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BRUCE TREADMILL TEST IN HEALTHY TURKISH CHILDREN: ENDURANCE TIME, HEART RATE, BLOOD PRESSURE AND ELECTROCARDIOGRAPHIC CHANGES*

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SUMMARY: Lenk MK, Alehan D, Çeliker A, Alpay F, Sarıcı Ü. (Department of Pediatrics, Gülhane Military Medical Academy and Cardiology Unit, Department of Pediatrics, Hacettepe University Faculty of Medicine, Ankara, Turkey). Bruce treadmill test in healthy Turkish children: endurance time, heart rate, blood pressure and electrocardiographic changes. Turk J Pediatr 1998; 40: 167-175.

Heart rate, systolic and diastolic blood pressure and electrocardiographic changes were studied in 80 healthy children during treadmill exercise with Bruce protocol. Mean duration of exercise in boys increased from 10.01 ± 1.61 minutes at age four to six years with a mean body surface area of 0.75 ± 0.06 m^2, to 17.86 ± 2.66 minutes at age 13 to 15 years with a mean body surface area of 1.48 ± 0.10 m^2. Mean endurance time in girls increased from 11.06 ± 1.92 minutes at age four to six years with a mean body surface area of 0.76 ± 0.08 m^2, to 15.69 ± 2.23 minutes at age 13 to 15 years with a mean body surface area of 1.41 ± 0.07 m^2. Mean maximal heart rate was 193.38 ± 10.89 beats/minute in boys and 196.78 ± 10.99 beats/minute in girls. The maximum level of systolic blood pressure attained at peak exercise was lower in girls. Although data of healthy Turkish children including mean endurance time, heart rate and blood pressure responses to exercise were consistent with the results from several countries using the Bruce protocol, mean maximal heart rates for all groups were slightly higher than those obtained with the Balke protocol. The data obtained from this study offers age- and size-appropriate normal data in both sexes in healthy Turkish children and may be used as reference values during treadmill exercise. *Key words: treadmill exercise test, healthy children.*

Exercise, a common physiological stress, can elicit cardiovascular abnormalities not present at rest and can be used to determine the adequacy of cardiac function. Hemodynamic and cardiopulmonary responses of children with congenital heart lesions to exercise have been published for several years[1-6]. Exercise testing was also used as a principal method for exposing an arrhythmia,

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for identifying the patient at risk for a serious tachyarrhythmia and for evaluating the effect of an antiarrhythmic drug[7]. Many of these evaluations were accomplished by using either a bicycle ergometer or a treadmill.

The Bruce treadmill test has been commonly used to assess exercise capacity and the electrocardiographic response to exercise stress in adults[8]. To determine the normal values for heart rate, blood pressure and endurance time, numerous investigations have been done in various countries[9, 10]. This study is performed to obtain normal data for healthy Turkish children on the treadmill test using the Bruce protocol.

Material and Methods

Study Groups: 40 boys and 40 girls, a total of 80 children, with a normal cardiovascular system were selected for the study. For data analysis the subjects were classified into four groups according to their ages, body surface area and sexuality as follows: group I- four to six years old (0.64 to 0.86 m^2) 10 boys and 10 girls; group II- seven to nine years old (0.87 to 1.05 m^2) 10 boys and 10 girls; gorup III- 10 to 12 years old (1.06 to 1.35 m^2) 10 boys and 10 girls and group IV-13 to 15 years old (1.36 to 1.61 m^2) with 10 boys and 10 girls. As responses to exercise vary with age, size and sexuality we preferred such grouping as mentioned.

Treadmill Protocol: All children exercised on a Quinton 4000-Q55 model treadmill. The protocol was programmed as outlined by Bruce et al.[8], using stages at which the speed and grade were progressively increased at three minute intervals from 1.7 through six miles per hour (mph) and from 10 through 22 percent, respectively. Heart rates, blood pressures and electrocardiograms were monitored and 12-lead electrocardiographic strep was recorded before the test while the child was standing and at the end of each stage during exercise. Finally, last strips were recorded after the exercise, at the end of each minute for five minutes. Blood pressures were obtained from the left arm with a system connected to the treadmill's monitor (Model 410 Quinton Blood Pressure Recorder). Blood pressure values were obtained using cuff sizes of 9.5 and 12.5 cm, the cuff covering at least two thirds of the upper arm length.

