The evaluation of cardiovascular response to exercise in healthy Turkish children

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The purpose of our study was to determine the normal cardiovascular responses of healthy Turkish children to exercise and to determine the reference values. Two hundred and eighty-four healthy children (115 girls, 169 boys) aged 5-14 were enrolled in the study. Exercise time (ET), workload that can be tolerated with exercise (MET value), change in heart rate (Δ HR), peak systolic and peak diastolic blood pressures (SBP_{max} and DBP_{max}), change in systolic blood pressure (Δ SBP), and peak rate-pressure product (RPP_{max}) were positively correlated with age. There was no correlation between peak heart rate (HR_{max}) and age and there was also no significant increase in change in diastolic blood pressure (Δ DBP) with increasing age. The means ± SD values for ET, workload, HR_{max}, Δ HR, $SBP_{max,}$ $DBP_{max,}$ Δ SBP, ΔDBP, and RPP_{max} were 13.18±1.4 min, 8.56±0.93 MET, 171.46±1.91/min, 67.22±6.65/min, 125.16±13.36 mmHg, 73.32±4.06 mmHg, 24.3±5.96 mmHg, 7.2±6.9 mmHg, and 21504.7±2176.4, respectively. The values found in our study may be accepted as reference values of healthy Turkish children for exercise testing. The formula modified as (200-age) x 0.85 is thought to be more suitable to predict the target heart rate in children.

***Key words:** cardiovascular response, exercise testing, healthy children, reference values.*

Exercise stress testing is an accepted mode of evaluating the peak oxygen consumption and cardiopulmonary status of children. Pediatric exercise testing can be used for many purposes, among them, for the observation of symptoms that are absent at resting state but can be provoked by exercising, determination of functional capacity, evaluation of response to medical or surgical therapy in children with cardiac disease, observation of progress in those in whom cardiac rehabilitation is applied, determination of response of arrhythmias to exercise, evaluation of congenital and acquired atrioventricular blocks, diagnosis of coronary artery disease, which is a rare clinical entity in children (e.g. congenital coronary arterial anomalies, Kawasaki disease, the coronary arterial involvement in connective tissue disease), evaluation of children who will participate in sports, and for the observation of the increase in the functional capacity of children actively involved in sports[1-3].

Diagnostic and prognostic tests are more commonly dynamic exercise. Treadmill exercise testing, bicycle ergometry and step tests are used for this purpose[4]. In pediatric cardiology, treadmill exercise testing can be applied to patients >4 years old[5]. Exercise capacity (MET value) roughly shows the oxygen expenditure in comparison with the resting state. In the treadmill test, this value is calculated by using the speed and slope and is expressed as multiples of the resting oxygen expenditure (oxygen expenditure at rest is 1 MET). Thus, the MET value is the reference value for maximal aerobic capacity in different age groups[4,6].

The accuracy of test results is dependent on a good knowledge of the normal physiological responses.

The purpose of our study was the determination of the normal cardiovascular responses of healthy Turkish children to exercise and to determine the reference values.

Material and Methods

Two hundred and eighty-four children (115 girls, 169 boys) aged 5-14, sent from the pediatric cardiology outpatient department to the exercise stress testing laboratory of İstanbul University, Institute of Cardiology, between January 1998 and January 2001 were enrolled in the study.

After a complete physical examination, a transthoracic echocardiogram was performed. Children without any abnormality were grouped according to their ages (5-6, 7-8, 9-10, 11-12 and 13-14 years old). All groups were comprised of at least 10 children of each sex. All of the children underwent a symptom limited exercise testing using a modified Bruce protocol on a commercial Marquette Case 15 (Cheshire, USA) treadmill device[7]. The target heart rate during exercise is calculated as (220-age) x 0.85. No training on the treadmill was performed before the exercise testing and parents were not allowed to accompany their children in the testing room. Blood pressure was measured at the resting state, at the 2nd minute of each stage and at the 1st, 3rd and 5th minutes post-exercise by the indirect auscultatory method using a cuff and a sphygmomanometer.

Exercise time (ET), exercise capacity (MET value), peak heart rate (HR_{max}), peak systolic blood pressure (SBP_{max}), peak diastolic blood pressure (DBP_{max}), heart rate change with exercise (ΔHR), systolic and diastolic blood pressure changes with exercise (ΔSBP, ΔDBP), and rate pressure product at the end of exercise (RPP_{max}) were evaluated for each group. Statistical analyses were performed with Statistical Package Program for Social Sciences (SPSS for Windows 10.0, Chicago, IL, USA). Statistical evaluations were made by using the Student-t test and linear regression analysis. Values were given as mean ± SD. P values less than 0.05 were accepted as significant.

