Echocardiographic dimensions and maximal oxygen uptake in oarsmen during training*

WOUTER WIELING, ELS A M BORGHOLS, ARIE P HOLLANDER,
SVEN A DANNER, AREND J DUNNING

From the Department of Medicine, Binnengasthuis, Academic Hospital, Amsterdam; Faculty of Physical Education, Free University, Amsterdam (Interdepartmental Section of Exercise Physiology); and Department of Physiology, University of Amsterdam, The Netherlands

SUMMARY We studied nine freshmen and 14 senior oarsmen undergraduates during seven months of training and compared them with 17 age and sex-matched sedentary control subjects in order to assess the influence of heavy physical exercise on cardiac dimensions and maximal oxygen uptake. Standard M-mode echocardiographic techniques were used.

At the start of the season senior oarsmen had a greater left ventricular end-diastolic dimension, and a thicker interventricular septum and posterior left ventricular wall than control subjects and freshmen oarsmen. The two latter groups did not differ from each other.

During the training period there was a slight and gradual increase in left ventricular end-diastolic dimension, and interventricular septum and posterior wall thickness in freshmen. In seniors only left ventricular end-diastolic dimension increased significantly. Maximal oxygen uptake showed a distinct increase between the fourth and seventh month during the period of intensive rowing training. There was no relation between echocardiographic variables and maximal oxygen uptake.

A combination of heavy dynamic and static exercise can thus lead to significant changes in both left ventricular wall thickness and chamber size within months. Echocardiographic variables measured at rest cannot be used as a suitable index of performance capacity.

Echocardiographic studies have shown that athletes' hearts differ in chamber size and wall thickness from those in sedentary control subjects.¹⁻⁵ Whether these differences in cardiac dimensions are merely the result of the effects of training or whether this represents genetic endowment is not known.¹

Several studies have shown changes in echocardiographic dimensions after short periods of training.⁶⁻⁸ Changes after longer training periods and the relation between echocardiographic variables and maximal oxygen uptake, however, have not been reported.

In order to assess the influence of a combination of heavy dynamic and static exercise on echocardiographic dimensions, senior and freshmen oarsmen were studied during seven months of training, and changes in maximal oxygen uptake were correlated with changes in cardiac dimensions.

Methods

Twenty-three male oarsmen undergraduates were studied: 14 were seniors and nine were freshmen. Seventeen healthy age-matched students without sports training served as control subjects. Physical characteristics are presented in Table 1.

The senior oarsmen had completed at least one rowing season. Five were competitors at the 1979 World Rowing Championship. The freshmen had

Table 1 *Characteristics of subjects at start of investigation (mean values $\pm$ standard deviations)*

	Control group (n=17)	Freshmen (n=9)	Seniors (n=14)
Age (y)	22.0 3.7	20.2 1.6	22.6 2.4
Height (cm)	184.3 8.0	182.5 4.4	186.8 4.9
Body surface area (m ²)	1.93 0.16	1.93 0.11	2.05 0.10

*Supported by a grant from the Dutch Heart Association.

Received for publication 27 April 1981

been active in high school sports, but none had participated before in a daily training programme.

For the oarsmen serial measurements included an echocardiogram, an electrocardiogram, maximal oxygen uptake, resting heart rate, blood pressure, and weight. These measurements were made in October before training started and after a fortnight, one, four, and seven months of training. Controls were re-examined after one month in order to study reproducibility.

From October until January there was an emphasis on non-specific endurance training, which gradually changed in interval training (training with periods of more intensive muscular work followed by periods of mild exercise or even rest).⁹ During the last months of the season almost all training was performed as rowing. Senior oarsmen spent 10 hours weekly training in the period before January, increasing to 14 hours a week during the last months of the season. Freshmen trained less: six hours a week before January, increasing to 12 hours a week at the end of the season.