After written consent was obtained, each child was given a general explanation about the equipment and the test procedure. The exercise test was continued for the maximal time allowed (21 minutes) or until severe fatigue prevented further exercise. After peak effort was reached, a walkdown period of one to two minutes was allowed with a very slow treadmill speed to prevent vagal responses. The remaining heart rate and blood pressure determinations in the postexercise recovery period were obtained in a supine position on a bed.

At the end of the test a tabular final report of speed (mph), grade (%), heart rate (beats/minute), blood pressure (mm Hg), endurance time (minutes) and electrocardiographic ST levels were given in all the stages, minute to minute, throughout the test. In the analysis and interpretation of ST segment changes on exercise electrocardiography, a line is drawn from the beginning of one QRS to the beginning of the next, which is known as the PQ-PQ isoelectric line method[11].

Continuous values were expressed as mean ± standard deviation. Student's t test was used for direct comparison of mean values of the patient population. A probability (p) value of < 0.05 was considered statistically significant.

Results

Duration of Exercise (Endurance Time): Table I shows the mean duration of exercise for each of the four groups based on age, sex and body surface area. There was an increase in exercise duration from the younger to the older boys which was not so in girls. Girls in group II had a longer duration of exercise than girls in group III ($p < 0.05$). Girls had a longer duration of exercise than boys in groups I and II and boys had longer endurance times than girls in groups III and IV, but the differences were not statistically significant ($p > 0.05$). The average duration of exercise was 13.86 ± 3.59 minutes in boys; 13.44 ± 2.5 minutes in girls ($p > 0.05$) and 13.63 ± 3.08 minutes in all groups. In general there was an increase in endurance time from the younger ages to the older ages.

Table I: Mean Duration of Exercise in Healthy Turkish Children (Minutes ± SD)

	Group I	Group II	Group III	Group IV
Boys	10.01 ± 1.61	12.67 ± 2.32	14.91 ± 1.98	17.86 ± 2.66
Girls	11.06 ± 1.92	14.15 ± 1.79	12.73 ± 1.42	15.69 ± 2.23
Total	10.53 ± 1.80	13.41 ± 2.15	13.82 ± 2.01	16.78 ± 2.64

Heart Rate Responses: Table II shows the heart rates before exercise, at one minute of exercise and at peak exercise. Although girls had slower heart rates than boys before exercise in groups I and II, they had faster heart rates in groups III and IV, but the differences were not statistically significant ($p > 0.05$). At peak exercise, girls had faster heart rates than boys in groups I, II and IV ($p > 0.05$). Figure 1 shows the minute to minute mean heart rates for all groups during and after exercise. All groups showed a similar trend, with an abrupt increase in heart rate during the first minute of exercise and a more gradual increase thereafter. The younger children had faster heart rates during exercise than the older children. The mean maximal heart rate was 193.38 ± 10.89 beats/minute (median 193) in boys; 196.78 ± 10.99 (median 199) in girls and 195.07 ± 11.00

(median 196) in all groups. The difference in the mean maximal heart rate was not statistically significant between boys and girls ($p > 0.05$). All groups had an abrupt decline in heart rate after exercise.

Table II: Mean Heart Rates of Both Sexes During Different Stages of Exercise (Beats/Minute ± SD)

	Group I	Group II	Group III	Group IV
Boys				
Pre exercise	113.3 ± 12.6	101.9 ± 15.8	97.2 ± 10.4	75.4 ± 10.9
1 min exercise	142.7 ± 15.6	131.0 ± 13.9	129.5 ± 13.0	115.0 ± 12.0
Peak exercise	187.9 ± 14.7	184.3 ± 18.5	190.0 ± 9.0	183.6 ± 13.2
Girls				
Pre exercise	106.3 ± 15.9	97.7 ± 9.9	101.0 ± 8.0	86.8 ± 16.7
1 min exercise	140.6 ± 15.4	134.0 ± 7.8	140.2 ± 14.0	114.2 ± 18.4
Peak exercise	188.1 ± 10.1	194.8 ± 12.1	188.9 ± 19.5	189.4 ± 5.6

1 min exercise: 1 minute of exercise.

