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THE DURATION OF THE RECOVERY PERIOD FOLLOWING STRENUOUS MUSCULAR EXERCISE, MEASURED TO A BASE LINE OF STEADY, MILD EXERCISE

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THE recovery period after severe exercise of short duration has been studied by several groups of workers [Hill *et al.* 1924; Best *et al.* 1929; Gemmill, 1931; Solandt & Ridout, 1933]. All are agreed that the respiratory exchange does not return to the basal level of complete rest for at least 1½ hours after such exercise. Gemmill believes that recovery takes even longer than 1½ hours.

In all these experiments the "basal" state was used as the base line from which the duration of the recovery period was determined. There is no fundamental reason for using "basal" metabolism as the base line in experiments of this type. The "basal" state is only one of many possible conditions in which the factors influencing metabolism can be controlled. It is also a condition which is rarely encountered in actual life, and can only be attained after prolonged rest. Prof. A. V. Hill therefore suggested that recovery after strenuous exercise might be more rapid if a more natural base line, such as that provided by mild, continuous exercise, were used. This is certainly the case with the recovery heat production of nerve [Feng & Hill, 1933].

Apparatus and technique. All the determinations of respiratory metabolism were done by the modified Douglas bag technique previously described [Solandt & Ridout, 1933]. The mild exercise used as the base line in these experiments was performed on a simple bicycle ergometer fitted with a friction brake. The subject pedalled in time with an electric metronome and was able to attain a very constant rate of pedalling. The strenuous exercise used was standing running, as fast as possible, for 30 sec. This type of exercise was chosen because the duration of the recovery period to the "basal" state had previously been determined following such exercise.

Experiments. As in the work previously reported [Solandt & Ridout, 1933], two types of experiments were performed. (1) Control experiments during which the subject pedalled steadily, on the bicycle ergometer, for about 2 hours. After a preliminary period of 15 min. to allow for attainment of the steady state, nine collections, each lasting for 8 min. and separated by 3 min. intervals, were taken. (2) Exercise experiments. After a preliminary period of 15 min. pedalling, one 8 min. collection was taken. The subject then stepped off the ergometer and ran, in place, as fast as possible, for 30 sec. Resuming his seat on the bicycle he continued pedalling at the former rate. The first post-exercise collection was begun at the start of the exercise and continued for 10 min. Successive collections were then taken as in the control experiments, continuing for 1½ hours after the strenuous exercise.

RESULTS

Duration of the recovery period. In the first series of experiments, the subject pedalled the unloaded ergometer at a rate of 97 rev. per min. For the first few experiments this exercise gave an oxygen consumption of about 400 c.c. per min. (The "basal" oxygen consumption of the same subject averaged 238 c.c. per min.) Recovery from the superimposed standing running appeared to be complete in about 40 min. With continued practice, however, the subject's oxygen consumption fell to about 350 c.c. per min. for the same rate of pedalling. Coincident with this fall in oxygen consumption there was an increase in the duration of the recovery period to 70–90 min. The carbon dioxide output and oxygen consumption curves for these experiments are so similar to those obtained with recovery to the basal state, in the same subject (T.B.), that they have not been reproduced. The usual period of carbon dioxide retention from 30 to 60 min. after the exercise is particularly prominent.

When the maximum lowering of oxygen consumption due to training had apparently been obtained, a second series of experiments was begun. In these the subject pedalled at a rate of 180 rev. per min. with a load of 500 g. on the belt of the ergometer. This exercise gave an oxygen consumption of about 660 c.c. per min. Four exercise and four control experiments were done at this level of oxygen consumption. The results are plotted in Fig. 1. The curves show the oxygen consumptions and the carbon dioxide outputs for the exercise experiments. As in the previous paper, the ranges of oxygen consumption and of carbon dioxide output during the steady pedalling are indicated, in the figure, by the average high and the average low values obtained in the control experiments. Recovery is considered to be complete when the oxygen consumption and carbon dioxide output return within, and remain within, these control limits.

Fig. 1 shows that recovery, thus defined, is complete within 20 min. in Exps. 2 and 4, within 35 min. in Exp. 1 and within 45 min. in Exp. 3.

