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Hormonal and metabolic response to three types of exercise of equal duration and external work output

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Summary. Five normal men, aged 20–30 years, participated in three types of exercise (I, II, III) of equal duration (20 min) and total external work output (120–180 kJ) separated by ten days of rest. Exercises consisted of seven sets of squats with barbells on the shoulders (I; Maximal Power Output $\dot{W}_{\max} = 600–900$ W), continuous cycling at 50 rev · min^{-1} (II; $\dot{W}_{\max} = 100–150$ W) and seven bouts of intermittent cycling at 70 rev · min^{-1} (III; $\dot{W}_{\max} = 300–450$ W).

Plasma cortisol, glucagon and lactate increased significantly ($P < 0.05$) during the exercise and recovery periods of the anaerobic, intermittent exercise (I and III) but not in the continuous, aerobic exercise (II). No consistent significant changes were found in plasma glucose. Plasma insulin levels decreased only during exercise II. The highest increase in cortisol and glucagon was not associated with the highest $\dot{V}_E$, $\dot{V}_{O_2}$, $\dot{W}_{\max}$ or HR; however it was associated with the anaerobic component of exercise (lactic acid). It is suggested that in exercises of equal duration and total external work output, the continuous, aerobic exercise (II) led to lowest levels of glucogenic hormones.

Key words: Exercise — Anaerobic — Aerobic — Cortisol — Glucagon — Insulin — Lactate

Introduction

Major determinants of the metabolic responses to exercise are the intensity and duration of the exercise. Although various authors (Kuoppasalmi et al. 1976; Kinderman et al. 1982) have attempted to show that the type of exercise is also an important determinant, the results are conflicting as the other variables of intensity and duration of the exercises being compared were not standardized. Two recent studies have shown that, under conditions of equal workload and duration, the type of exercise is an important determinant of growth hormone secretion. Intermittent anaerobic cycling induces a greater growth hormone response than continuous aerobic cycling (Vanhelder et al. 1984a), and a heavy, low frequency weight-lifting regime induces a greater growth hormone response than one of a lighter intensity but higher frequency (Vanhelder et al. 1984b).

It was our hypothesis that the type of exercise may also be a significant factor in regulating hormones involved in glucose metabolism.

Materials and methods

Five healthy men, aged 20–30 years, volunteered for this investigation. Their maximum aerobic power and percentage of body fat were 44.6±4.4 (mean ±SD) ml · kg^{-1} · min^{-1} and 16.4±2.5% respectively. Maximum aerobic power was determined by a direct method using a cycle ergometer and continuous gas sampling and analysis. Percentage of body fat was estimated by the method of Durnin and Womersley (1974) from skinfold thickness measurements.

Three different types of exercise were used in this study with a ten-day interval between each type. Total time of exercise, including work and rest intervals, was 20 min. The first was a series of squats with a predetermined load on the shoulders (I). The second was continuous cycling (II) and the third, intermittent, high intensity cycling (III).

Six weeks before the experiment, subjects were trained in the technique of squats and use of the cycle ergometer. The load used for squats was a barbell placed on the subject's shoulders. The lowest point in every squat was determined by

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the subject's position: thighs parallel to the ground, in order to minimize an elastic energy utilization. To determine the load for Type I exercise the subject performed squats with a load on his shoulders such that only 10 repetitions were achieved with maximal effort (DeLorme and Watkins 1948; Vanhelder et al. 1984b). This load was designated the ten Repetition Maximum (10 RM). Subjects ate a standardized meal six hours before the beginning of each exercise.

Exercise I (squats). At zero time, each subject performed ten full squats with a load on his shoulders equal to 80% of his 10 RM. On completion of the first set the subject rested, in the standing position, with the load removed. This sequence was repeated at 3, 6, 9, 12, 15 and 18 minutes. The total work done by each subject was calculated according to the number of squats (n), height of the lift (Ht), weight carried on the shoulders (L) and the relative weight of parts of the body vertically displaced during the exercise, calculated as 85% of total body weight (BW) (Fischer 1906). Thus, work output $= n \times Ht \times (L + 0.85\ BW)$. The duration of one set of ten squats was one-half minute. The power output during this period was in a range of 600—900 W. Total external work output per 20 min was 120—180 kJ.