ECHOCARDIOGRAPHIC MEASUREMENTS

Examinations were performed in the morning with a Unirad echocardiograph. An M-mode scan was obtained using the standard technique.¹⁰ Considerable care was taken to obtain identical transducer

localisation and body position for subsequent studies. Measurements were made according to recently recommended criteria.¹¹

The following ultrasound measurements were made (Fig. 1):

- (1) Left ventricular internal diameter at end-diastole (LVID_d).
- (2) Left ventricular internal diameter at end-systole (LVID_s).
- (3) Interventricular septal thickness at end-diastole (IVS).
- (4) Left ventricular posterior wall thickness at end-diastole (LVPW).
- (5) Right ventricular internal diameter at end-diastole (RVID_d).
- (6) Diameter of the aortic root at end-diastole (aorta).
- (7) Diameter of the left atrium at end ventricular systole.
- (8) Percentage shortening of the left ventricular internal diameter, calculated as: $(LVID_d - LVID_s) / LVID_d \times 100$.

All echocardiograms were analysed in random order after the end of the training period. Pre- and post-training echocardiograms of the oarsmen were also analysed by an independent observer without any knowledge of their training status.

Since the adjustment of echocardiographic variables to body surface area is questionable¹² and since

Fig. 1 Echocardiogram of a silver medal winner at the 1979 World Rowing Championship. LVID_d, left ventricular end-diastolic diameter (mm); LVID_s, left ventricular end-systolic diameter (mm); LVPW, left ventricular posterior wall thickness (mm); RVID_d, right ventricular end-diastolic diameter (mm).

we found only minor differences between echocardiographic data in raw form and after correction for body surface area, only absolute data are presented.

Because the accuracy of echocardiographic estimation of left ventricular volumes and mass is uncertain,¹³ only linear echocardiographic variables, as measured from the M-mode scan, are presented.

MEASUREMENT OF MAXIMAL OXYGEN UPTAKE

Maximal oxygen uptake in oarsmen was determined four times during the training period by means of the Douglas bag method on a bicycle ergometer.⁹

ELECTROCARDIOGRAPHIC MEASUREMENTS

The following criteria were examined to test the presence of left ventricular hypertrophy:

- 1: $SV_1 + RV_5$ or $V_6 > 35$ mm,¹⁴
- 2: $SV_1 + RV_5$ or $V_6 > 44$ mm,¹⁵
- 3: point score system according to Romhilt and Estes.¹⁶

STATISTICS

Student's *t* test for unpaired data was used to determine differences between groups. Differences

between the first examination in October and subsequent examinations were evaluated by Student's *t* test for paired data. Correlation coefficients were calculated according to Pearson. Differences for all statistical tests were considered significant if $p < 0.05$.

Results

At the beginning of the rowing season senior and freshman oarsmen had slower heart rates than control subjects. Blood pressure did not differ among the three groups (Table 2).

During the training period resting heart rate and systolic blood pressure decreased; in senior oarsmen there was also a decrease in diastolic blood pressure. At the end of the season diastolic blood pressure in seniors was lower than in control subjects. In the oarsmen body weight decreased towards the end of the season. In the control subjects re-examined after one month there was only a decrease in systolic blood pressure.

ECHOCARDIOGRAPHIC DATA

The measurements of left ventricular end-diastolic

Table 2 Mean values $\pm$ standard deviations for control group, freshmen, and seniors during seven months' training