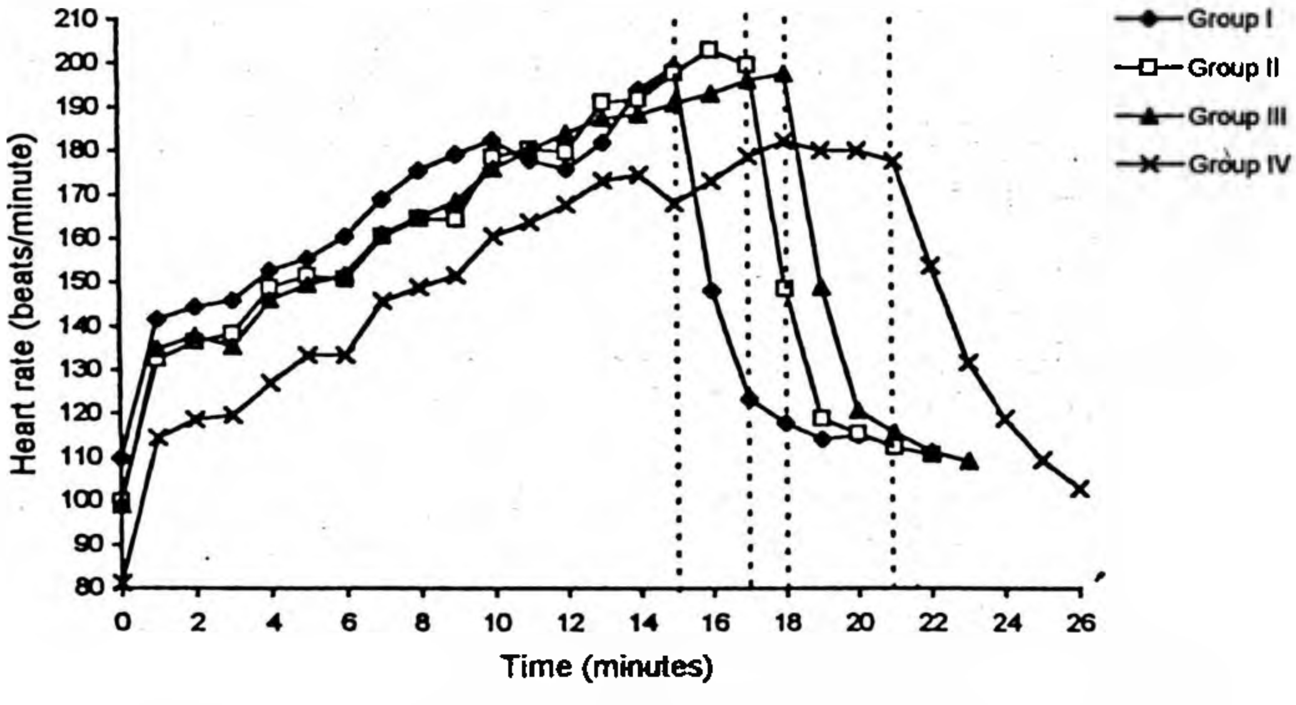

Fig. 1: Minute to minute mean heart rate responses during exercise in four groups (the peak mean heart rate values are shown as vertical thin lines and the values after lines indicate the postexercise values).

Blood Pressure Responses: The mean minute to minute systolic and diastolic blood pressure responses of the children are shown in Figures 2, 3, 4 and 5. A gradual, but not an abrupt, increase in systolic blood pressure occurred in all age groups. Diastolic blood pressures remained relatively constant and even tended to decrease in the older children, resulting in an increased pulse pressure during exercise. All groups had an abrupt decline in systolic blood pressure after exercise. The rate of increase in systolic pressure during exercise and the maximum level attained at peak exercise were greater in older ages with a larger body surface area (Fig. 6).

