Transactions of the Illinois Academy of Science
(1985), Volume 78, 1 and 2, pp. 97-102

UNDERWATER SWIMMING OF MALE RATS: AN EFFECTIVE MODEL FOR INVESTIGATING THE PHYSIOLOGY OF ANAEROBIC EXERCISE

Anthony M. Garcy
Department of Biological Sciences
Chicago State University
Chicago, Illinois 60628

ABSTRACT

The effect of underwater swimming intensity on plasma concentrations of lactic acid and glucose, as indexes of anaerobic glycolysis activity in exercising muscles, was studied in 48 adult male rats divided equally into the non-swimming, 1, 10, 17, 24 and >24 repetitions of underwater swimming groups. At the conclusion of the group number of underwater swimming repetitions, blood samples were collected by decapitation, and then centrifuged for analysis of the plasma by standard procedures. The mean lactic acid levels for the 1 ($x \pm SE$: 13.7 ± 2.3 mEq/l), 10 (23.1 ± 0.7 mEq/l), 17 (20.6 ± 0.9 mEq/l), 24 (17.2 ± 1.3 mEq/l) and >24 (6.9 ± 1.1 mEq/l) repetitions of underwater swimming groups were significantly ($P<0.05$) elevated above the levels for the non-swimming (0.3 ± 0.1 mEq/l) group. The mean glucose levels for the 10 ($\bar{x} \pm SE$: 195 ± 10 mg%), 17 (226 ± 8 mg%), 24 (243 ± 8 mg%) and >24 (182 ± 22 mg%) repetitions of underwater swimming groups were significantly ($P<0.05$) greater than the values for the non-swimming (120 ± 5 mg%) group. These data indicate that underwater swimming activates anaerobic glycolysis. Furthermore, the intensity of underwater swimming determines the activity of anaerobic glycolysis in working muscles.

INTRODUCTION

Investigators have demonstrated that anaerobic glycolysis is a significant source of muscular energy in intact animals or humans (Dawson et al., 1971; Holmer, 1979; Pendergast et al., 1980), and isolated muscle preparations (Jones, 1973; Piiper et al., 1968) performing intense exercise. Furthermore, studies have shown that the level of glycolytic activity in exercising muscles is associated with increments in plasma concentrations of lactic acid (Gollnick and Hermansen, 1973; Hermansen and Stensvald, 1972; Komi et al., 1977; Margaria et al., 1963) and glucose (Hagenfeldt et al., 1980; Wahren and Bjorkman, 1981).

The underwater swimming (UWS) of rats has been described as a high intensity training procedure (Halvorsen II et al., 1978); however, the UWS of rats as a model for investigating the physiology of anaerobic exercise remains unclear. Therefore, the present study focused on the effect of increasing the level of UWS intensity on the activity of anaerobic glycolysis by determining the plasma levels of lactic acid and glucose.

MATERIALS AND METHODS

Forty-eight adult male Harlan Sprague Dawley rats, weighing 175-199 g, were maintained in an animal facility with a controlled environment, and supplied with food and water ad libitum. The animals were divided equally into the non-swimming (NS), 1, 10, 17, 24 and >24 repetitions of UWS groups. The animals swam 20 sec according to a procedure that was described in a previous study (Garcy, 1982), and rested 2 min until the group number of UWS repetitions were completed. For the >24 repetitions of UWS group, the maximum number of swimming repetitions were determined by repeating the swimming and resting cycles until the animals were unable to swim on the surface of the water. At the conclusion of swimming the designated or maximum numbers of repetitions, blood samples were collected by decapitation within 1 min following the final repetition of UWS. Samples were centrifuged for analysis of the plasma. Lactic acid concentrations were determined by measuring the oxidation of lactate to pyruvate with a Du Pont Automatic Clinical Analyzer. Glucose levels were obtained by quantifying the rate of glucose oxidation with a Beckman Glucose Analyzer-System I.

The data were evaluated by one way analysis of variance. The statistical significance of differences in means ($P<0.05$) was determined by the Student's-Newman-Kuels test.

