Relationship of Adaptive Capabilities in Athletes to the Type of Reaction of Their Opioid System to Stressful Physical Exercise

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Eleven highly skilled skiers are examined during and after prolonged exercising on a bicycle ergometer at a Vo_2 equal to 80% of the maximum. Parameters of mechanical work, Vo_2, plasma lactate concentration, and activity of δ-type opioid receptor ligands are recorded. The opioid system is found to develop two types of reaction to the exercise: activation in the course of work on the ergometer with a tendency toward normalization in the recovery period (Type A) or inhibition during the exercise (Type B). The reaction of Type B involved a rapid increase in the activity of the opioid system immediately after the exercise in some cases and a further fall in the activity of plasma opioids in others. Skiers with Type B reaction performed a lesser amount of work at a higher energy cost than did those with Type A. It is concluded that the latter type of reaction is more efficient than the former.

Key Words: *adaptation; opioid system; physical exercise; energy supply*

One important mechanism of adaptation is associated with functioning of the opioid system (OS) which participates both in stress-promoting reactions by mobilizing the appropriate neuroendocrine processes and in stress-limiting reactions by restricting overactivation of adaptation mechanisms. The OS not only wards off damaging effects of stress but also sets up an adaptation reserve of functional capabilities in the body [5].

One of the most common stressors is strenuous physical activity and adaptation to it activates physiological mechanisms characteristic of stress. Study of these mechanisms during exercising has several advantages; thus, the parameters of stress are measurable, the work load is gradable, and the results are reproducible.

That the OS is involved in body's reactions to stress has been demonstrated in numerous investigations. In particular, plasma concentrations of β-endorphin and enkephalins were shown to be elevated in the course of and after intensive and prolonged work [7,10,11], and opioid peptides were found to influence the synthesis and secretion during work of stress-mediating hormones such as catecholamines [10], growth hormone and prolactin [8], corticotropin and cortisol [11].

The purpose of the present study was to establish how adaptive capabilities of the body relate to the reaction of the OS to stressful exercise. The criteria of adaptation were parameters of mechanical work (its duration and the ability to sustain its present power) and energy supply (oxygen consumption [Vo_2] and lactate level in the blood during exercising).

MATERIALS AND METHODS

The subjects were 11 first-class race skiers aged 17-20 with 6 to 11 years of experience in skiing and with no signs of any disease at the time of the study or during the two preceding months.

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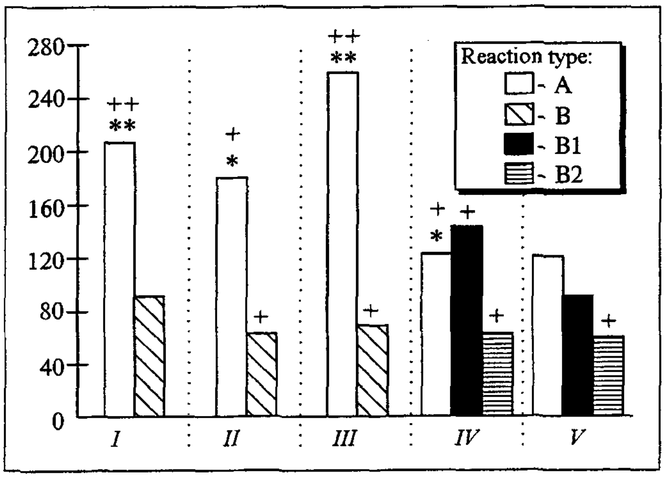

Fig. 1. Variations of plasma δ-OR ligand activity in athletes during bicycle ergometer exercise and in the recovery period. A and B are the type of reaction shown by the OS. Ordinate: δ-OR ligand activity, expressed in % of its baseline level (66.4±10.6 pmol/labeled ligand equivalent/ml). Recording points: *I*) level of anaerobic metabolism threshold (5-10 min after the start of exercising); *II*) attainment of steady state (20-25 min after the completion of exercising); *III*) at the time the exercise was completed; *IV*) 5-15 min after its completion; *V*) 24 h after its completion. *p<0.05 for the significance of differences between the groups of athletes with different (A or B) types of the OS reaction to physical activity; +p<0.05, ++p<0.01 relative to the baseline level.