	Control group (n=17)	Freshmen (n=9)					Seniors (n=14)				
		Months					Months				
		0	½	1	4	7	0	½	1	4	7
Resting heart rate (beats/min)	71.8 8.4	56.1* 7.7	53.0 6.2†	49.5 6.2†	49.1 6.1†	51.9* 4.0†	57.7* 15.0	54.3 12.2	54.6 12.2	54.0 11.2	51.2* 10.1†
Systolic blood pressure (mmHg)	128.4 10.7	132.2 13.5	126.1 7.4	120.0 10.0†	123.9 9.9†	122.8 10.0†	128.6 16.3	129.3 10.9	130.3 12.9	127.1 14.0	122.9 12.0†
Diastolic blood pressure (mmHg)	73.4 12.3	76.6 7.5	74.4 5.3	75.5 6.8	72.2 10.6	69.4 6.3	75.4 9.3	73.2 8.2	76.8 6.4	70.3 5.3†	66.1* 6.8†
$SV_1 + RV_5$ or V_6 (mm)	25.4 7.7	29.1 7.8	31.9 9.1	30.4 7.5	31.1 5.8	33.9* 7.9†	29.7 8.9	29.5 6.3	31.9 9.9	28.8 6.8	28.9 6.8
Weight (kg)	70.9 10.2	72.9 7.2	73.0 7.5	72.5 7.5	73.1 7.7	71.8 6.6†	81.0*† 6.5	80.8† 6.4	80.6† 5.7	81.5† 5.6	79.1*† 5.5†
Maximal oxygen uptake (ml/min per kg)	—	—	58.0 8.2	62.0 5.7†	60.3 4.3	65.4 5.7†	—	62.1 7.6	63.5 6.0	62.9 5.2	71.7† 7.0†
Aorta (mm)	29.9 2.8	28.8 2.0	28.8 1.3	29.3 2.4	28.4 2.0	29.0 1.6	31.3† 1.5	31.6† 1.9	31.5† 1.6	31.1 2.1	31.2† 2.0
LA (mm)	31.0 5.9	36.3* 2.4	37.0 2.7	38.1 3.4	38.3 2.6	37.5* 2.7	38.8*† 3.1	39.5 4.1	40.3 3.9	39.7 4.2	38.7* 3.4
LVID _d (mm)	49.8 4.1	51.5 2.4	52.6 2.1	51.9 1.8	53.3 1.7†	53.3* 2.2†	56.1*† 2.7	56.9† 2.7	57.2† 3.0†	57.3† 2.3†	57.9*† 2.9†
LVID _s (mm)	33.8 2.7	35.0 2.4	36.0 2.4†	36.3 1.6	36.8 1.6†	36.8 2.5†	37.3* 3.4	38.1 1.8	38.3 3.3	39.4† 2.9†	38.4* 2.9
IVS (mm)	8.4 0.9	8.9 1.0	8.9 0.8	8.8 1.1	9.4 0.9†	10.0* 1.1†	11.1*† 0.9	11.1† 0.8	11.0† 0.9	11.4† 1.0	11.5*† 0.9
LVPW (mm)	8.0 0.7	8.3 0.5	8.4 0.5	8.6 1.0	8.6 0.9	9.2* 0.8†	10.1*† 0.7	10.2† 0.8	9.9† 0.9	10.2† 0.9	9.9* 0.9
RVID _d (mm)	22.1 5.2	25.0 4.4	27.0 6.0†	27.0 5.2†	27.3 4.2†	25.0 5.2	26.8* 5.7	27.7 6.0	27.7 4.9	29.3 5.6†	27.8* 6.8
SF (%)	32.0 4.4	32.1 3.1	31.4 3.1	31.0 3.9	31.1 2.8	31.1 2.8	33.5 4.5	33.0† 2.0	34.0 3.9	31.2 3.1	33.7 3.8

*Difference between oarsmen and control group.

†Difference between freshmen and seniors.

‡Difference between first and subsequent examinations.

Aorta, aortic root diameter; IVS, interventricular septal thickness; LA, left atrial diameter; LVID_d, left ventricular internal diameter at end-diastole; LVID_s, left ventricular internal diameter at end-systole; LVPW, left ventricular posterior wall thickness; RVID_d, right ventricular internal diameter at end-diastole.

diameter, interventricular septal thickness, and left ventricular posterior wall thickness, made in control subjects one month apart by the same investigator, were not statistically different (Table 3A). When echocardiograms of the oarsmen at the beginning of the training period were analysed by a second observer, slightly lower values for interventricular septal thickness and left ventricular posterior wall thickness were found (Table 3B). Despite absolute differences between the two investigators, probably a result of measurement technique, the observed differences between freshman and senior oarsmen and the changes during the rowing season were identical.