Exercise II (continuous cycling). The rate of pedalling in Exercise II was 50 $rev \cdot min^{-1}$ and the load (range 100—150 W) was calculated for each subject to match the external work performed during Exercise I. The subjects cycled continuously on the ergometer (Monark) for 20 min. Total external work output was 120—180 kJ.

Exercise III (intermittent cycling). At zero time, the subjects began cycling for one minute. This was followed by 2 min rest. The sequence was repeated at 3, 6, 9, 12, 15 and 18 min. The pace of the cycling was set at 70 $rev \cdot min^{-1}$ and as in Exercise II, the load (range 300—450 W) was calculated to match the total external work done in Exercise I (range of 120—180 kJ).

Analysis of plasma constituents. Indwelling catheters were inserted at least 45 minutes prior to the beginning of each exercise program into the antecubital vein of each subject. Venous blood samples were withdrawn at −10 and −3 min prior to exercise, at 4, 7, 10, 16 and 20 min of exercise, and at 10, 40 and 70 min of recovery. Plasma hormones were assayed by radioimmunoassay utilizing commercial kits according to the instructions of the individual manufacturers: insulin (Pharmacea), glucagon (Radioassay Systems), and cortisol (Clinical Assays). The metabolites assayed included lactate (Sigma lactate kit), glucose (Statzyme Glucose 50, Worthington kit), and free fatty acids (FFA) (Smith 1975).

Oxygen uptake and ventilation measurements. Oxygen uptake and ventilation were determined during the experiment by continuous sampling and gas analysis (Ergo Oxyscreen, Jaeger). The average values were calculated for every minute as well as for five-minute intervals. The heart rate (HR) was monitored by the means of an ECG (Litton Inc.).

Statistics. Values of plasma constituent concentrations were normalized with respect to two resting levels. Significance of differences from resting levels were determined using the Student's *t*-test. Oxygen consumption and ventilation were also compared by the Student's *t*-test.

Results

The hormone and metabolite responses during the three types of exercise and recovery are shown in Figs. 1 to 4 and are expressed as the percentage of levels prior to the commencement of exercise.

Cortisol

Significant increases in cortisol levels occurred in the two intermittent exercises I and III (Fig. 1). No such an increase occurred during or after the continuous exercise (II).

Insulin

No significant changes were observed in insulin (Fig. 2) during the intermittent exercises (I and III) with the exception of the last recovery value. In the continuous exercise (II) insulin decreased significantly during the first 10 min of exercise.

Glucagon

In both intermittent exercises (I and III), glucagon increased significantly (Fig. 2). In the continuous exercise (II), however, glucagon levels decreased.

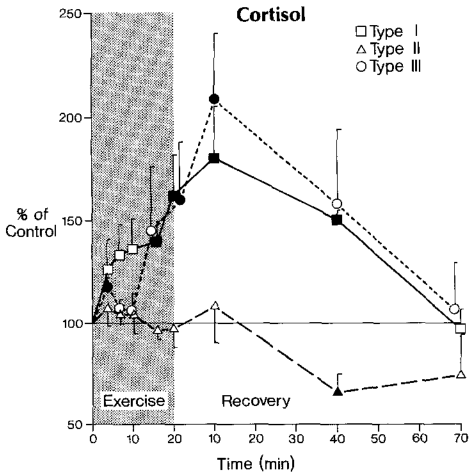

Fig. 1. Cortisol levels during and after the three types of exercise as percentages of control levels (mean ±SEM). Solid symbols represent significant differences ($P < 0.05$) from preexercise values

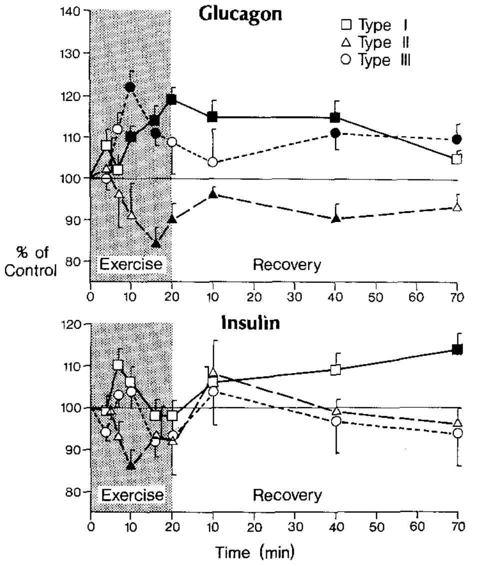

Fig. 2. Insulin and glucagon levels, details as in Fig. 1

Free fatty acids

No consistent significant changes were observed in FFA levels during the continuous exercise (II) (Fig. 3). In the exercises I and III, FFA showed a significant decrease.