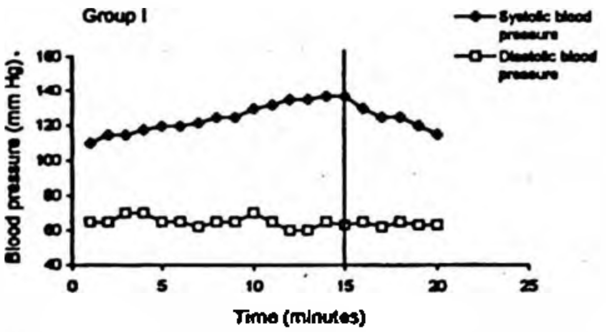

Fig. 2: Minute to minute mean systolic and diastolic blood pressure responses during exercise in group I (the values after the vertical line indicate the postexercise values).

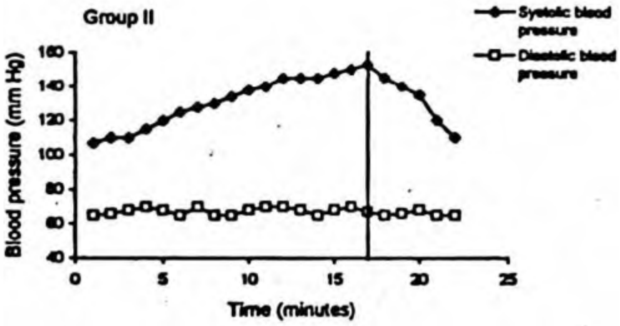

Fig. 3: Minute to minute mean systolic and diastolic blood pressure responses during exercise in group II (the values after the vertical line indicate the postexercise values).

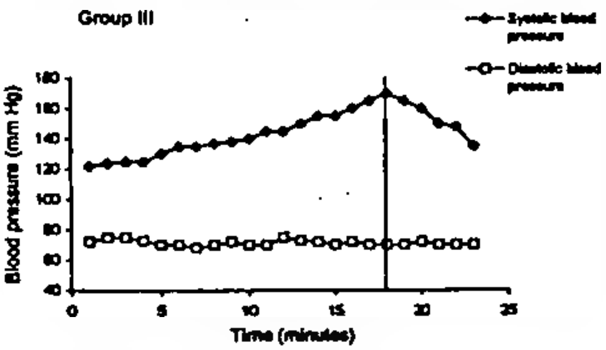

Fig. 4: Minute to minute mean systolic and diastolic blood pressure responses during exercise in group III (the values after the vertical line indicate the postexercise values).

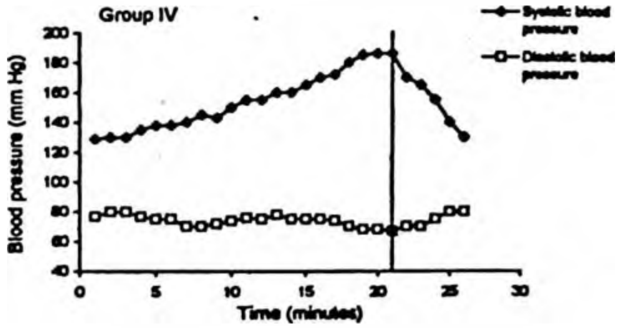

Fig. 5: Minute to minute mean systolic and diastolic blood pressure responses during exercise in group IV (the values after the vertical line indicate the postexercise values).

