresis, antinaturesis and increased urine osmolarity. In general, the findings in the subject agree with those of Graveline, *et al.* (5) and Reeves, Beckman and DeForest (6) who observed a water diuresis and increased sodium excretion in subjects undergoing immersion while receiving a replacement diet. This water diuresis associated with immersion, also noted by Beckman, *et al.* (7), Graveline and Jackson (8) and Mahan, *et al.* (9) has been attributed by Gauer, Henry and Sieker (10) to a distention of the left atrium by a relative increase in central blood volume. The left atrium has been shown in dogs to contain receptors which initiate a diuresis upon distention of that chamber (11). Therefore, a relatively increased blood volume occasioned by submergence would cause distention of the central circulating bed and an activation of the Gauer-Henry reflex. The diuresis of the Gauer-Henry reflex is presumably effected by a diminished secretion of antidiuretic hormone. This water diuresis of immersed subjects has been shown to be abolished by injections of pitressin (12,13).

The controlling mechanism for sodium excretion is not definitely known. However, Anderson, *et al.* (14) have demonstrated that the right atrium of dogs contains receptors, which when stimulated by distention are associated with a decrease in aldosterone secretion when the hormone is quantitated from adrenal vein blood. Gowenlock, *et al.* (15) have shown that there is a decreased aldosterone excretion and an increased sodium excretion in the urine of humans standing in water at shoulder level. He has also demonstrated an increased aldosterone excretion and decreased sodium excretion in the urine of these subjects when standing erect on land. Similar changes in sodium excretion have been frequently measured in persons undergoing immersion (5,6,8). It seems reasonable to assume that the environmental changes undergone by the subject swimmer are in essence identical to those undergone by the above referred-to subjects. In view of evidence for volume receptors in the atria, the water diuresis with increased sodium excretion during submersion might then be explained by the following sequence of events, admittedly incomplete: (1) Immersion in water greatly reduces the dependent vascular engorgement of the lower abdomen and legs. (2) The reduction of the vascular distention by the compensating external hydrostatic pressure displaces blood into the thorax. (3) The blood volume displaced into the thorax could cause a relative distention of the atria with reflex diminution of ADH and aldosterone secretion. (4) The consequence of decreased ADH and aldosterone secretion would be increased renal excretion of water and sodium; thus, the commonly observed water and sodium diuresis of immersed subjects. However, upon the return to terrestrial environment, the reverse of the above sequence of events might occur, resulting in an antinaturesis and antidiuresis. Thirst, a prominent symptom, would aid in the replacement of the lost volume. An alternative interpretation for the findings in the observed subject would be that he was simply insufficiently replaced. However, the observations of others (5,6) confirm that these renal losses of sodium and water associated with immersion continue either with or without replacement. This is looked upon as evidence against the insufficient replacement interpretation.

From this investigation it was shown that the study of an individual while swimming underwater is possible with a reasonable degree of accuracy. It was learned that the maintenance of relative homeostasis under these conditions might also be possible. The swimmer believed that feeding every one-half hour was preferable to that of every 2 or 3 hours as had been done on his previous swims, because the frequent liquid replacement seemed to prevent the usual throat irritation associated with the large volume of dry air delivered over prolonged periods of time from the SCUBA. Another reason was that, subjectively, he felt he had more energy than he had had during his previous swims.

The appearance of a large Great White Shark (*Carcharodon carcharias:* Man-Eating Shark), whose behavior became persistently more aggressive after failure of the lights at night necessitated termination of the swim. Approximately one-fourth of the intended distance had been covered by that time.*

CONCLUSIONS

1. The replacement of nutritional needs in a continuous long distance underwater swim is believed both possible and desirable.

2. The described methods for the investigation of caloric consumption in a long distance swimmer are deemed satisfactory.

3. A net loss of sodium and water, mainly from the extracellular space, is believed to occur during submersion with exercise.

RECOMMENDATIONS

1. Investigations of nutritional balance in underwater swimmers should be continued in a more controlled environment and over a longer period of time.

2. The apparent extracellular fluid shift should be investigated using plasma volume determinations both before and after the swim.

3. The dietary intake should be controlled over longer periods of time before and after the swim.

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* The operational procedures and data are also presented in a 16 mm., color, sound motion picture.

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