Glucose

Glucose levels (Fig. 3) did not change significantly during exercises II and III. A small but significant increase in glucose occurred in exercise I.

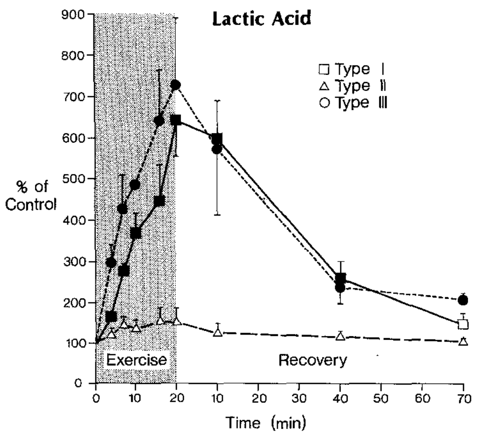

Fig. 4. Lactate levels, details as in Fig. 1

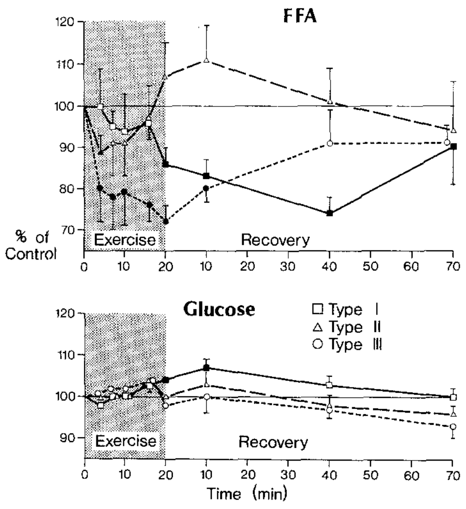

Fig. 3. Free fatty acid (FFA) and glucose levels, details as in Fig. 1

Lactic acid

The two intermittent exercises (I and III) produced similar lactate responses with large increases occurring during exercise and peaking at the end of 20 min of exercise (Fig. 4). No significant lactate changes were observed in the continuous exercise (II).

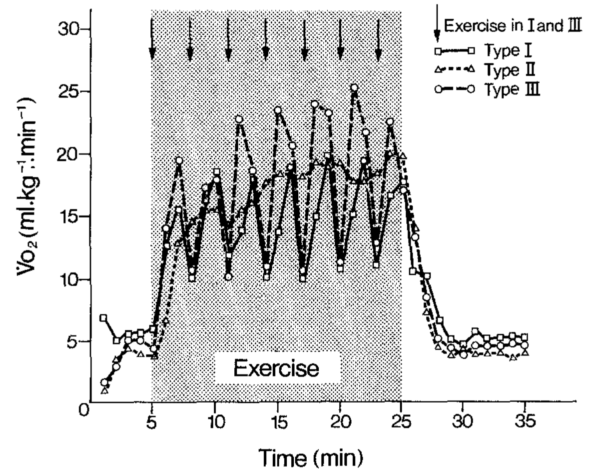

Fig. 5. Oxygen consumption ($\dot{V}_{O_2}$) of one subject

Oxygen consumption

The pattern of oxygen consumption ($\dot{V}_{O_2}$) differed for each exercise (Fig. 5). The minute-to-minute