Table 3 Mean differences $\pm$ standard deviations for left ventricular end-diastolic dimension, and interventricular septum and left ventricular posterior wall thickness

Variable	A	B
LVID _d (mm)	0.2 $\pm$ 1.6	0.4 $\pm$ 1.4
IVS (mm)	0.1 $\pm$ 1.1	-0.5 $\pm$ 0.9*
LVPW (mm)	0.2 $\pm$ 0.8	-0.5 $\pm$ 0.8*

(A) For control group (n=17) analysed by the same investigator at the start of the study and one month later.

(B) For oarsmen (n=23) analysed by two independent investigators at the start of the study.

*Difference, $p < 0.05$.

IVS, interventricular septal thickness; LVID_d, left ventricular end-diastolic dimension; LVPW, left ventricular posterior wall thickness.

At the beginning of the season senior oarsmen had greater left ventricular end-diastolic dimensions, interventricular septal thickness, and left ventricular posterior wall thickness than freshman oarsmen and control subjects (Table 2 and Fig. 2). Right ventricular end-diastolic diameter was greater in seniors than in control subjects. Aortic root diameter was greater in senior oarsmen than in freshmen, but did not differ from control subjects. Left atrial diameter was greater

in seniors than in both the other groups and greater in freshmen than in control subjects. The percentage shortening did not differ in the three groups examined. In none of the oarsmen or control subjects was septal thickness abnormally increased, ratios of septal to left ventricular wall thickness being less than 1.3 in all subjects.

During the training period there was an increase in left ventricular end-diastolic diameter, interventricular septal thickness, and left ventricular posterior wall thickness in freshman oarsmen. In seniors only left ventricular end-diastolic diameter increased. At the end of the season seniors still had greater left ventricular end-diastolic diameter, interventricular septal thickness, and aortic root diameter than freshmen, but did not differ any longer in left ventricular posterior wall thickness and left atrial size. At the end of the season freshmen differed from control subjects in left atrial size, left ventricular end-diastolic dimension, and interventricular septum and left ventricular posterior wall thickness. No consistent increase was observed in right ventricular end-diastolic dimension, aortic root diameter, and percentage shortening.

ELECTROCARDIOGRAPHIC DATA

Left ventricular hypertrophy as assessed from the sum of the S wave in V₁ and the R wave in V₅ or V₆ was found at the beginning of the season in four of the seniors, two of the freshmen, and one control subject. During the season there was an increase in SV₁+RV₅ or V₆ in the freshmen. Seniors did not change. At the end of the season five freshmen had an SV₁+RV₅ or V₆ > 35 mm. When the age-adjusted criterion of 44 mm was applied,¹⁵ only one freshman had voltage sufficient to qualify as left ventricular hypertrophy. With the point score system of Romhilt and Estes¹⁶ no left ventricular hypertrophy was found. There was a poor correlation between the sum of SV₁+RV₅ or V₆ and echocardiographic variables.

MAXIMAL OXYGEN UPTAKE

There were no differences in maximal oxygen uptake between freshmen and seniors at the start and during the first four months of the rowing season, but there was a difference in the last months of the rowing season (Table 2, Fig. 2). Maximal oxygen uptake of freshmen after one and seven months of training and maximal oxygen uptake of senior oarsmen after seven months of training differed from maximal oxygen uptake at the start of the rowing season.

RELATION BETWEEN ECHOCARDIOGRAPHIC VARIABLES AND MAXIMAL OXYGEN UPTAKE

Correlation coefficients between echocardiographic variables and maximal oxygen uptake were calculated overall. Calculation of correlation coefficients for each

Fig. 2 Changes in $\dot{V}_{O_2}$ max, LVID_d, SV₁+RV₅ or V₆, and septal and left ventricular posterior wall thickness during seven months of training. Arrows indicate significant differences from control values.

period and for each group separately did not improve the correlation coefficients. The correlation between maximal oxygen uptake and left ventricular end-diastolic dimension for freshmen and seniors was, respectively, -0.07 and 0.05 , between maximal oxygen uptake and interventricular septum, respectively, -0.18 and 0.24 .