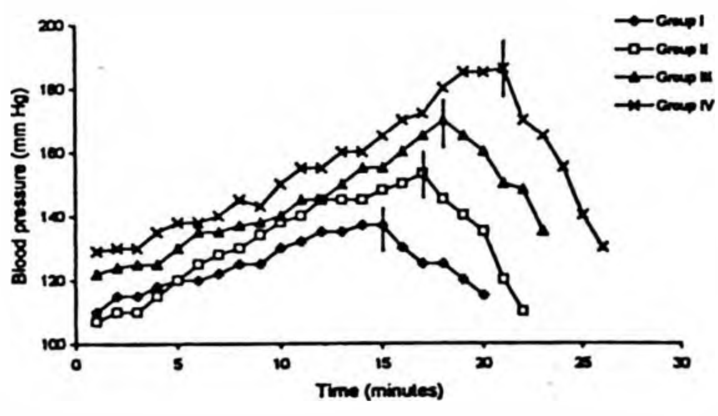

Fig. 6: Minute to minute mean systolic blood pressure responses during exercise in four groups (the peak mean systolic blood pressure values are shown as vertical lines and the values after lines indicate the postexercise values).

Tables III and IV list the systolic and diastolic blood pressure values before exercise, at one minute of exercise and at peak exercise for all the groups. Differences in systolic pressures of boys and girls of each group and of all groups before exercise were not statistically significant ($p > 0.05$). The maximum levels attained at peak exercise were lower in girls ($p > 0.05$).

Table III: Mean Systolic Blood Pressure of Both Sexes During Different Stages of Exercise (mm Hg ± SD)

	Group I	Group II	Group III	Group IV
Boys				
Pre exercise	105.2 ± 4.2	107.2 ± 4.0	113.0 ± 3.7	119.6 ± 2.6
1 min exercise	107.7 ± 16.0	112.2 ± 9.2	132.0 ± 11.0	127.3 ± 5.9
Peak exercise	160.6 ± 32.5	163.7 ± 6.2	179.2 ± 22.3	176.4 ± 5.5
Girls				
Pre exercise	105.0 ± 4.3	106.8 ± 3.7	112.1 ± 4.0	117.9 ± 2.1
1 min exercise	104.4 ± 7.0	111.5 ± 7.6	123.8 ± 3.7	120.0 ± 4.7
Peak exercise	146.1 ± 4.9	153.2 ± 7.2	175.3 ± 26.5	166.5 ± 5.8

1 min exercise: 1 minute of exercise.

Table IV: Mean Diastolic Blood Pressure of Both Sexes During Different Stages of Exercise (mm Hg ± SD)

	Group I	Group II	Group III	Group IV
Boys				
Pre exercise	63.4 ± 3.2	65.6 ± 3.5	71.2 ± 2.2	76.1 ± 2.9
1 min exercise	59.7 ± 6.9	62.9 ± 12.2	61.6 ± 3.9	62.6 ± 3.5
Peak exercise	57.8 ± 11.9	60.3 ± 5.6	64.1 ± 8.0	49.8 ± 3.4
Girls				
Pre exercise	61.9 ± 2.2	64.9 ± 3.3	70.8 ± 3.2	75.3 ± 2.5
1 min exercise	58.3 ± 5.3	62.9 ± 4.7	62.1 ± 3.3	62.0 ± 2.6
Peak exercise	58.0 ± 5.1	61.0 ± 3.7	59.3 ± 9.3	47.7 ± 3.4

1 min exercise: 1 minute of exercise.

Electrocardiographic Changes: All children were in sinus rhythm before exercise and maintained sinus rhythm throughout the test.

T Wave: The mean T wave amplitude for all groups increased from 4.2 ± 2.8 mm before exercise to 6.8 ± 2.4 mm at peak exercise and returned to baseline values during the recovery period.

J-point Depression: Parallel to increase in heart rates, a J-point depression of ≤ 1 mm occurred in all groups.

ST Segment Changes: The ST segment was normal in all children before exercise. Parallel to increase in heart rates during exercise, the ST segment tended to have an upward slope in all groups. No child had a flat or downsloping ST segment depression during the exercise.

Discussion

Exercise testing evaluates work performance and identifies mechanisms that limit the work performance of children with cardiac and other problems. Several protocols using the cycle ergometer or treadmill have been used in children[12]. As the Bruce treadmill test is a commonly used exercise test to assess exercise capacity we used the same treadmill protocol in our study.

