Cardiac Effects of a Competitive Road Race in Trained Child Runners

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ABSTRACT. Background. Animal studies and investigations of adult endurance athletes indicate a transient depression of myocardial function after prolonged high-intensity exercise.

Purpose. To determine whether a similar decrease is observed in child distance runners after a 4-km competitive road race.

Methods. Anthropometric measures, resting M-mode echocardiograms, maximal cycle exercise tests with estimation of cardiac output, and electrocardiograms were performed before a 4-km road race in nine run-trained boys (mean age, 12.2 years). Weight and resting echocardiogram and electrocardiogram were assessed immediately after the race. The entire test battery was repeated 24 hours later.

Results. Small but significant decreases in mean body weight and left ventricular end-diastolic dimension were observed immediately after the race, but there were no changes in shortening fraction. These findings are consistent with the effects of dehydration. Measurements returned to prerace values by 24 hours of recovery. Peak work capacity, maximal stroke volume, and maximal cardiac output were similar on prerace and 24-hour postrace testing. No electrocardiographic abnormalities were observed.

Conclusions. No adverse cardiac effects were observed from a competitive 4-km road race in male child distance runners. Pediatrics 1997;100(3). URL: http://www.pediatrics.org/cgi/content/full/100/3/e2; echocardiography, children, exercise.

ABBREVIATIONS. LVSF, left ventricular shortening fraction; VTI, velocity time integral; LVED, left ventricular end diastolic dimension; bpm, beats per minute.

The emergence of the elite-level child athlete has raised concern regarding possible adverse physiologic and psychologic effects of intense sports training and competition during the growing years. Little scientific data are available, however, to evaluate the reality of these potential risks. Consequently, creating appropriate guidelines for safe participation by children in competitive sports remains difficult.

Evidence does exist that high-intensity sports may impose significant acute stress on the cardiovascular system. Echocardiographic evidence of myocardial dysfunction immediately after competition in prolonged distance running events has been demonstrated in adult endurance athletes. This depressed contractility, manifested as a decrease in left ventricular shortening fraction (LVSF), typically resolves within 24 hours after a race. Findings of left ventricular dysfunction after sustained running have also been corroborated in the laboratory setting. Animal studies support the concept that transient myocardial fatigue after sustained high-intensity exercise may be expressed as depressed contractility, possibly related to alterations in calcium transport capacity of the sarcoplasmatic reticulum.

This study was performed to determine whether cardiac functional alterations are evident after shorter distance competitions in trained child runners. Resting electrocardiograms and two-dimensional echocardiograms were performed before and immediately after a 4-km road race in nine boys 9.3 to 14.5 years of age. In addition, cardiac variables were measured during maximal cycle exercise with Doppler echocardiography before and 24 hours after the race.

METHODS

Nine run-trained boys (mean age, 12.2 years; range, 9.3 to 14.5 years) were recruited for assessment of cardiac function before and after a 4-km road race. All were in good health with the exception of one boy with a history of mild exercise-induced asthma. None were taking medications that would affect exercise performance. Two reported voice change, shaving, or pubic hair development indicative of early puberty.

The children were all members of a local running club and had been running on a regular basis for an average of 3.2 (1.2) years. Current run training was 4.2 (0.9) days per week. This study was conducted in the summer months, when most of the training time was spent on speed rather than on distance runs. Average training mileage was 9.8 (4.5) miles per week. The children had all participated in the 4-km race several times previously, with an average best race time of 15:20, equivalent to a 6:08 per mile pace. All runners reported participation in other organized sports including basketball, soccer, and football.

The 4-km road race, an organized weekly event held for runners 15 years of age, was held on a gently rolling, shaded course. To facilitate postrace measurements, children were studied surrounding two separate races. Ambient temperatures at the times of these races were 68°F and 86°F, with high humidity on both days. Fluid intake was limited to ~4 ounces of a sports drink consumed immediately after crossing the finish line.