Results

The responses to exercise in the different age groups for both sexes are shown in Table I. ET positively correlated with age (r=0.95,

Table I. Responses to exercise within the age groups according to sex*

Age groups (years)	ET	MET	HR_{max}	Δ HR	SBP_{max}	ΔSBP	DBP_{max}	RPP_{max}
5-6 (n=22)	11.1±2.7	7.2±1.5	172.9±14.2	56.9±16.9	108.1±14.7	15.8±11.2	68.1±9.5	19611.5±5606.1
Boys (n=10)	10±3.1	6.3±1.5	176±8.2	57.3±18.3	116.3±18	16.3±17	73.8±9.5	18710±1987.8
Girls (n=12)	11.6±2.4	7.4±1.6	171.4±16.4	56.8±17.5	104.4±12.4	15.6±8.8	65.6±8.8	18086.7±3081.8
7-8 (n=45)	12.6±1.9	8.1±1.3	170±1	66.4±17.8	118.2±14.2	22.1±12.3	71.8±7.2	19769.6±3616.7
Boys (n=27)	12.9±1.8	8.4±1.3	168.2±15.9	66.9±19.2	117.4±14.6	20.7±12.1	72.2±7.5	19030.4±3587.1
Girls (n=18)	12±2	7.7±1.3	172.7±13.8	65.8±16	119.4±14.7	24.2±12.6	71.1±6.8	20878.3±3465.2
9-10 (n=77)	13.4±2.4	8.8±1.6	170.3±18.3	68±18.6	124.7±15.5	24.6±12.3	72.4±8.1	21184±3994.3
Boys (n=42)	14±2.3	9.1±1.5	167±19.3	68.2±18.5	128±15.3	26.8±12.5	73.2±8.4	21353.1±4026.4
Girls (n=35)	12.7±2.4	8.3±1.6	174.1±16.5	69.9±18.9	120.7±15	22±11.6	71.4±7.7	20981.1±4004.5
11-12 (n=79)	14.1±2.1	9.1±1.5	170±17.5	69.6±18.6	131.3±15.1	27.3±13.9	75.4±7.5	21987.1±4024.1
Boys (n=45)	14.5±2.3	9.4±1.6	168.7±18.7	70.9±19	132.4±15.3	28.2±17	77.3±6.2	22093.1±4326.8
Girls (n=34)	13.5±1.8	8.7±1.3	171.7±15.9	67.9±18.1	129.7±15.1	27.4±8.6	72.9±8.4	21846.8±3643.9
13-14 (n=61)	14.7±2.4	9.6±1.7	174.1±16.6	75.2±17.1	143.5±13.5	31.7±13.8	78.9±6	24971.6±3335.1
Boys (n=45)	14.9±2.6	9.8±1.8	171.4±15.3	74.3±16.6	143.9±13.9	32.8±13.4	78.6±6.6	24641.2±3270.3
Girls (n=16)	14.1±1.8	9.3±1.3	181.8±18.1	77.8±18.7	142.5±12.4	28.8±15	80±3.7	25900.6±3445.6

*Plus-minus values are means±SD.

ET: Exercise time. MET: Oxygen expenditure in comparison with the resting state. HR_{max}: Peak heart rate. ΔHR: Change in heart rate. SBP_{max}: Peak systolic blood pressure. ΔSBP: Change in systolic blood pressure. DBP_{max}: Peak diastolic blood pressure. RPP_{max}: Peak rate pressure product.

p=0.015). When the increase in ET with age was evaluated for boys (r=0.91, p=0.03) and girls (r=0.99, p=0.0004) separately, there were still significant correlations. The mean ET was 13.18±1.4 minutes (min).

The workload that can be tolerated with exercise (MET value) was also positively correlated with age (r=0.99, p=0.002). When this was evaluated for boys (r=0.91, p=0.03) and girls (r=0.99, p=0.004) separately, there were again significant correlations. The mean MET value was 8.56±0.93 (Fig. 1).