Activity of the OS was evaluated by radioreceptor determination of the displacing activity shown by ligands of δ-type opioid receptors (δ-OR ligands) in blood plasma. As the labeled ligand, ^{3}H-[D-Ala^2-D-Leu^5]-enkephalin (Amersham) was used [4].

Energy supply was assessed by measuring V_{O2} with a Medicro semiautomatic gas analyzer, blood lactate was determined enzymatically on a Spicol apparatus, while mechanical work was recorded on a Monark bicycle ergometer. The data obtained were statistically analyzed by Student's *t* test.

The power of work and Vo_2 during the testing procedure amounted to 80% of their maximal values determined preliminary in a stepwise test for exercise "to the limit". The duration of exercising on the bicycle ergometer varied from 60 to 90 min depending on the athlete's ability to maintain the preset parameters of work. The amount of exercise was therefore selected individually for each skier, and the exercise was of reasonably long duration and intensity, performed in the aerobic mode, and was subjectively perceived by the skiers as causing fatigue. They were not always able to maintain the preset work power, usually because of acute fatigue in the lower limb muscles. In such cases, the resistance offered by the ergometer pedals was lowered. Accordingly, the parameters of energy metabolism were considered in relation to the power of the mechanical work (as measured in watts) actually performed at the time of recording.

Vo_2 and blood lactate were measured continually during exercising. OS activity was recorded in the resting state; three times during exercising when the anaerobic metabolism (AM) attained its threshold level and steady state was established as determined by the shape of the Vo_2 curve; at the time when the exercise was completed; and in the early and late recovery periods (5-15 min and 24 h after the testing procedure.

RESULTS

Variations in plasma δ-OR ligand activity recorded during exercising and in the recovery period enabled us to identify two types of OS reaction to the work the athletes were requested to perform (Fig. 1).

Type A reaction (5 subjects) was characterized by considerably elevated OS activity at the threshold level of AM, the attainment of highest activity at the time the exercise was completed, and a tendency to its rapid return toward baseline during the recovery period. Type B reaction (6 subjects) was characterized by reduced OS activity at the threshold level of AM and by the establishment of steady state at the time the exercise was completed. In Type B reaction, two variants of the recovery process were observed: a rapid rise of activity immediately at the completion of exercising in one variant (B1; 3 subjects) and a further decline in plasma opioid activity during the recovery period (B2; 3 subjects).

Thus, Type A reaction is thus marked by OS activation in response to exercise and the Type B reaction, by inhibition of this activity. The subjects with Type A maintained the preset work power throughout the period of exercise. In the subjects with Type B, the resistance offered by the ergometer pedals had to be decreased by a factor of 1 to 4 because of the fatigue they experienced in the limb muscles. Overall, the resistance was lowered for these subjects by 2.45-14.7 N during the exercising period.

Despite the reduced work power, the duration of exercising in the subjects with Type B reaction was shorter than in those with Type A (69.6±1.8 against 85.5±2.2, respectively; p<0.05).

The working capacity of subjects with Type A reaction was therefore higher than of those with Type B. Energy expenditure, as estimated from the blood level of lactate, in the latter subjects was greater than in the former. The largest differences in blood lactate between the two groups of subjects was recorded when the threshold of AM was attained and shortly after the establishment of steady state (Fig. 2). The two groups did not differ with regard to variations in Vo_2 during

