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ORIGINAL ARTICLE

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Heart rate is lower during ergometer rowing than during treadmill running

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Abstract This study evaluated whether the heart rate (HR) response to exercise depends on body position and on the active muscle mass. The HR response to ergometer rowing (sitting and using both arms and legs) was compared to treadmill running (upright exercise involving mainly the legs) using a progressive exercise intensity protocol in 55 healthy men [mean (SD) height 176 (5) cm, body mass 71 (6) kg, age 21 (3) years]. During rowing HR was lower than during running at a blood lactate concentration of 2 $mmol \cdot l^{-1}$ [145 (13) compared to 150 (11) $beat \cdot min^{-1}$, $P < 0.05$], 4 $mmol \cdot l^{-1}$ [170 (10) compared to 177 (13) $beat \cdot min^{-1}$, $P < 0.05$], and 6 $mmol \cdot l^{-1}$ [182 (10) compared to 188 (10) $beat \cdot min^{-1}$, $P < 0.05$]. Also during maximal intensity rowing, HR was lower than during maximal intensity running [194 (9) compared to 198 (11) $beat \cdot min^{-1}$, $P < 0.05$]. These results were accompanied by a higher maximal oxygen uptake during rowing than during running [rowing compared to running, 4.50 (0.5) and 4.35 (0.4) $l \cdot min^{-1}$, respectively, $P < 0.01$]. Thus, the oxygen pulse, as an index of the stroke volume of the heart, was higher during rowing than during running at any given intensity. The results suggest that compared to running, the seated position and/or the involvement of more muscles during rowing facilitate venous return and elicit a smaller HR response for the same relative exercise intensity.

Keywords Exercise · Oxygen uptake · Oxygen pulse

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Introduction

Oxygen uptake ($\dot{V}O_2$) increases as the muscle mass involved increases (Secher et al. 1974, 1977; Mitchell 1990). During arm-and-leg exercise $\dot{V}O_2$ is higher than during exercise involving only the arms or only the legs (Secher et al. 1974, 1977). Also, maximal oxygen uptake ($\dot{V}O_{2max}$) is higher during rowing than during running (Secher 1983). Rowing involves both upper and lower body exercise, while running mainly involves the legs (Secher 1983; Clifford et al. 1994).

It is controversial whether the magnitude of the heart rate (HR) response to exercise follows $\dot{V}O_2$. For example, during two-legged exercise HR is higher than during one-legged exercise (Davis and Sargeant 1974; Klausen et al.1982). The magnitude of the HR response to isometric leg extension (Leonard et al. 1985) and handgrip (Mitchell et al. 1989; Mitchell 1990) depends on the amount of the active muscle mass taking part. On the other hand, HR for combined arm and leg exercise is similar to that elicited during leg exercise (Toner et al. 1983). An indication of an influence of specific training on the HR response to exercise is that in arm-trained subjects, the HR response to arm, leg, and combined arm-and-leg exercise is different (Secher et al. 1974). Thus, it is not clear which type of exercise elicits the highest HR response. An increasing active muscle mass facilitates venous return, and thereby increases the central blood volume and therefore reduces the HR response (Ray et al. 1993; Van Lieshout et al. 2001). Differences in posture affect HR by way of the central blood volume (Ray et al. 1993; Wilmore and Costill 1999; Van Lieshout et al. 2001).

We examined the HR response to both rowing and running at various intensities and also determined $\dot{V}O_2$

as an index of the amount of the active muscle mass (Secher et al. 1974, 1977; Savard et al. 1989).

Methods

Subjects

We examined the HR and $\dot{V}O_2$ responses to two periods of progressive exercise, rowing on an ergometer (Concept II model C, Morrisville, Vt., USA) and running at an incline of 3.0% on a treadmill. A group of 55 male subjects were thoroughly informed of all methods and procedures and consented to participate in this study as approved by the Ethics Committee at the National Institute of Health and Nutrition. The same subjects took part in both types of exercise and none had any cardio-respiratory illness or injury. Percentage body fat was derived according to the equation of Brozek et al. (1963) using body density determined by the BOD POD system (Life Measurement Instruments, Concord, Calif., USA; Dempster and Aitkens 1995). The physical characteristics of the subjects were as follows [mean (SD)] height 176 (5) cm, body mass 71 (6) kg, body fat 11 (3)%, age 21 (3) years].

Protocol

The subjects performed a discontinuous incremental intensity protocol on a rowing ergometer. The initial intensity was 150 W and was increased by 50 W every 2 min. The subjects stopped rowing for 20 s between each stage so that blood samples could be drawn. Exercise was terminated when the subjects were no longer able to maintain the required intensity. On another day, the subjects exercised on a treadmill. The initial velocity was 160 m·min^{-1} and increased by 20 m·min^{-1} every 2 min. Exercise was terminated when the subjects could not complete a given running speed.