Discussion

Echocardiographic dimensions found in our control subjects (Table 2) are very similar to those of comparable control groups in recent studies.^{2, 12}

Our senior oarsmen had a left ventricular end-diastolic dimension, left ventricular posterior wall thickness, aortic root diameter, and percentage shortening comparable to champion sprinters, a left atrial diameter comparable to marathon runners, and an interventricular septal thickness in between sprinters and marathon runners in one of these studies.² Right ventricular end-diastolic diameter was not mentioned in that study, but an increase in this variable in athletes has been described before.³⁻⁵

Freshman oarsmen differed from control subjects only in left atrial size at the beginning of the rowing season. An increase in left atrial size in athletes has been described before^{2, 5} and has been explained by volume overload or by a dilatation of the left atrium as a response to a left ventricular hypertrophy induced by training.^{2, 5} Ikäheimo *et al.*² favoured the last hypothesis, since they found good correlation between left atrial size and left ventricular posterior wall thickness. We could not confirm this.

During the training period there was an increase in left ventricular end-diastolic dimension, and interventricular septum and left ventricular posterior wall thickness in freshmen. In seniors only the left ventricular end-diastolic dimension increased. The changes in our study were small, but almost all oarsmen have shown this increase.⁶⁻⁸ The magnitude of the changes we found is difficult to compare with those in previous studies since, in the latter, subjects with a lower $\dot{V}O_2$ max were studied, an indirect measurement of the $\dot{V}O_2$ max was sometimes used, and the observation periods were always shorter.⁶⁻⁸ It is likely that the influence of training upon echocardiographic ventricular dimensions depends on the age and the physiological status of the subjects involved.⁸

The percentage shortening did not differ in oarsmen compared with control subjects and did not change during the training. Data from other investigations also indicate that there is no important difference between mean resting ventricular performance of athletes and control subjects.^{1, 3-5, 7} Previous studies have shown that athletes participating primarily in dynamic exercise have an increase in the left

ventricular end-diastolic dimension, with little increase in left ventricular wall thickness, whereas athletes participating primarily in static exercise have an increase in left ventricular wall thickness associated with a normal left ventricular end-diastolic diameter.¹

In senior oarsmen years of rowing training, a combination of heavy static and dynamic exercise, seem to have induced both a moderate physiological hypertrophy and a dilatation of all cardiac chambers. During the training period there was no further increase in wall thickness and only a slight increase in left ventricular end-diastolic dimension.

In freshman oarsmen both left ventricular wall thickness and dimension increased. This increase in wall thickness could also be documented by an increase in total voltage of $SV_1 + RV_5$ or V_6 on the electrocardiogram, as has been described before.⁶ A poor correlation between echocardiographic variables of left ventricular size and the sum of $SV_1 + RV_5$ or V_6 has been found in a previous study.¹⁷ The fact that freshman oarsmen had smaller left ventricular cavities and wall dimensions than senior oarsmen, but almost identical praecordial voltages must mean that a praecordial voltage is related to factors other than left ventricular hypertrophy such as body type and muscle mass. Freshman oarsmen differed in almost all echocardiographic variables from control subjects at the end of the rowing season—they had become more "senior".

Since no relation was found between maximal oxygen uptake and echocardiographic dimensions and since there is a poor correlation between echocardiographic measurements and competitive performance in well-trained and world-class athletes,^{1, 5} ultrasound measurement at rest cannot be a simple substitute for the determination of maximal oxygen uptake.

During the training the programme was changed from nonspecific training, consisting mainly of endurance and interval training outside the boat, to very specific training, consisting of rowing only. The remarkable increase in maximal oxygen uptake that was found between four and seven months of training in both freshmen and senior oarsmen occurred only during the latter. Differences in weekly duration of the training during the whole year do not seem to be extensive enough to explain the change of maximal oxygen uptake in this period. The possibility exists that the intensity of the training was considerably changed from the moment that the specific training began. Perhaps it provided better motivation to work at higher intensity. Another explanation may be that the limitation of maximal oxygen uptake has to be sought in the use of muscles that are employed in rowing,¹⁸ which are not called on during the training outside the boat.