RESULTS

The mean plasma concentrations of lactic acid and glucose in each group are presented in Figs. 1 and 2. The data in Fig. 1 indicate that plasma levels of lactic acid tend to increase with number of UWS repetitions up to 10 repetitions, and then decrease, but even at >24 repetitions of UWS remain higher than in the NS group. The lactic acid levels for the 1 ($\bar{x} \pm$ SE: 13.7 ± 2.3 mEq/1), 10 (23.1 ± 0.7 mEq/1), 17 (20.6 ± 0.9 mEq/1), 24 (17.2 ± 1.3 mEq/1) and >24 (6.9 ± 1.1 mEq/1) repetitions of UWS groups were significantly ($P<0.05$) higher than the levels for the NS (0.3 ± 0.1 mEq/1) group. Furthermore, plasma lactic acid levels for groups 1, 10, 17 and 24 repetitions of UWS were significantly ($P<0.05$) more elevated than the values for the >24 repetitions of UWS group. The results also show that lactic acid levels for the 10 and 17 repetitions of UWS groups were significantly ($P<0.05$) greater than the levels for the 1 and >24 repetitions of UWS groups.

The mean plasma glucose concentrations as shown in Fig. 2 are approximately the same in the NS and 1 bout of UWS groups, increase up to 24 repetitions of UWS, and then decrease with >24 repetitions, but are still higher with >24 repetitions of UWS than in the NS and 1 bout of UWS groups. The glucose levels for the 10

($\bar{x} \pm$ SE: 195 ± 10 mg%), 17 (226 ± 8 mg%), 24 (243 ± 8 mg%) and >24 (182 ± 22 mg%) repetitions of UWS groups were significantly ($P<0.05$) elevated above the values for the NS (120 ± 5 mg%) and 1 (100 ± 11 mg%) bout of UWS groups. Moreover, glucose concentrations for the 24 repetitions of UWS group were significantly ($P<0.05$) greater than the glucose levels for the 10 and >24 repetitions of UWS groups.

DISCUSSION

The lactacidemias reported in this study are in accordance with those values published elsewhere for animals and humans performing other forms of exercise in vigorous fashion, such as bicycling (Wahren et al., 1971), running (Holmer et al., 1974) or swimming on the surface of the water (Holmer et al., 1974; Pendergast et al., 1980). Moreover, the elevated levels of plasma lactic acid from a single 20 sec bout of UWS, suggest activation of anaerobic glycolysis which occurs at approximately 60-80% of maximum oxygen uptake (Hermansen and Stensvald, 1972; Jones and Ehrsom, 1982), and within 10 sec from the onset of exercise (Gollnick and Hermansen, 1973). Although, oxygen tensions were not monitored for arterial or venous blood, hypoxia does not appear to be a likely explanation for stimulation of anaerobic glycolysis during UWS, since investigators (Holmer et al., 1974) have shown that there is sufficient oxygen available in order to maintain oxidative metabolism during the performance of intense exercise. Thus, the lactacidemias noted in this study reflect glycolytic responses to exercise loads imposed on the muscles by varying the level of UWS intensity.

The increments in plasma lactic acid with advancing levels of UWS intensities reported herein, have been noted in other studies (Hermansen and Stensvald, 1972; Margaria et al., 1963; Pendergast et al., 1980), and explained on the basis of increased glycolytic activity. Furthermore, the highest elevations in lactic acid which were recorded for the 10 and 17 repetitions of UWS groups, suggest that these levels of exercise intensities stimulated maximal glycolytic activity in the working muscles. On the other hand, the less than maximal concentrations of lactic acid that were associated with animals performing the greatest numbers (>24) of UWS repetitions (Fig. 1) may be attributed to the interaction between the production and the oxidative utilization of lactic acid (Brooks et al., 1973). Hermansen and Stensvald (1972) have shown that the rate of lactic acid removal is accelerated by increasing the intensity of exercise load, whereas other investigators (Jones and Ehrsom, 1982; Robin and Hance, 1980) have cited the acidosis from increased glycolytic rate as having a negative feedback effect on the production of lactic acid.

The levels of glucose during exercise probably are determined by the co-ordinated regulation of muscle glycolysis and hepatic glucose output which are stimulated by catecholamines acting on the α-receptors of these tissues (Clark et al., 1983). The basal levels of plasma glucose observed during the performance of 1 UWS bout (Fig. 2), suggest that the intermuscular stores of glucose were sufficient for maintaining anaerobic glycolysis or production and utilization of glucose were at a steady state during the short duration of exercise. The variable increments in plasma concentrations of glucose for increasing intensities of UWS (Fig. 2), indicate a compromise between glucose production by the liver and utilization by muscles working at various levels of exercise performance (Hagenfeldt et al., 1980).