Exercise Endurance Time: The mean endurance time for all children in the study groups was 13.63 ± 3.08 minutes (median 13.45). Endurance times using the Bruce protocol for children in similar age groups averaged between 12 and 13 minutes[9]. In another study using the Balke protocol, the average duration of exercise for all groups was reported to be 10.0 ± 1.3 minutes[10]. In our series, older boys had longer endurance times than girls whereas younger girls had longer endurance times than boys. In general, there was an increase in endurance time from the younger to the older ages. These findings were similar to those obtained in previous studies[9, 10].

Heart Rate Responses: The immediate response of the cardiovascular system to exercise in our study groups was an increase in heart rate due to a decrease in vagal tone. Initially, there was a rapid increase in heart rate during the first minute of exercise, and then a linear increase in heart rate occurred until peak exercise was reached. Although Cumming et al.[9] (using the Bruce exercise protocol) reported no differences in maximal heart rate between boys and girls, we found slightly faster heart rates in girls. The younger children had faster heart rates during exercise than the older children as they compensated for a smaller heart and lower stroke volume by an increased heart rate at a given rate of work, thus attaining higher maximal heart rates than the older children. The mean maximal heart rate for all groups in our study was 195.07 ± 11.00 beats/minute (median 196) which is similar to results obtained with the Bruce protocol[9] and slightly higher than those obtained with the Balke protocol[10]. It has been reported that maximal oxygen consumption was approached when the heart rate was 180 beats/minute or greater[13]; therefore, the mean heart rate of 195.07 ± 11.00 beats/minute attained by our subjects should reflect the achievement of a level of exercise at or near maximal oxygen consumption.

The mean heart rates returned to preexercise levels in the recovery period within five minutes after exercise was stopped. As the decrease in resting heart rate is characteristic of conditioning, our children lying down during the recovery period might have played a role in the abrupt decrease in the heart rate.

Blood Pressure Responses: Current guidelines for exercise testing[14] indicate the importance of obtaining blood pressures during the test, as blood pressure recordings during exercise were reported to be important both in adults with coronary artery disease[15] and in children with congenital heart defects[14].

A gradual, but not an abrupt, increase in systolic blood pressure occurred in all age groups in our study throughout the exercise test. This finding was not in accordance with the observations of the previous study by Riopel et al.[10]. There was a progressively higher rise in systolic pressures with age. As males have a higher maximal stroke volume than females, boys in our study had a higher systolic blood pressure response. Diastolic blood pressures tended to remain constant or to increase or decrease slightly during exercise. These circulatory changes can be explained by the dilation of local vascular beds in skin and muscle during exercise. Systolic blood pressure increases as the cardiac output increases to a greater degree than the reduction of resistance. Dilation of the vascular beds, however, causes the diastolic blood pressure to decrease slightly or remain constant.

It was reported that a maximal exercise systolic blood pressure above 220 mm Hg in adults was considered an excessive rise, and it rarely exceeded 200 mm Hg in children[14]. Maximal systolic pressures in our study groups were below 200 mm Hg.

Electrocardiographic Changes: The increase in T wave amplitude during exercise is a well known entity in normal subjects[15]. We observed the same findings in T wave amplitude during and at peak exercise, which then normalized in the recovery period. Changes in ST segment during exercise have been well described in adults[16, 17] and in children[11]. None of the children in our study met the criteria for significant ST segment J-point depression (a J-point depression of ≥ 2 mm and an ST depression of > 1 mm with a flat or downsloping ST segment at 60 milliseconds). These electrocardiographic changes during ventricular repolarization were reported to be used to identify a mismatch of myocardial oxygen demand and supply[14]. Parallel to increase in heart rates, we observed normal physiological J-point depression and the ST segment tended to have an upward slope in all groups.

Although our data, including mean endurance time, heart rate and blood pressure responses to exercise, were similar with the findings from several countries using the Bruce protocol, mean maximal heart rates for all groups in our study were slightly higher than those obtained with the Balke protocol.

In conclusion, the data obtained from this study offers age- and size- appropriate normal data in both sexes in healthy Turkish children and may be used as reference values during treadmill exercise.

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