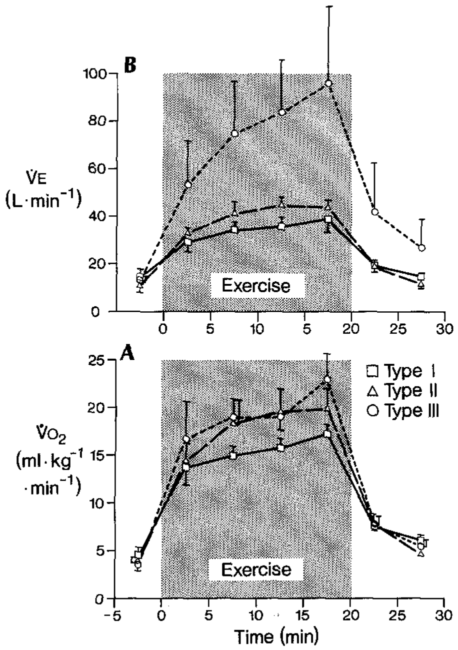

Fig. 6. $\dot{V}_{O_2}$ (A) and $\dot{V}_E$ (B) (averaged over 5 min) during and after exercise (mean ±SEM)

averaged values are shown for one subject. All other subjects showed a similar pattern. The five-minute averaged $\dot{V}_{O_2}$ values increased continuously with time (Fig. 6A), the relative magnitude of the increase between the types of exercise being: III > II > I. Averaged $\dot{V}_{O_2}$ for the total duration of exercise (0—20 min) was 15.5 ± 0.37, 18.2 ± 0.84 and 19.6 ± 0.86 ml · kg^{-1} · min^{-1} in Exercises I, II, and III, respectively. There was a significant difference in Exercise I vs II and I vs III ($P < 0.05$), but not in II vs. III.

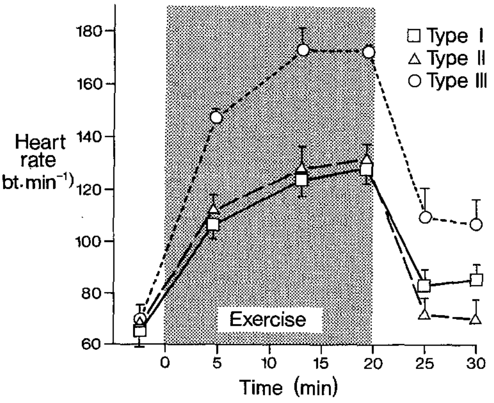

Fig. 7. Heart rates (averaged over 5 min) during and after exercise (mean ±SEM)

Mean ventilation

Mean ventilation ($\dot{V}_E$) values (Fig. 6A), determined for five-minute intervals also increased continuously with time during exercise in order of III > II > I. There was a significant difference in Exercise I vs II, I vs III and II vs III ($P < 0.05$).

Heart rate

A significantly higher average heart rate (Fig. 7) was observed in Exercise III as compared to both Exercise I and II ($P < 0.05$).

Discussion

Of the three types of exercise examined, Type I (intermittent squats) is used by athletes to develop strength (Harre 1979) and muscle mass (anabolic effect), Type II (continuous aerobic) to develop aerobic power, and III (intermittent) to improve anaerobic power and speed. Although total external work output and duration were equal different cardiovascular and metabolic responses were observed.

Both intermittent exercise (I and III) were anaerobic as evident from the similar large increases in blood lactate whereas the aerobic nature of the continuous exercise (II) was confirmed by the lack of any observable increase in lactate levels. Types I and III also produced similar responses with respect to cortisol, insulin, glucagon, FFA levels and growth hormone (Vanhelder et al. 1984a). On the other hand, exercises I and II appeared to be similar with respect to cardiovascular responses, whereas exercise III resulted in higher heart rates, ventilatory volumes, and oxygen consumption than I and II. It seems that the factors that precipitate the similar metabolic responses in I and III, do not appear to be heart rate, or oxygen consumption. Furthermore, the highest intensity of exercise was not associated with the highest increase in the levels of the counter-regulatory hormones. The highest power output occurred during the work intervals I yet, it was III in which the highest concentrations of the counter-regulatory hormones were found.

While the total external work output was equalized, efficiency and energy consumption may have varied between the three types of exercise. Indeed, the three types of exercise differed in their aerobic and anaerobic components as shown by different $\dot{V}_{O_2}$ and lactate levels. If an unquantified energy was consumed during the eccentric phase of the squats, this further accentuates our finding that the squat exercise led to the lowest $\dot{V}_{O_2}$, $\dot{V}_E$ and HR as well as second lowest lactate response; yet, it was associated with significant increases in glucogenic hormones.