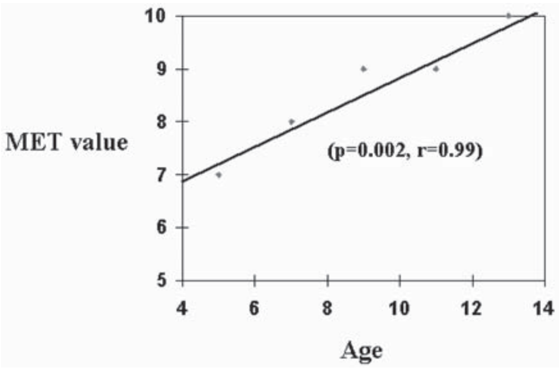

Fig. 1. The relationship between age and MET value.

When the HR response to exercise was evaluated, mean HR_{max} was found to be 171.46±1.91/min. There was no correlation between HR_{max} and age for either sex; however, there were significant correlations between HR_{max} and ET, and HR_{max} and MET value (for ET: r=0.82, p=0.0003; for exercise workload: r=0.89, p=0.0006) (Tables II, III). A linear correlation was found between ΔHR and age (r=0.94, p=0.018). When evaluated according to sex, there were significant correlations for both boys (r=0.94, p=0.017) and girls (r=0.92, p=0.026). Mean ΔHR was 67.22±6.65/min. Seventy percent of the children could not reach the target HR. In all age groups, the HR_{max} was on average 81.8±8.3% of the target HR. There was no difference according to sex.

When the SBP response to exercise was evaluated, mean SBP_{max} was found to be 125.16±13.36 mmHg. SBP_{max} was positively correlated with age in the study group as a whole (r=0.99, p=0.0007) and also in boys (r=0.97, p=0.0053) and girls (r=0.97, p=0.005). SBP_{max} increased with increasing ET and exercise workload (for ET: r=0.91, p<0.0001, for exercise workload: r=0.92, p=0.0002) (Tables II, III). Δ SBP was also positively correlated with age (r=0.99,

Table II. Heart Rate and Blood Pressure Responses According to Exercise Time*

Exercise¶ Time (min)	HR_{max}	SBP_{max}	DBP_{max}	RPP_{max}
6	156±30	110±14	65±7	16890±1146
7	171±1	97±6	67±6	17833±2902
9	151±20	111±5	71±7	16725±2080
10	163±21	117±16	69±9	19373±4139
11	164±15	110±10	66±7	17735±2122
12	169±16	124±19	74±8	20737±3861
13	168±15	132±16	77±6	21548±3563
14	168±12	131±16	75±7	22046±3117
15	175±17	132±16	75±7	23360±4187
16	169±21	137±9	75±8	23167±3420
17	175±18	137±14	75±6	23920±4350
18	186±13	128±8	74±10	22660±3351
20	184±18	140±0	80±14	24075±4957
21	181±9	148±18	75±14	26773±4451
P value†	p=0.0003	p<0.0001	p=0.0003	p<0.0001
r value†	r=0.82	r=0.91	r=0.82	r=0.94

*Plus-minus values are means±SD.
¶No child had an exercise time of 8 and 19 mins.
†P and r values are for the correlations between the parameter of the related column and exercise time.
HR_{max}: Peak heart rate. SBP_{max}: Peak systolic blood pressure. DBP_{max}: Peak diastolic blood pressure. RPP_{max}: Peak rate pressure product.

Table III. Heart Rate and Blood Pressure Responses According to MET Values*

MET	HR_{max}	SBP_{max}	DBP_{max}	RPP_{max}
5	165±18	102±11	66±6	17456±2192
6	158±21	113±14	69±8	18180±3880
7	164±15	110±10	66±7	17735±2122
8	169±16	128±18	75±7	21142±3859
9	168±12	131±16	75±7	22046±3117
10	174±18	133±15	75±7	23329±4052
12	186±13	128±8	74±10	22660±3351
11	175±18	137±14	75±6	23920±4350
13	184±18	140±0	80±14	24075±4957
14	181±9	148±18	75±14	26773±4451
P value†	p=0.0006	p=0.0002	p=0.005	p<0.0001
r value†	r=0.89	r=0.92	r=0.80	r=0.94

*Plus-minus values are means±SD.
†P and r values are for the correlations between the parameter of the related column and MET value.
HR_{max}: Peak heart rate. SBP_{max}: Peak systolic blood pressure. DBP_{max}: Peak diastolic blood pressure. RPP_{max}: Peak rate pressure product.

p=0.0017). The correlation between ΔSBP and age was present in both boys and girls (boys: r=0.99, p=0.0019; girls: r=0.90, p=0.038). Mean ΔSBP was 24.3±5.96 mmHg.