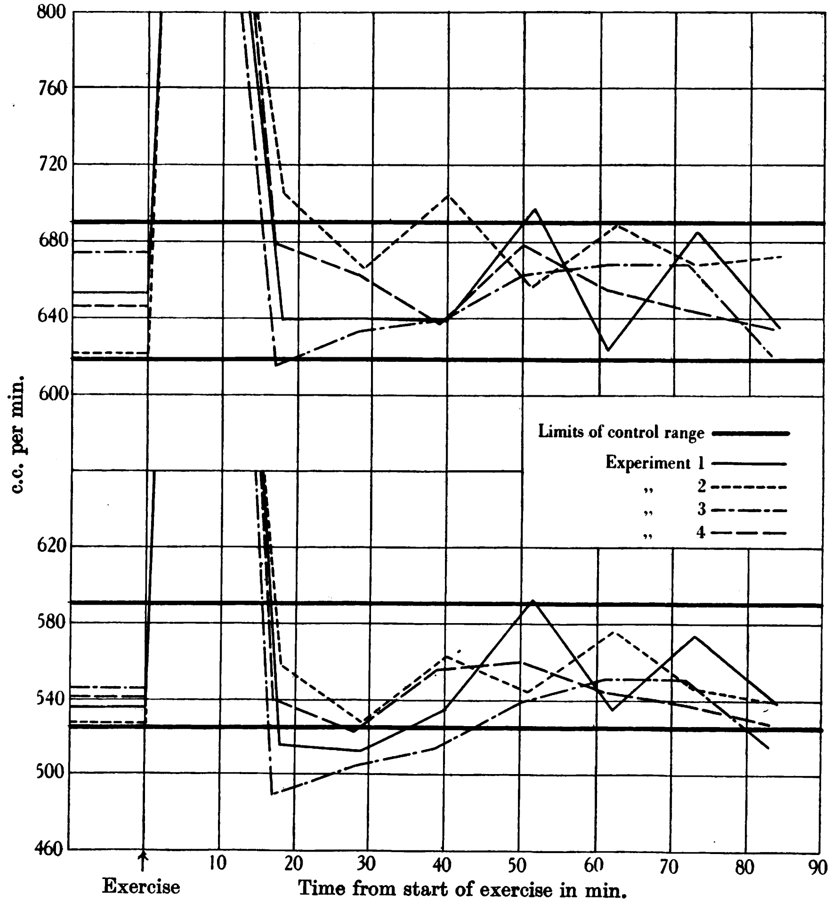

Fig. 1. Showing the oxygen consumption (upper graph) and carbon dioxide production (lower graph) following 30 sec. standing running at top speed. Recovery is to a steady state of mild exercise. The "limits of the control range" are the limits of metabolism during that steady state as determined in separate experiments.

It is also apparent that recovery may have occurred even sooner than this in Exps. 2 and 4 since the first collection after exercise is within normal limits. In Exps. 1 and 3 the post-exercise period of carbon dioxide retention is still apparent but seems to end earlier than when recovery is to the basal state.

In order to investigate the immediate post-exercise period in greater detail a further series of experiments was performed in which the post-exercise collections were made over much shorter intervals, and recovery was only followed for 35–40 min. The results of these experiments are shown in Fig. 2. In the four exercise experiments recovery is complete in