Four days before the race, the children visited the laboratory for anthropometric measurements, resting electrocardiogram and two-dimensional echocardiogram, and maximal cycle test with cardiac measurements by Doppler echocardiography. Immediately after the race, children were transported to the laboratory for weight and resting electrocardiogram and echocardiogram. All measurements were made within 35 minutes after the end of the race. Twenty-four hours later the children returned for a repeat of the studies performed 4 days before the race.

Weight was determined to the nearest 0.1 kg using the same
balance scale with the subject wearing only running shorts. Triceps and scapular skinfolds were measured in triplicate using standard techniques and summed to create a skinfold score. Standard 12-lead supine electrocardiograms were obtained and analyzed for rate, dysrhythmias, ischemic changes (ST depression > 1 mm greater in left precordial leads), and ventricular hypertrophy. Right ventricular hypertrophy was defined as RV1 + SV6 > 15 mm, and left ventricular hypertrophy was identified as SV1 + RV6 > 35 mm.

M-mode echocardiograms with two-dimensional guidance were performed with the children in a left-lateral position using a Hewlett Packard Sonos (Andover, MA) 1000 echocardiograph with a 3.5-MHz transducer. Left ventricular measurements were recorded using standard techniques.5 Left ventricular dimensions were recorded at or just below the tips of the anterior mitral valve leaflet in the parasternal long-axis view. End-diastolic dimension was measured from the posterior aspect of the ventricular septum to the endocardium of the left ventricular posterior wall at the Q wave of the electrocardiogram. Left ventricular end-systolic dimension was defined as the vertical distance from the point of maximum systolic excursion of the left ventricular posterior wall to the ventricular septum. The LVSF, an index of contractility, was determined as systolic dimension minus end-systolic dimension divided by end-diastolic dimension, expressed as a percentage. Values were recorded as the average of a minimum of three measurements.

Maximal upright cycle testing on a mechanically braked Monark (Stockholm, Sweden) ergometer was performed in an air-conditioned laboratory (temperature, 20°C to 22°C). The initial and incremental exercise work loads were 25 watts, with 3-minute stages. Pedaling cadence was constant at 50 rpm. The test was terminated when the pedaling rate could no longer be maintained. Endurance fitness was assessed by peak work capacity relative to body mass, which is closely related to mass–relative maximal oxygen uptake $(r = 0.88$ for 10- to 13-year-old boys in this laboratory) (unpublished data).

Heart rate during exercise was measured by electrocardiogram. Using standard Doppler echocardiographic technique, cardiac stroke volume at rest and during exercise was estimated as the product of the aortic root cross-sectional area (measured in the upright resting state) and the integral of ascending aortic blood velocity and time.$^6$ A 2.0-mhz continuous-wave Doppler transducer (Pedof, Hewlett Packard, Andover, MA) directed from the suprasternal notch was used to record velocity of blood in the ascending aorta. The contour of the velocity curve throughout time was traced both on-line and off-line, with automatic integration of the velocity time integral (VTI). The same pediatric cardiac ultrasonographer collected all data. VTI values were averaged from the 3 to 10 curves with the highest values which demonstrated crisp spectral envelopes. VTI measurements and heart rate were recorded during the final minute of each workload and in the final 30 seconds before termination of exercise.

The maximal diameter of the ascending aorta at the sinotubular junction (just superior to the sinuses of Valsalva) from inner edge to inner edge in systole was recorded by two-dimensional echocardiography with the subject seated at rest. The average of 5 to 10 measurements was used to calculate the mean aortic diameter, assuming the aorta to be circular. This value was used for all subsequent resting and exercise stroke volume calculations.

Cardiac output was calculated as the product of stroke volume estimated by Doppler (VTI $\times$ aortic root cross-sectional area) and heart rate. Peak aortic ejection velocity was recorded from the velocity-time envelope.

The reproducibility of this methodology has been previously assessed in this laboratory. Average test–retest correlation coefficients for Doppler-derived stroke volume during exercise in 13 children was $r = 0.74$, compared with that of heart rate $(r = 0.80)$ and cardiac output $(r = 0.81)$ (unpublished data).