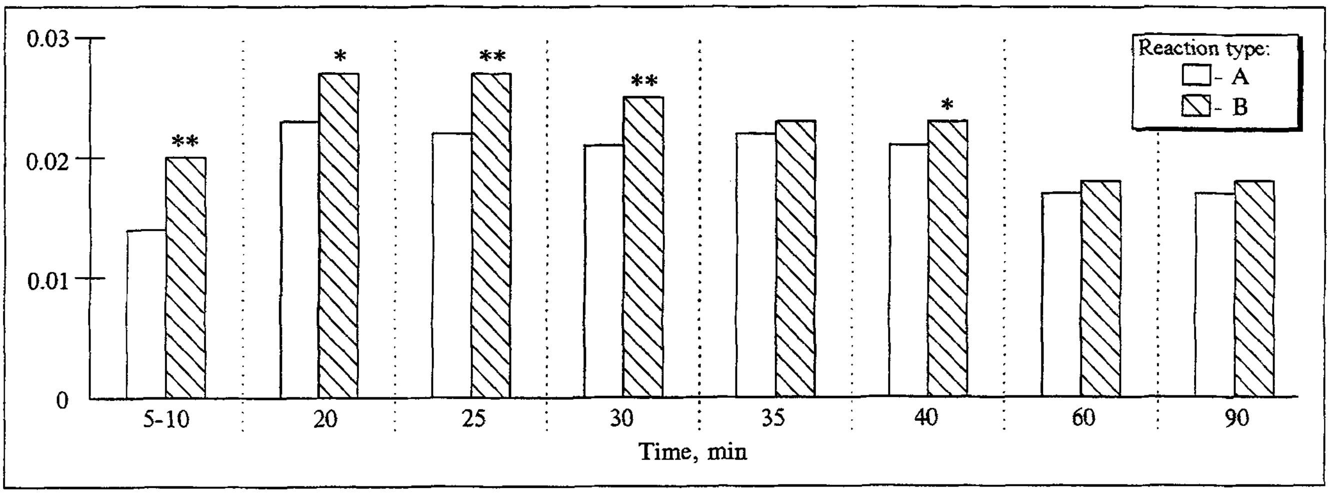

Fig. 2. Variations of blood lactate concentration in athletes with different types (A or B) of the OS reaction to exercising on the bicycle ergometer. Ordinate: lactate concentration in relation to the power of the work (mmol/W) performed at the time of its recording; the AM reached its threshold level 5-10 min after the start of exercising, while steady state was established 20 or more min before its completion. *$p<0.005$, *$p<0.01$ for the significance of differences between the groups of athletes with different types (A or B) of the OS reaction to exercise.

exercising. These findings indicate that Type B reaction to exercise is accompanied by greater mobilization of anaerobic metabolism than Type A reaction.

The work of shorter duration and lesser power performed by athletes with signs of OS inhibition thus involved greater physiologic expenditures than did the greater work load in those in whom the OS was activated during exercise.

This conclusion is supported by our data on alterations in the blood level of immunoreactive β-endorphin in persons with different degrees of training for exercising on a bicycle ergometer. In well-trained athletes who show high aerobic capacity, the level of this peptide at the end of exercising was at its maximum, whereas in less well-trained athletes its level was below baseline. A feature of the latter athletes was also low aerobic capacity [2].

The mechanism through which OS activity declines during exercise is not clear. One possible cause of this phenomenon may be central inhibition of limbic structures [1] and of the hypothalamus-pituitary-adrenal system [3].

Inadequate functioning of the OS may be also responsible for the feeling of fatigue, since the subjective perception of effort is decreased through inhibition of excessive excitation of the sympathoadrenal system when OS activity is elevated [9]. This mechanism also appears to play an important part in the economy of energy expended during physical work [6].

The two variants of Type B reaction require separate consideration. When OS activity rapidly increased after the completion of work (B1), temporary inhibition of the OS is likely to have occurred. Recovery of opioid secretion may be due to operation of a central neurogenic mechanism. On the contrary, a prolonged depression of OS activity (B2) continuing after the termination of exercise may be regarded as a consequence of impaired peptide biosynthesis, i.e., as temporary exhaustion of the system.

The results of this study allow Type A reaction of the OS to prolonged intensive exercise to be considered as adequate and Type B reaction as inadequate (insufficiently effective). The response of this system of stressful physical activity may therefore serve as an index of effectiveness of adaptation to stress.

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