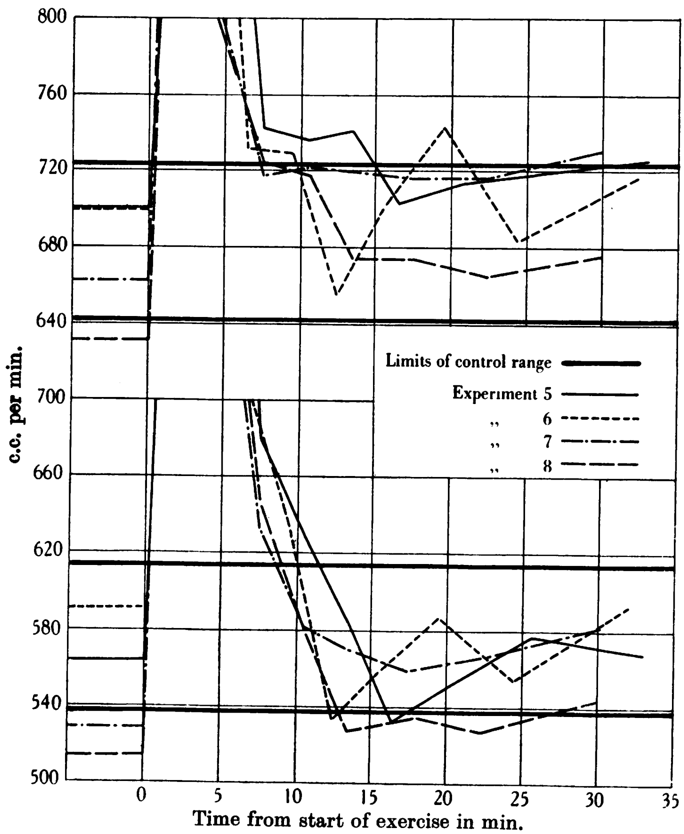

Fig. 2. Showing the oxygen consumption (upper graph) and carbon dioxide production (lower graph) following 30 sec. standing running at top speed. Similar to Fig. 1 but showing the early part of recovery in greater detail.

20–30 min. In these experiments there is a definite, post-exercise elevation of the oxygen consumption. This phenomenon has been discussed in the previous paper. Unfortunately the subject did not exercise quite as vigorously for Exps. 5–8 as for Exps. 1–4. The average excess oxygen for Exps. 1–4 was 4·3 l. and for Exps. 5–8 3·6 l.

Observations on the steady state. The control experiments in these series provide further data concerning the "steady state". The exercise performed was well within the range in which a steady state can be maintained and there was no evidence of any progressive change in the metabolism during the control experiments. The control ranges in Figs. 1 and 2 have been arbitrarily limited by the averages of the highest and the lowest oxygen consumptions and carbon dioxide outputs obtained in each of the four control experiments. In Fig. 1 the range for the oxygen consumption is 11 p.c. of the average oxygen consumption at this level of exercise and the carbon dioxide range is 12 p.c. of the average carbon dioxide production. For Fig. 2 the corresponding values are 12 and 13 p.c. In thirty estimations of basal metabolism on the same subject the corresponding ranges were 12 and 16 p.c. It appears therefore that the variability of the oxygen consumption and of the carbon dioxide output is, if anything, slightly less during a steady state of mild exercise than it is in the basal state.

Summary

The duration of the recovery period following standing running at top speed for 30 sec. has been determined using a steady state of mild exercise as a base line instead of the basal state of complete rest. Recovery is complete in from 20 to 45 min. after exercise of this type. Recovery to the basal state, after similar exercise, takes at least 90 min.

It is a pleasure to acknowledge our indebtedness to Prof. A. V. Hill for suggesting this problem. Mr T. Brodie served faithfully as subject for all the experiments. Mr J. G. Truax rendered valuable assistance in the performance of many of the gas analyses.

REFERENCES

Best, C. H., Furusawa, K. & Ridout, J. H. (1929). *Proc. Roy. Soc.* B, **104**, 119.
Feng, T. P. & Hill, A. V. (1933). *Ibid.* **113**, 369.
Gemmill, C. L. (1931). *Amer. J. Physiol.* **98**, 135.
Hill, A. V., Long, C. N. H. & Lupton, H. (1924). *Proc. Roy. Soc.* B, **96**, 455.
Solandt, O. M. & Ridout, J. H. (1933). *Ibid.* **113**, 327.

Since this paper was written a report has appeared (Newman, E. V., Dill, D. B., Edwards, H. T. and Webster, F. A. [1937], *Amer. J. Physiol.* **118**, 457) of the results of somewhat similar experiments in which the rate of removal of lactic acid from the blood following violent exercise of short duration was followed during continued mild exercise. It was found that the rate of removal of lactic acid from the blood was considerably greater during a steady state of mild exercise than at rest. This observation probably explains the more rapid recovery noted in our experiments in which an exercise base line was used.

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