Stopping and starting the flywheel during intermittent cycling may have influenced the hormonal and metabolic response to our exercise. However, the flywheel was stopped and started twenty times during the study of Karagiorgos et al. (1979) while no significant differences in hormonal levels were observed. Moreover, there was no significant difference in averaged $\dot{V}_{O_2}$ between our continuous (II) and intermittent (III) cycling.

The mean $\dot{V}_{O_2}$ equal or less than 50% $\dot{V}_{O_{2\max}}$ indicates that relatively light exercise was used in our study in terms of aerobiosis. However, 80% of maximal strength had to be used in squats (80% of 10 RM) and the averaged HR reached 170 beats · $\min^{-1}$ during bouts of intermittent cycling.

The significant increases found in cortisol in the two anaerobic exercises (I and III) have also been reported by Kinderman et al. (1982) and Kuoppasalmi et al. (1980) during short-term anaerobic running tests. It has been described previously that cortisol secretion appears to be related to exercise intensity and duration (Galbo et al. 1977; Scheele et al. 1979), and prolonged exercise at an intensity of 75% of maximal oxygen uptake elicits a higher increase of this hormone than a single short-term high-intensity exercise (Kinderman et al. 1982). Our study has demonstrated that, external work output and duration being equalized, the type of exercise, intermittent versus continuous, anaerobic versus aerobic, is an important determinant of not only cortisol responses, but also glucagon and growth hormone.

Although glucose and insulin levels remained relatively stable during all three exercises in this study, the counter-regulatory hormones, cortisol and glucagon were significantly elevated in the two anaerobic exercises. Increases in both cortisol and glucagon during exercise have been associated with an increase in gluconeogenesis (Ahlborg et al. 1974; Thorp 1975), and it has been suggested that increased cortisol levels may enhance the gluconeogenic properties of glucagon. If gluconeogenesis was increased in exercises I and III in our study, it was not reflected in the glucose levels. However, increases in glucose consumption might balance off increases in gluconeogenesis.

Augmented increases of cortisol, glucagon and GH concentrations have been reported to occur during exercises which are preceded by a state of low insulin availability, such as diabetes or low carbohydrate diet, as compared to exercise in normoinsulinemic subjects (Galbo et al. 1979; Berger et al. 1977). Thus, one cannot exclude the possibility that intermittent exercises (I and III) which led to significantly higher cortisol, glucagon and GH levels in our normoinsulinemic subjects, would be associated with further increases of these hormonal concentrations in a hypoinsulinemic state.

It has been reported previously that the changes in hormonal secretion rather than their disappearance or blood flow are primarily responsible for the exercise induced changes in insulin (Hilsted et al. 1980) and glucagon levels. The blood flow through liver and kidney, where glucagon is mainly eliminated, does not further decrease after first several minutes of continued exercise (Rowell 1974); yet, plasma concentrations of glucagon continue to increase far beyond this point (Ahlberg et al. 1974). Furthermore, the exercise induced changes in hormonal levels may be superimposed on the diurnal variations of cortisol (Follenius et al. 1977) and insulin (Vanhelder et al. 1980), making the evaluation of these more difficult.

It is unlikely that the decreases in FFA levels observed in Types I and III are due to enhanced fat utilization as the main source of energy during these exercises is classically carbohydrate. A negative correlation between lactic acid levels and FFA has been previously reported in dogs (Issekutz and Miller 1962) and in man (Ahlborg et al. 1976). Lactate infusion in dogs inhibited FFA mobilization (Issekutz and Miller 1962) whereas in man, it increased the rate of removal without affecting mobilization (Ahlborg et al. 1976). Either mechanism would result in a decrease in FFA levels during the exercise period.

In conclusion, the higher levels of counter-regulatory hormones resulted from intermittent anaerobic than continuous exercise. The increase in concentrations of these was not consistent with the levels of $\dot{V}_{O_2}$ or $\dot{V}_E$ nor with the intensity of the exercise. However, this increase in the hormones was associated with a rise in lactate levels and thus with the anaerobic component of the exercise. The aerobic, continuous exercise led to no increases in glucogenic hormones.

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