Peak diastolic blood pressure (DBP_{max}) positively correlated with age (r=0.98, p=0.0028). This correlation was present only in girls (girls: r=0.94, p=0.019). Mean DBP_{max} was 73.32±4.06 mmHg. There were positive correlations between DBP_{max} and ET (r=0.82, p=0.0003) and DBP_{max} and workload (r=0.80, p=0.005) (Tables II, III). However, there was no significant increase in ΔDBP with increasing age. Mean ΔDBP was 7.2±6.9 mmHg.

When RPP_{max} was evaluated, there was a significant correlation with age in the whole study group (r=0.94, p=0.018) and in boys (r=0.97, p=0.0055) and girls (r=0.93, p=0.022) separately. There was a linear correlation between RPP_{max} and ET (r=0.94, p<0.0001) and RPP_{max} and MET value (r=0.94, p<0.0001). Mean RPP_{max} was 21504.7±2176.4. There was no significant difference in RPP_{max} between boys and girls.

Arrhythmia with exercise was seen in 8 children (5 girls, 3 boys). Five of those had frequent atrial premature beats and 3 had ventricular premature beats with exercise. One child had a transient right bundle branch block (RBBB). All of the children had taller P and T waves with exercise and none had ischemic ST depression.

Discussion

Treadmill exercise testing for children ≥4 years of age is an easily applicable, cheap and low- risk stress test. Symptoms and signs undetectable at rest may become manifest with exercise. In dynamic exercises, the cardiovascular response is correlated with the rigorousness of the exercise. ET shows the personal performance in a staged test[1]. ET is evaluated according to sex and age. The functional capacity of the subject is determined by comparison with healthy people of the same age and sex. Cumming[5] applied maximal exercise testing using the Bruce protocol to 715 healthy children and 830 children with congenital heart disease (age range: 5-18). They found an ET of 10-17 min in healthy boys and 9-14 min in healthy girls, and also reported an increase in ET with habitual exercising. In another study by Cumming et al.[6], 327 children aged 4-18 underwent exercise testing and the mean ET for boys was 10.4±1.9 min in the 4-5-year-old group, 11.8±1.6 min in the 6-7-year-old group, 12.6±2.3 in the 8-9-year-old group, 12.7±1.9 in the 10-12-year-old group, and 14.1±1.7 in the 13-15-year-old group, while mean ETs for girls were 9.5±1.8, 11.2±1.5, 11.8±1.6, 12.3±1.4, and 11.1±1.3 in the 4-5, 6-7, 8-9, 10-12, and 13-15-year-old groups, respectively. Maffulli et al.[8] applied exercise testing using the Bruce protocol to 140 boys and 140 girls and showed that ET increased with increasing age in older age groups.

The ETs for boys and girls were reported as 15.2±2.8 min and 13.7±2.3 min, respectively. Riopel et al.[9] in their study done with 288 healthy children and young adults aged 4-21 found an ET of 10.1±1.3 min (boys: 10.6±1, girls: 8.9±0.3 min). In our study, we also found an increasing ET with increasing age.

Brooks[10] reported that exercise capacity and maximal oxygen expenditure increase with age and that this increase accelerates during puberty and is greater in boys. Cumming et al.[5,6] in their two studies showed that oxygen consumption increases with age, and unless there is serious heart disease, the exercise capacity is not restricted and increases with regular training. In our study, we also found a linearly increasing MET value with increasing age in both boys and girls.

Maximum heart rate attained (HR_{max}) shows the level of aerobic capacity. In children aged 5-16, mean HR_{max} is reported as 180±10/min[4]. Cumming et al. in one study[5] found a mean HR_{max} of 193-206/min and showed a linear relationship between ET and HR_{max}. In their other study, 89% of the children had a HR_{max} >180/min[6]. Riopel et al.[9] reported a mean HR_{max} of 187±14/min. They found no difference between boys and girls. Bruce et al.[11] in their study done with 405 healthy children and 137 children with heart disease found a mean HR_{max} of 192±10/min in the healthy group. Although the reported mean HR_{max} is 180±10/min, we found a value of 171.46±1.91/min. Only the children that could reach an ET of 18 min and a workload of 12 METs reached a mean HR_{max} of 180/min. We found no difference between the two sexes. When the target HR was calculated with the (220-age) x 0.85 formula, 70% of the children could not reach that target HR. When the formula was modified as (200-age) x 0.85, 90% of the children attained the target HR. Therefore, the latter formula is thought to be more suitable to predict the target HR in children. There were positive relationships between HR_{max} and ET and MET value. ΔHR increased with increasing age in both boys and girls.