Whether the high intensity or the specificity of the training regimen is responsible for the increase in the maximal oxygen uptake, from this study it is clear that, for oarsmen, rowing seems to improve their performance capacity much more than nonspecific endurance or interval training.

We thank the oarsmen of the Amsterdam Student Rowing Club "Nereus", without whose co-operation this study could not have been performed.

References

- 1 Morganroth J, Maron BJ. The athlete's heart syndrome: a new perspective. *Ann NY Acad Sci* 1977; **301**: 931-41.
- 2 Ikäheimo MJ, Palatsi IJ, Takkunen JT. Non-invasive evaluation of the athletic heart: sprinters versus endurance runners. *Am J Cardiol* 1979; **44**: 24-30.
- 3 Gilbert CA, Nutter DO, Felner JM, Perkins JV, Heymsfield SB, Schlant RC. Echocardiographic study of cardiac dimensions and function in the endurance-trained athlete. *Am J Cardiol* 1977; **40**: 528-33.
- 4 Roeske WR, O'Rourke RA, Klein A, Leopold G, Karliner JS. Non-invasive evaluation of ventricular hypertrophy in professional athletes. *Circulation* 1976; **53**: 286-92.
- 5 Underwood RH, Schwade JL. Non-invasive analysis of cardiac function of elite distance runners—echocardiography, vector-cardiography and cardiac intervals. *Ann NY Acad Sci* 1977; **301**: 297-309.
- 6 DeMaria AN, Neumann A, Lee G, Fowler W, Mason DT. Alterations in ventricular mass and performance induced by exercise training in man evaluated by echocardiography. *Circulation* 1978; **57**: 237-44.
- 7 Ehsani AA, Hagberg JM, Hickson RC. Rapid changes in left ventricular dimensions and mass in response to physical conditioning and deconditioning. *Am J Cardiol* 1978; **42**: 52-6.
- 8 Wolfe LA, Cunningham DA, Rechnitzer PA, Nichol PM. Effects of endurance training on left ventricular dimensions in healthy men. *J Appl Physiol* 1979; **47**: 207-12.
- 9 Astrand P, Rodahl K. *Text book of work physiology*. 2nd ed. New York: McGraw-Hill, 1977: 297-398.
- 10 Feigenbaum H. *Echocardiography*. 2nd ed. Philadelphia: Lea & Febiger, 1976: 73.
- 11 Sahn DJ, DeMaria AN, Kisslo J, Weyman A. Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. *Circulation* 1979; **58**: 1072-83.
- 12 Reneman RS, Schmitz JFF, Snoeckx LHEH, Lambregts JAC. Differences in echocardiographic dimensions of the heart between females and males. In: Lancée CT, ed. *Echocardiography*. The Hague: Martinus Nijhoff, 1979: 53.
- 13 Linhart JW, Mintz GS, Segal BL, Kawai N, Kotler MN. Left ventricular volume measurement by echocardiography: fact or fiction. *Am J Cardiol* 1975; **36**: 114-8.
- 14 Sokolow M, Lyon TP. The ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. *Am Heart J* 1949; **37**: 161-86.
- 15 Simonson E. *Differentiation between normal and abnormal in electrocardiography*. St Louis: CV Mosby, 1961: 150.
- 16 Romhilt DW, Estes EH Jr. A point-score system for the ECG diagnosis of left ventricular hypertrophy. *Am Heart J* 1968; **75**: 752-8.
- 17 Raskoff WJ, Goldman S, Cohn K. The "athletic heart": prevalence and physiological significance of left ventricular enlargement in distance runners. *JAMA* 1976; **236**: 158-62.
- 18 Kaijser L. Oxygen supply as a limiting factor in physical performance. In: Keul J, ed. *Limiting factors of physical performance*. Stuttgart: Georg Thieme, 1973: 145.

Requests for reprints to Dr Wouter Wieling, Department of Medicine, Academic Medical Centre, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands.