CARDIOVASCULAR FUNCTION AND MUSCLE BLOOD FLOW DURING INCREMENTAL STEPWISE EXERCISE

by

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The objective of this study was to find out the influence of external factors (training) on relation in changes of cardiac indices and peripheral blood flow during the incremental endurance and sprint exercise test. Two exercise test protocols (during every 1 minute, and second, during every 6 minutes incremental stepwise exercise on an ergocycle) were used for the evaluation of central and peripheral reactions of the cardiovascular system. Arterial blood pressure, stroke volume, cardiac output and arterial blood flow in the calf muscle were assessed. The obtained results show that the values and velocity of changes in indices of cardiovascular function differ depending on the protocol of incremental exercise. They also reflect the functional state of the organism and the whole complex and specificity of acute and chronic adaptation. Synchronous registration of changes in muscle blood flow and the indices of heart function give the possibility to assess precisely the reactions of muscle blood flow and understand the physiological expediency of these changes. We conclude that external factors, i.e. long-term adaptation to sprint or endurance training modifies the ratio between the central and peripheral reactions of the cardiovascular system. It seems that the differences in the heterogeneity of various regulatory mechanisms of cardiovascular reactions depend on the chosen exercise protocol, and belong to endogenous factors.

Key words: cardiovascular system, muscle blood flow, exercise test

Introduction

The ratio between external factors (training) and endogenous ones is an important problem remaining to be solved in sport physiology. At the onset of exercise the cardiovascular system adapts with a series of integrated responses to meet the metabolic demands of the exercising muscles. The blood flow to

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muscles is generally proportional to their metabolic activity [Bangsbo and Hellsten, 1998; Hughson and Tschakovsky, 1999; Knight et al., 1996]. Total response to exercise compromises an increase of cardiac output and vasodilation in the active muscles [Hughson and Tschakovsky, 1999; Joyner and Proctor, 1999; Shoemaker and Hughson, 1999]. Endurance and high-intensity sprint training have been shown to alter skeletal muscle blood flow and factors that govern muscle perfusion under various conditions [Delp, 1998; Delp and Laughlin, 1998]. We tested the hypothesis that long-term adaptation to sprint or endurance training has an influence to heterogeneity of various regulatory mechanisms what reflects in a ratio of changes of cardiovascular indices to exercise. The objective of this study was to find out the influence of external factors (training) on changes in cardiac indices and peripheral blood flow during incremental exercise protocols of endurance and sprint character.

Material and methods

Two exercise test protocols were used for the evaluation of central and peripheral reactions of the cardiovascular system. The indices of cardiovascular function (arterial blood pressure, stroke volume, cardiac output and muscle blood flow) were assessed at first, during every minute, and secondly, during every 6 minutes of incremental stepwise exercise. The subject underwent an increase in workload and they exercised to a predetermined goal i.e. till the inability to continue exercising or unless distressing cardiovascular symptoms supervened.

The intensity of arterial circulation in the calf muscle was registered by Whitney plethysmograph joined through Winstone bridge. An IBM personal computer and a curve analysis program “Adrec” was used for the interpretation of the recorded plethysmographic curve. The amount of calf blood flow was estimated using the method based on the acting mechanism of the muscle pump [Stoida et al., 1998]. Stroke volume and cardiac output were evaluated by the tetrapolar reography.

The subjects of this study were 14 non-athletes, 17 sprinters, and 22 long distance runners. To the group of athletes were selected subjects with no less than 6 years of training in these events. There were no statistically significant differences between the groups by body mass index (21,2±0,50; 22,3±0,35 and 21,9±0,29 respectively). The age of non-athletes was 23,3±0,92 years, sprinters – 20,2±0.61 years and long distance runners – 23,1±1,30 years. The significance of the differences between values was evaluated by computing the t criterion. The differences were considered statistically significant, when p was <0,05 (95 CI).

Results and discussion

The obtained results show that the values and velocity of changes in indices of cardiovascular function differ depending on the protocol of incremental exercise that reflect the functional state of the organism and the whole complex and specificity of chronic adaptation. The duration of incremental exercise in each case was dependant on one hand on the chosen exercise protocol and on the other hand on the physical working capacity of participants (Fig. 1, 2). Only a few subjects were able to perform the maximal workloads and these data compounds a less number of cases. As an example all subjects were able to continue the task up to 150 W when the workload was increased every 6 minutes. Figure 1 illustrates the changes of the stroke volume during both incremental exercises. The highest values were observed in the endurance group and during the performance the stroke volume increased while in the group of non-athletes only a small increase at the beginning of the test and a decrease of stroke volume during the later phase of work were found. Similar changes, i.e. decrease of cardiac output during the later phase of exercise was registered in the group of non-athletes and in the sprint group. This data shows that external factors, i.e. the type of training play an essential role in chronic adaptation of the cardiovascular system. We observed a different trend in the changes of stroke volume when the duration of workout in each step was 6 minutes. In this case the increase of the stroke volume was found in all groups. This means that longer duration of exercise induces an increase in the stroke volume during exercising.

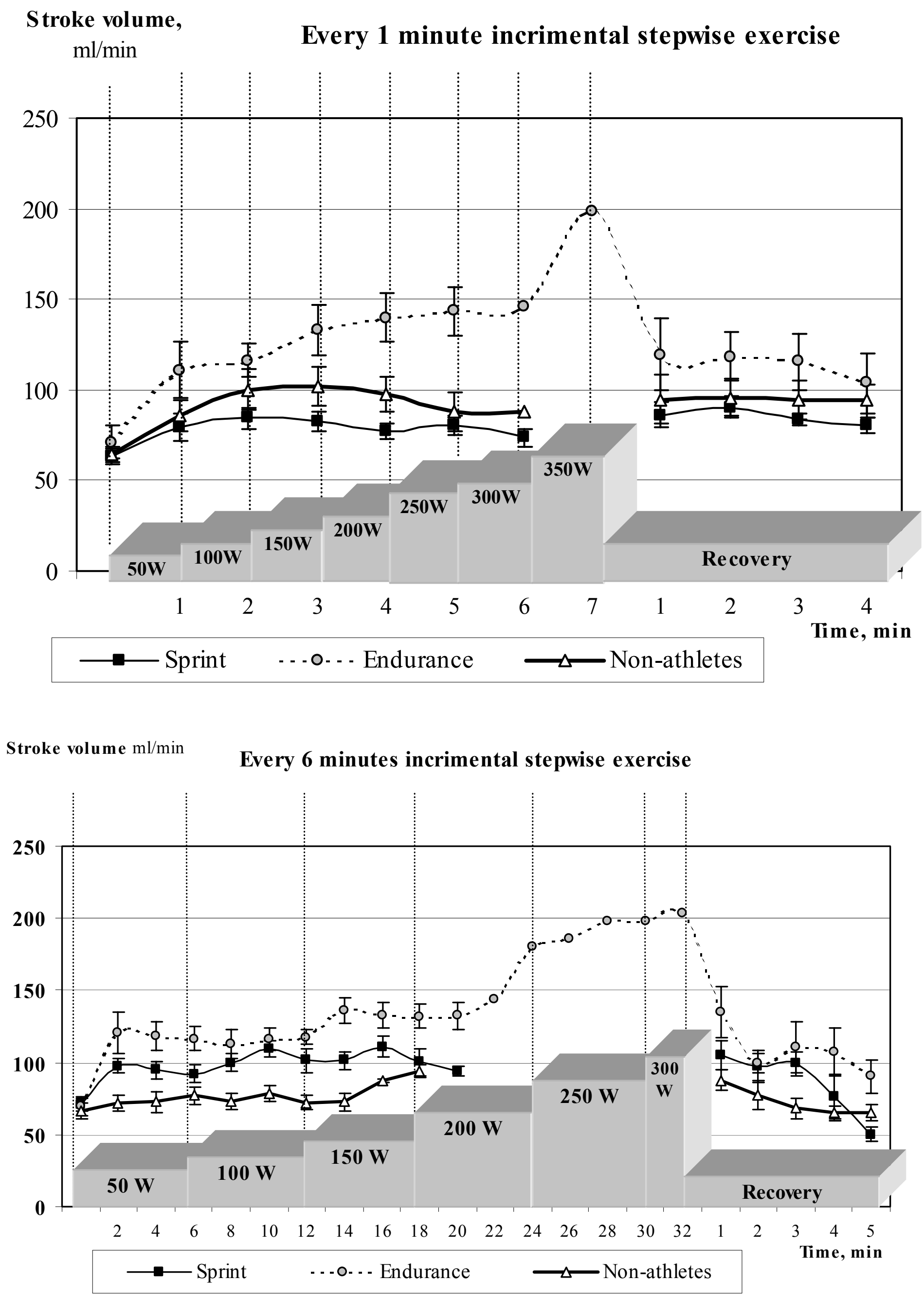

Fig. 1. Changes in stroke volume during the incremental exercise

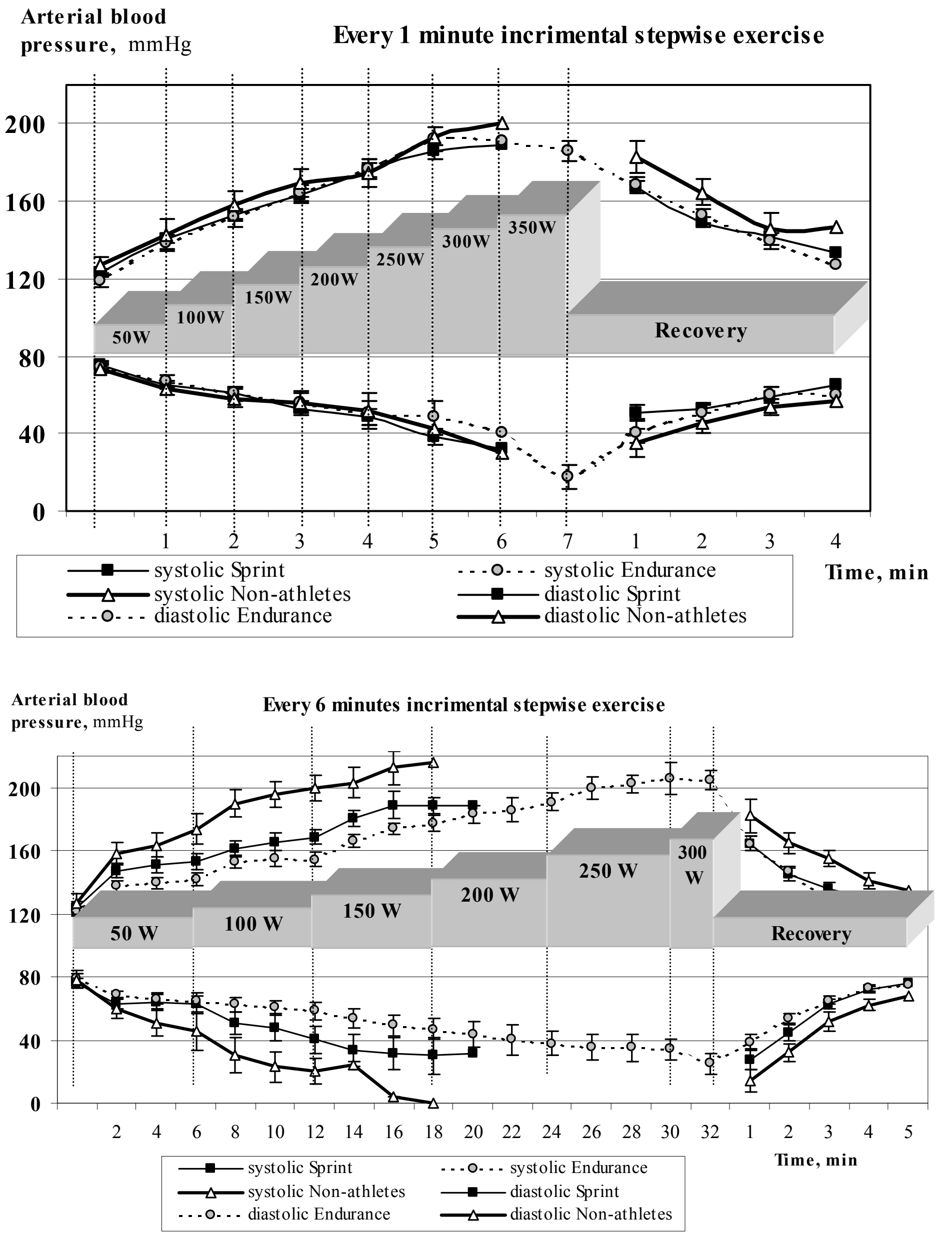

Fig. 2. Changes in arterial blood pressure during the incremental exercise

The increase of arterial blood flow was dependent on the protocol of investigation and there was a statistically significance difference in the registered values between the groups ($p<0,05$) while the intensity of exercise was not maximal. Table 1 presents the maximal values of cardiac output and muscle blood flow registered during the incremental stepwise exercise. The analysis of all this data shows that long-term adaptation to sprint or endurance training modifies the ratio between the central and peripheral reactions of the cardiovascular system to physical work. This means that the heterogeneity of various regulatory mechanisms were dependent on the chosen exercise protocol.

Table 1

Maximal values of cardiac output (l/min) and muscle blood flow (ml/min/100 cm^3) registered during the incremental stepwise exercise

Indices	Non-athletes	Sprint group	Endurance group
Cardiac output, $\frac{\text{1 min. stepwise test}}{\text{6 min. stepwise test}}$	$\frac{15,1 \pm 1,3}{19,3 \pm 2,7}$	$\frac{14,8 \pm 1,4}{16,7 \pm 1,1}$	$\frac{27,4 \pm 2,3}{31,7 \pm 2,4}$
Muscle blood flow, $\frac{\text{1 min. stepwise test}}{\text{6 min. stepwise test}}$	$\frac{89,3 \pm 6,5}{122,1 \pm 6,4}$	$\frac{89,3 \pm 6,5}{119,5 \pm 8,1}$	$\frac{97,4 \pm 4,4}{91,7 \pm 4,8}$

Regulatory mechanisms of the systemic blood circulation is oriented to sustain a gradient of pressure, necessary to insure needed blood circulation intensity in working muscles. The major portion of the exercise cardiac outputs is diverted to the working muscles [Delp, 1998; Joyner and Proctor, 1999; Saltin et al., 1998]. This happens in the combination of heart work indexes and changes of peripheral resistance [Hughson and Tschakovsky, 1999; Joyner and Proctor, 1999; Shoemaker and Hughson, 1999]. Figure 2 presents the changes of arterial blood pressure. The analysis of this data along with the data of physical working capacity allows us to understand more precisely the biological expediency of these reactions. The decrease of arterial blood pressure during the dynamic exercise is in relation with the decrease of total peripheral resistance. Our findings suggest that good control of the vascular tone is a result of chronic adaptation to exercise. The greatest changes in diastolic blood pressure during physical work were observed in the group of non-athletes. In most cases the diastolic blood pressure fell to zero during exercise and the inability to continue the work soon occurred. The decrease of diastolic blood pressure in the endurance group occurred at the onset of exercise but drop till zero did not occur in any case. Total response to exercise compromises an increase of cardiac output, vasodilation in the active muscles, vasoconstriction in the vicera, inactive muscles, and the skin, with a reflex increase in the tone of the venous capacity vessels [Shephard, 1987]. The distribution of blood flow occurs between active muscles and within muscle tissue, i.e. depending on active and passive motor units [Armstrong et al., 1989]. It is likely that the loss of peripheral vascular control makes it difficult for appropriate distribution of blood flow to the active muscles or within the muscle.

In summarizing we conclude that external factors, i.e. long-term adaptation to sprint or endurance training modifies the ratio between the central and peripheral reactions of the cardiovascular system to physical work. It seems that the differences in the heterogeneity of various regulatory mechanisms of cardiovascular reactions depends on the chosen exercise protocol which belongs to endogenous factors.

REFERENCES

Armstrong, R.B., Hayes, D.A. & Delp, M.D. (1989) Blood flow distribution in rat muscle during preexercise anticipatory response. *J. Appl. Physiol.* 67, 1855-1861.

Bangsbo J., Y. Hellsten (1998) Muscle blood flow and oxygen uptake in recovery from exercise. *Acta Physiol. Scand.* 162(3):305-312

Delp M.D. (1998) Differential effects of training on the control of skeletal muscle perfusion. *Med. Sci. Sports Exerc*. 30(3):361-374

Delp M.D., MH Laughlin (1998) Regulation of skeletal muscle perfusion during exercise. *Acta Physiol. Scand*. 1998 162(3):411-419

Hughson R.L., M.E. Tschakovsky (1999) Cardiovascular dynamics at the onset of exercise. *Med. Sci. Sports Exerc*. 31(7):1005-1010

Joyner M.J., D.N. Proctor (1999) Muscle blood flow during exercise: the limits of reductionism. *Med. Sci. Sports Exerc.* 31(7):1036-1040

Knight D.R., D.C. Poole, M.C. Hogan, D.E. Bebout, P.D. Wagner (1996) Effect of inspired O2 concentration on leg lactate release during incremental exercise. *J. Appl. Physiol.* 81(1):246-251

Poderys J. (1998) Influence of the short term preliminary occlusion on the dynamics of arterial blood flow and working capacity of the calf muscles. *J. Educ. Phys. Training Sport* 1:49 – 57.

Saltin B., G. Radegran, M.D. Koskolou, R.C. Roach (1998) Skeletal muscle blood flow in humans and its regulation during exercise. *Acta Physiol. Scand.* 162(3):421-436

Shoemaker J.K., R.L. Hughson (1999) Adaptation of blood flow during the rest to work transition in humans. *Med. Sci. Sports Exerc.* 31(7):1019-1026

Shephard R.J. *Exercise physiology.* Toronto Philadelphia: B.C.DECKER INC. 1987, 207.

Stoida Iu.M., Vinogradova O.L., Golovachev A.I. (1998) Effect of 3-day immersion on calf blood flow during physical loading test. *Aviakosm. Ekolog. Med*.32(2):24-27 (in Russian, English abstract)