The increase in SBP with exercise increases with age. This increase is more prominent during puberty[10]. SBP increases progressively with increasing ET and workload. SBP_{max} rarely reaches 200 mmHg in children[1]. Riopel et al.[9] reported an increasing SBP_{max} with increasing age and body surface area (BSA). James et al.[12] in 149 children and young adults aged 5-33 (mean: 14.5) found a parallel increase in SBP_{max} with increasing age and BSA. Bruce et al.[11] evaluated the exercise tests of 405 healthy children and 137 children with heart disease and reported a SBP_{max} of 145±26 mmHg in healthy children. Maffulli et al.[8] in their study of 280 children aged 4-17 showed that the SBP_{max} increases with increasing exercise workload. We found a SBP_{max} of 127.3±17.3 mmHg in our study. Linear correlations were found between SBP_{max} and age, ET and exercise workload, and no difference was seen among boys and girls. ΔSBP also increased with increasing age, but this was statistically significant only in boys.

The normal DBP response to exercise is not definitely known because of the insufficient number of studies reported, but in those studies performed, no excessive increase in DBP is reported. We found an increase in DBP_{max} with increasing age, ET and workload in both boys and girls. No relationship was found between ΔDBP and age, ET and workload.

Rate-pressure product (RPP), also known as double-product, is accepted as an indicator of myocardial oxygen consumption. In healthy people, RPP changes in accordance with increased myocardial blood flow and oxygen consumption during exercise. Riopel et al.[9] found increasing RPP_{max} values with increasing age and BSA in healthy children of both sexes. Maffulli et al.[8] found a similar increase with age and also reported a greater RPP_{max} in boys. In our study, RPP_{max} also increased with age but no significant difference in RPP_{max} was found between boys and girls.

The finding of negative T waves in V1 to V4 on the resting ECG is physiological until the ages of 8 to 10 (juvenile ECG). Between the ages 8-16, both the adult type QRS complexes and juvenile pattern can be seen[12]. In our study, all of the children aged 5 to 8 and 122 of the 178 children (68%) aged 9 to 14 showed a juvenile ECG pattern. In healthy adults, the physiological depression of the ST segment with exercise quickly disappears (in 80 msec), i.e. it is commonly upsloping and not downsloping or horizontal[13]. Furthermore, in children, a normal J point depression can be observed during exercise. In their study done with healthy black children, Thapar et al.[14], using the PQ isoelectric line method, found J point depression with exercise in 9% of the boys and 18% of the girls. In the same study, with PR isoelectric line method, they found a physiological J point depression in 2.3% of the children. Riopel et al.[9] reported that the T wave amplitude increased and the J point was depressed with exercise in all of the 288 healthy children studied, and none of the children had ischemic ST depression. We also found increased P and T wave amplitudes. Twenty-one percent of the children had J point depression. Maffulli et al.[8] reported an increase in P and T wave amplitudes in all of the 280 healthy children studied; no child had ST depression and 78% had J point depression, 11% had J point elevation and 11% had no J point shift.

Bundle branch blocks and ventricular arrhythmias are rarely seen in children without heart disease[13]. Eight of the children had arrhythmia and one child had a transient RBBB with exercise.

In conclusion, the means±SD values for ET, workload, HR_{max}, ΔHR, SBP_{max}, DBP_{max}, ΔSBP, ΔDBP and RPP_{max} were 13.18±1.4 min, 8.56±0.93 MET, 171.46±1.91/min, 67.22±6.65/min, 125.16±13.36 mmHg, 73.32±4.06 mmHg, 24.3±5.96 mmHg, 7.2±6.9 mmHg, and 21504.7±2176.4, respectively. These values may be accepted as reference values of healthy Turkish children for exercise testing. The formula modified as (200-age) x 0.85 is thought to be more suitable to predict the target HR in children.

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