Comparison of prerace, postrace, and 24-hour postrace values of weight and echocardiographic variables was performed with one-way analysis of variance with repeated measures. Newman–Keuls test was used to examine post-hoc paired differences. Peak Doppler exercise test were assessed with Student’s t test. Comparisons of prerace and 24-hour posttest cardiac variables were made with Pearson moment correlation coefficients. Statistical significance was defined as $P < .05$.

The children and their parents signed informed assent/permission to participate in this study. This study was approved by the Institutional Review Board of the Baystate Medical Center.

**RESULTS**

The mean initial weight of the runners was 39.9 (9.7) kg, height 151 (14) cm, and skinfold sum 12.9 (2.5) mm. These values place the subject cohort at approximately the 50th, 40th, and 20th percentiles for weight, stature, and adiposity, respectively, of the United States population norms published for 12-year-old boys.$^7$ Average peak work capacity was 146 (29) watts, or 3.70 (0.30) watts/kg.

Anthropometric and physiologic variables for the three testing occasions are outlined in Table 1. A small but significant mean weight loss was observed immediately after the race, but values returned to prerace values by 24 hours later (Fig 1). Eight of the nine runners demonstrated this pattern, with an average loss after the race of 0.51 (0.23) kg.

Similarly, mean left ventricular end diastolic (LVED) dimension declined immediately postrace compared with prerace measurements. This fall was seen in eight of nine runners, with an average decline of 1.7 (1.2) mm. By 24 hours’ postrace, however, mean values increased back to prerace diameters (Fig 2). No systematic changes were observed in left ventricular end–systolic dimension or LVSF on any of the three tests (Fig 3).

The resting electrocardiogram in the prerace assessment exhibited criteria for left ventricular hypertrophy in three boys, and two demonstrated sinus bradycardia (rate <60 beats per minute (bpm)). Mean heart rates were 64 (12) bpm, 93 (16) bpm, and 65 (9) bpm on the prerace, immediate postrace, and 24-hour postrace tracings. Other than the increase in heart rate, no ischemic changes, dysrhythmias, or conduction delays were seen in the immediate postrace tracing. Twenty-four-hour follow-up electrocardiograms were also unchanged.

Cardiac variables were obtained during maximal cycle testing in all children except one, in whom respiratory artifact obscured peak VTI values in the follow-up test. Identical average maximal

| TABLE 1. Exercise and Cardiac Variables Before and After a 4-km Road Race* |
|-----------------|-------------------|------------------|-----------------|
|                 | Prerace           | 15-Min Postrace  | 24 Hr Postrace  |
| Weight (kg)     | 39.9 (9.7)        | 39.5 (9.9)$^+$   | 39.9 (9.9)      |
| Resting electrocardiogram |                   |                  |                 |
| LVED (mm)       | 45.7 (3.6)        | 44.2 (4.0)$^+$   | 45.8 (3.2)      |
| LVES (mm)       | 29.0 (2.9)        | 29.0 (3.2)       | 29.6 (2.1)      |
| LVSF (%)        | 36.3 (5.2)        | 34.5 (3.1)       | 35.6 (2.0)      |
| Maximal exercise test |                   |                  |                 |
| Heart rate (bpm)| 188 (112)         | 188 (10)         |                |
| PV (cm/sec)     | 195 (33)          | 219 (50)         |                |
| SI (mL/MF)      | 65 (6)            | 70 (9)           |                |
| CI (L/min/MF)   | 12.27 (1.75)      | 12.93 (1.40)     |                |
| PWC (watts/kg)  | 3.70 (3.0)        | 3.68 (2.77)      |                |

Abbreviations: LVED, left ventricular end diastolic dimension; LVES, left ventricular end systolic dimension; LVSF, left ventricular systolic fraction; PV, peak aortic velocity; SI, stroke index; CI, cardiac index; PWC, peak work capacity.

* Values are mean (standard deviation).
+$ P < .05$ prerace vs 15-min postrace and $P < .05$ 15-min post vs 24-hr postrace.
hearts of 188 (11) and 188 (10) bpm indicate an equal effort on both pretests and posttests. Table 1 outlines cardiac variables on the two tests. No significant changes were seen in maximal stroke index, cardiac index, peak velocity, or peak work capacity. Submaximal (50-watt) correlation coefficients between test 1 and test 2 were \( r = 0.82 \), \( r = 0.70 \), and \( r = 0.77 \) for heart rate, stroke volume, and cardiac output.