In conclusion, the results from this study indicate that UWS is an effective stimulus for activation of anaerobic glycolysis. In addition, predictable changes in glycolytic activity may be determined by varying the level of UWS intensity.

ACKNOWLEDGMENTS

Support for this study was in part by grants from the Rockefeller Foundation-Howard University and the Department of Health and Human Services (2S03RR03323-02). Appreciation is extended to Jean Mandel from the Sheridan Road Hospital in Chicago for her technical assistance. Special thanks are given to Gregory Knox from Chicago State University for preparation of the graphs.

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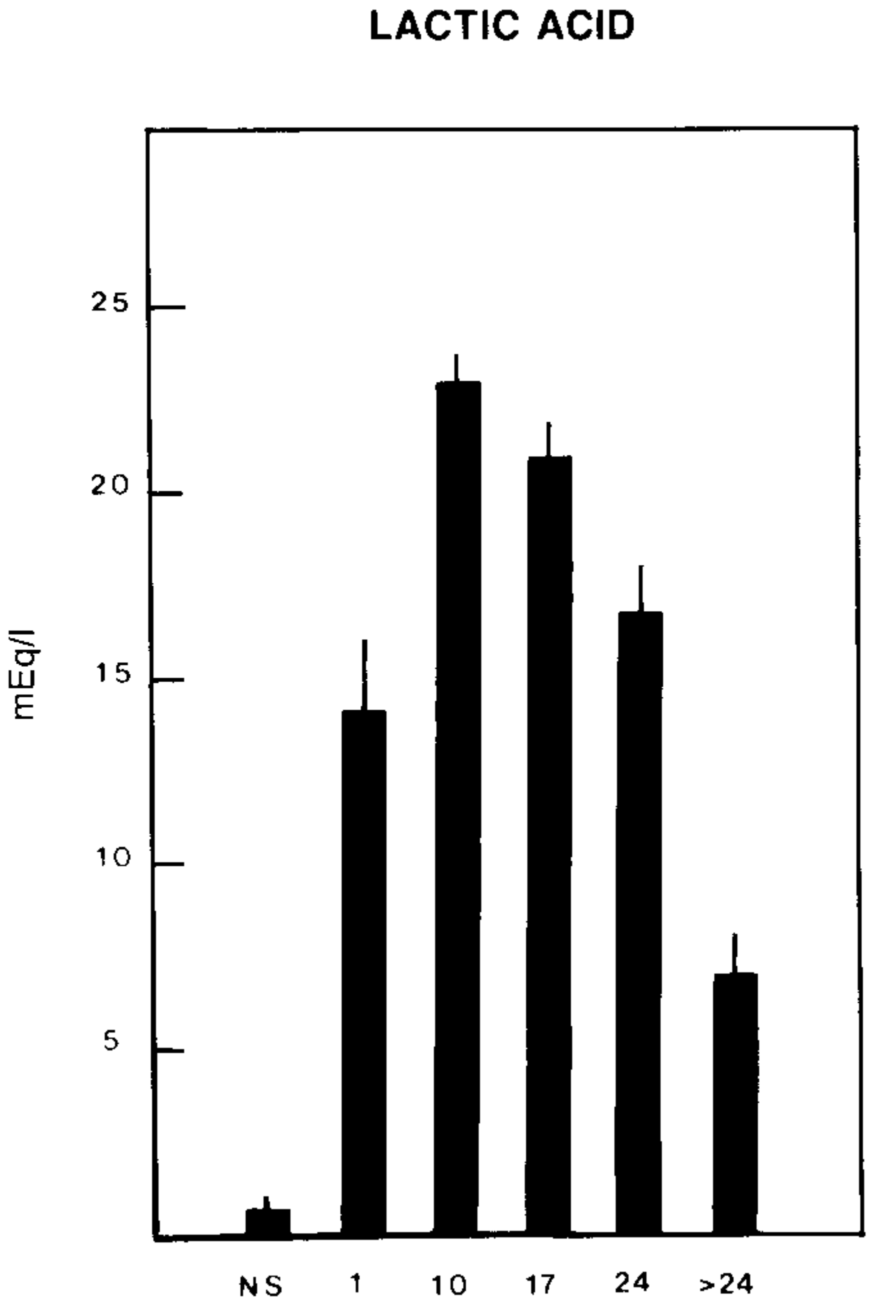

Fig. 1. Plasma lactic acid concentrations (mEq/l) for the non-swimming (NS), 1, 10, 17, 24 and >24 repetitions of underwater swimming groups. Bars with vertical lines indicate the means ± standard errors.

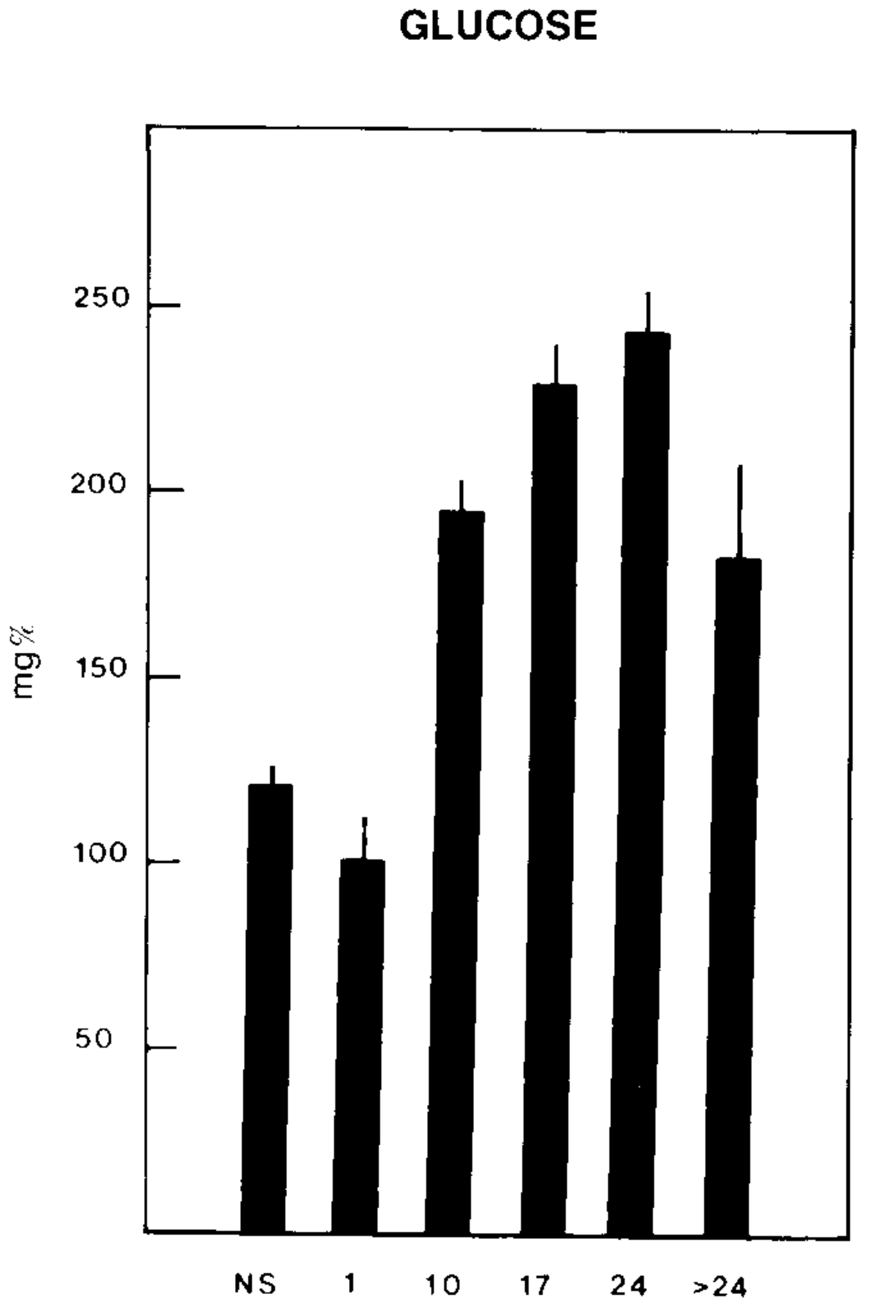

Fig. 2. Plasma glucose concentrations (mg%) for the non-swimming (NS), 1, 10, 17, 24 and >24 repetitions of underwater swimming groups. Bars with vertical lines indicate the means ± standard errors.