It was required that each subject met each of the following criteria to ensure that $\dot{V}O_{2max}$ was reached:

1. A plateau in $\dot{V}O_2$ against exercise intensity
2. A respiratory exchange ratio exceeding 1.15
3. Blood lactate concentration exceeding 8–9 mmol·l^{-1}
4. Achievement of age-predicted maximal HR (HR_{max})
5. A rating of perceived exertion of 19 or 20 (Bassett and Howley 2000)

The expired gas was collected in Douglas bags during the last 1 min of each stage, and the volume was measured using a dry gas meter and the concentrations of O_2 and CO_2 were determined (Respiromonitor RM-300i, Minato Medical Science Co., Tokyo, Japan). The HR was determined electrocardiographically (Nihon Kohden Co., Tokyo, Japan). Blood samples were taken using heparinized glass capillaries from the fingertips immediately after each stage and at the termination of exercise. Blood lactate concentration ($[La^-]_b$) was analysed by an enzymatic membrane method using a 1500 Analyser (Yellow Springs, Ohio, USA).

Statistics

Data are reported as means and standard deviations (SD). The *oxygen pulse* ($\dot{V}O_2$/HR) was calculated as an index of stroke volume (Heath et al. 1981). For comparison of variables between rowing and running, a paired Student's *t*-test was used. Statistical significance was set at $P < 0.05$.

Results

At rest HR was lower when sitting on an ergometer than when standing on a treadmill [70 (12) compared to 78 (11) beat·min^{-1}, $P < 0.05$; Fig. 1]. During rowing HR was also lower than during running [145 (13) compared to 150 (11) beat·min^{-1} at a $[La^-]_b$ of 2 mmol·l^{-1}, 170 (10) compared to 177 (13) beat·min^{-1} at 4 mmol·l^{-1}, and 182 (10) compared to 188 (10) beat·min^{-1} at 6 mmol·l^{-1}, all $P < 0.05$]. Also, during rowing HR_{max} was lower than during running [194 (9) compared to 198 (11) beat·min^{-1}, $P < 0.05$].

Whereas $\dot{V}O_2$ at rest was similar for the two postures, during rowing $\dot{V}O_2$ was higher than during running [2.79 (0.7) compared to 2.42 (0.8) l·min^{-1} at a $[La^-]_b$ of 2 mmol·l^{-1}, 3.89 (0.5) compared to 3.65 (0.7) l·min^{-1} at 4 mmol·l^{-1}, 4.18 (0.5) compared to 4.01 (0.5) l·min^{-1} at 6 mmol·l^{-1}, all $P < 0.01$]. Also, during rowing $\dot{V}O_{2max}$ was higher than during running [4.50 (0.5) compared to 4.35 (0.4) l·min^{-1}, $P < 0.01$; Fig. 2]. Immediately after the maximal effort, $[La^-]_b$ was higher following rowing than following running [10.6 (1.5) compared to 9.3 (1.9) mmol·l^{-1}, $P < 0.05$]. The oxygen pulse was higher during rowing than during running at any $[La^-]_b$ and also during maximal exercise (Fig. 1).

Discussion

The main finding was that during rowing HR was lower than during running at both submaximal and maximal exercise intensities. Thus, the results indicate that the mode of exercise and/or the muscle mass affect the HR response to exercise.

During rowing, subjects use both arms and legs while during running they use mainly their legs (Secher 1983; Hagerman 1994). Also, during rowing, the upper body is used with the involvement of trunk, back, and abdominal muscles (Secher 1983; Clifford et al. 1994). The finding of a higher $\dot{V}O_2$ during rowing than during running supported the contention that rowing involved a larger muscle mass than did running (Secher et al. 1974, 1977; Sarvard et al. 1989). This study was conducted to evaluate the HR response to exercise involving an increase in the active muscle mass that could be of importance by way of enhancing central blood volume. At the same time, it was considered that the central blood volume would be larger during the seated position of rowing than during running. These assumptions of a larger central blood volume during rowing than during running seemed to be confirmed as the oxygen pulse, as an index of the stroke volume of the heart, was larger during rowing than during running.

Active muscle mass is a powerful pump and provides a force to assist returning blood to the right ventricle of the heart during exercise (Sheriff et al. 1993; Van Lieshout et al. 2001). Additionally, during dynamic exercise an increase in active muscle mass leads to an increased venous return and central blood volume (Davis and Sargeant 1974; Klausen et al. 1982; Toner et al. 1983). Standing up displaces blood from the chest to lower parts of the body by gravity, blood pressure is augmented as sympathetic nervous activity increases HR, and vascular resistance increases (Pedersen et al. 1995;