**DISCUSSION**

The high caliper of the distance runners in this study was indicated by their race times and performance on maximal cycle testing. The average best 4-km finish time was 15:20 (6:08 per mile), faster than the boy runners described by Unnithan et al\(^1\) (mean age, 11.7 years), who demonstrated a mean race time of 12:51 for 3 km (6:54 per mile pace). Daniels and Oldrige\(^12\) reported average 2-mile run times of 11:49 (5:54 ‘per mile) in endurance-trained 14-year-old boys. In contrast, the average 1-mile run time for 12-year-old American boys in school field testing is 8:21.\(^{10}\)

Prerace mean peak work capacity during exhaustive cycle testing in these runners was 3.70 (0.30) watts/kg. Normal values for nontrained, active boys of this age group in our laboratory is 3.00 (0.55) watts/kg (unpublished data).

This study was designed to address concerns that distance running competition may produce transient depression of myocardial function. Niemela et al\(^3\) showed a 24% and 16% reduction in left ventricular stroke dimension and LVSF, respectively, in male ultramarathon runners after a 24-hour run. Douglas et al\(^2\) described similar echocardiographic changes in participants in the Hawaii Ironman Triathlon. In both cases, these findings, consistent with depressed myocardial contractility, resolved during the 24 to 48 hours after competition.

Seals et al\(^4\) noted similar findings in adult male nonathletes who exercised on a treadmill at 69% VO\(_{\text{max}}\) for 170 minutes. LVED diameter and fractional shortening decreased significantly, leading the authors to conclude that prolonged exercise may result in depressed left ventricular function. Maher et al\(^5\) reported similar findings in rats, the left ventricular muscle for which showed significant reduction in both peak isometric tension and velocity of shortening after exhaustive treadmill exercise.

Demonstration of similar findings in children in distance running events would be troublesome, considering the possibility that repetitive episodes of myocardial fatigue during sports training and competition might have negative effects on growing heart tissue. This study provides reassuring evidence that a 4-km road race in trained prepubertal and circumpubertal boys has no acute negative effects on myocardial function. Resting echocardiograms performed immediately postrace revealed no evidence of depressed left ventricular contractility, and electrocardiograms revealed no race effects. Exercise testing performed 24 hours after the race demonstrated no changes in endurance fitness, maximal stroke volume, maximal cardiac output, or peak aortic velocity compared with prerace values. These findings indicate not only normal cardiac function but a remarkable capacity for recovery within 24 hours after a highly competitive race.

The small but consistent decrease in weight immediately after the race is consistent with the effects of dehydration. Similarly, the parallel fall in LVED dimension suggests decreased cardiac filling from a fall in plasma volume. That both observations can be
explained by fluid loss during racing competition is supported by the normalization of these measures to prerace values in the 24-hour follow-up study.

The findings of this study support other limited evidence indicating that children tolerate cardiac work with sports training and competition without adverse short-term cardiac effects. Rost\textsuperscript{13} described increases in cardiac volume and chamber size in a 10-year longitudinal assessment of child swimmers that exceeded that of nonathletic children. The author noted that “there was no evidence to suggest that the early start of high-performance training had any bearing on the development of cardiac damage.”

Cardiac responses to sustained steady-state exercise are no different in children than in adults.\textsuperscript{14–16} Rowland and Rimany\textsuperscript{14} found a similar slow rise in oxygen uptake, heart rate, and cardiac output during 40 minutes of cycling at 63\% VO\textsubscript{2}max in premenarcheal girls and young women. Stroke volume did not change in either group in that study, in contrast with equal declines in stroke volume described in another study of prolonged exercise in children and adults.\textsuperscript{15}

More research information is necessary to address concerns regarding the physiologic stresses of intensive athletic training in the prepubertal years. This study provides no evidence that short-distance endurance road races in trained healthy children pose acute cardiac risks. Whether similar findings can be expected in less-trained children or after longer races awaits additional investigation.

REFERENCES


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