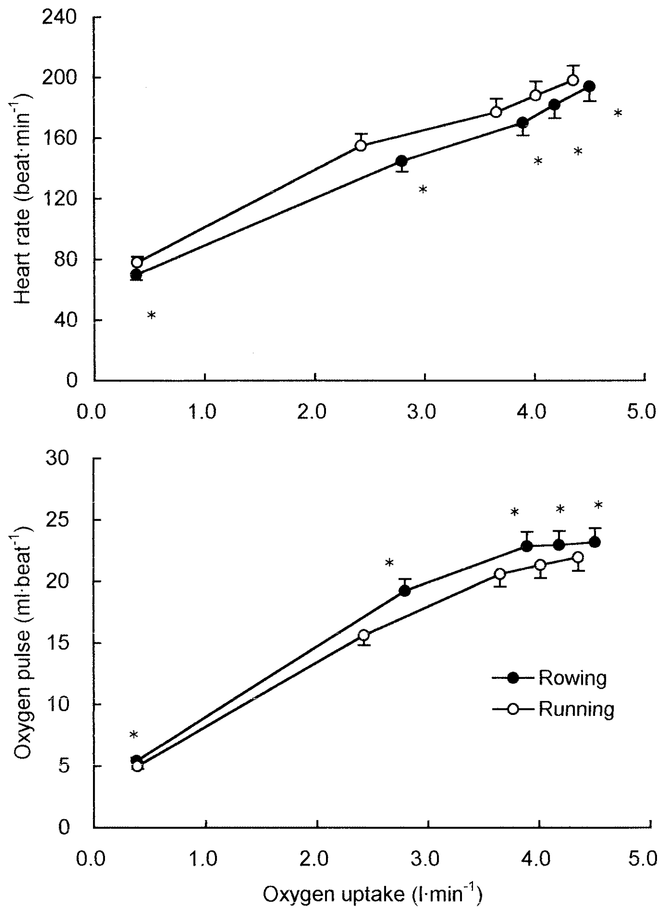

Fig. 1. Relationship between heart rate and oxygen pulse and oxygen uptake during rowing and running. $*P < 0.05$ Significantly different between rowing and running

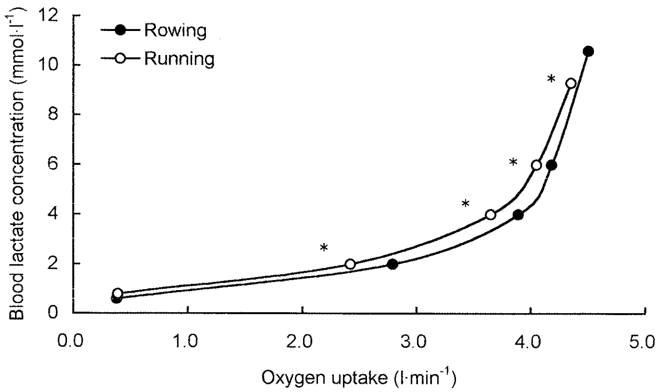

Fig. 2. The responses of oxygen uptake at a given blood lactate concentration and maximal effort during rowing and running. $*P < 0.05$ Significantly different between rowing and running

Tanaka et al. 1999; Wilmore and Costill 1999). During seated leg exercise (Ray et al. 1993) and upright leg exercise (Ten Harkel et al. 1994; Van Lieshout et al. 2001), the central blood volume increases due to an effect of the muscle pump with a resulting decrease in sympathetic nerve activity.

By the Frank-Starling mechanism, enhanced venous return stretches the ventricle, which results in an augmented stroke volume (Ray et al. 1993; Tate et al. 1994; Wilmore and Costill 1999). An elevated central blood volume enhances central venous pressure and stretches the venous and arterial vessels, and this stimulates the cardiopulmonary baroreceptors to slow HR and dilate the peripheral vasculature (Gabrielsen et al. 1993; Ray et al. 1993). This is so because an elevated central blood volume is accompanied by a decrease in sympathetic nerve activity (Ray et al. 1993; Saito et al. 1993; Van Lieshout et al. 2001). Thus, it is considered that increasing the active muscle mass during exercise may elevate the central blood volume and stroke volume as indicated by oxygen pulse, and thereby attenuate the increase in HR during rowing.

During rowing, mean blood pressure is similar to other types of exercise including running (Clifford et al. 1994), and the exercise-induced increase in blood pressure is not affected by posture or by gravity (Ray et al. 1993). It is unlikely that the arterial baroreflex was of major influence on the HR response in this study. Metaboreceptors may sense an increase in $[La^-]_b$ and pH, which induce sympathetic nerve activity and increase HR (Mitchell 1990; Mostoufi-Moab et al. 1998; Ray 1999). To avoid the complications of the metaboreflex in the present study, the HR responses to rowing and running were compared at submaximal intensities at similar $[La^-]_b$ instead of at similar percentages of $\dot{V}O_{2max}$. During rowing $\%\dot{V}O_{2max}$ was higher than during running at any submaximal $[La^-]_b$. However, HR was lower during rowing both at any given submaximal intensity and at maximal intensity despite a higher $[La^-]_b$ compared to running. During rowing a Valsalva-like manoeuvre is used to stabilize the upper body while both legs are vigorously extended and this could diminish the ventricular preload (Cunningham et al. 1975; Rosiello et al. 1987). In spite of this oxygen pulse was higher during rowing than during running.

This study showed that the HR response to (seated) ergometer rowing is attenuated compared to (upright) treadmill running. This finding was accompanied by a higher $\dot{V}O_2$ and thus oxygen pulse during rowing compared to running. The results suggest that compared to running, the seated position and the involvement of more muscles during rowing facilitate venous return and elevate the central blood volume.

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