Resting Electrocardiogram and Blood Pressure in Young Endurance and Non-Endurance Athletes and Non-Athletes

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Context: There is plenty of information on electrocardiogram (ECG) and blood pressure (BP) changes in senior athletes. However, a corresponding data in adolescent athletes are scarce.

Objective: To study the differences in resting ECG and BP between adolescent endurance athletes, non-endurance athletes, and non-athletes.

Design: Cross-Sectional Study

Setting: A total of 154 youth sports clubs from COUNTRY-XXX and 100 secondary schools for comparison data.

Patients or Other Participants: We recruited young athletes (n=410) aged 14-16 among 10 popular sport disciplines, including both winter and summer as well as team and individual sports, and categorized them as “endurance sports” or “non-endurance sports”. Comparison data composed of age-matched non-sports club participants (n=164) collected via secondary schools.

Main Outcome Measure(s): Resting ECG including heart rate, PR interval, QRS duration, QRS axis, QRS amplitude, T axis and QT interval as well as systolic and diastolic blood pressure from all participants.

Results: No differences in any ECG variable of interest was found between the endurance and non-endurance athletes. The PR interval was longer in endurance athletes than in non-athletes (P = .05).

The QRS amplitude (P = .03) was higher among non-endurance athletes than in non-athletes.

Diastolic BP among endurance (P = .002) and non-endurance (P = .02) athletes was lower than non-athletes. Endurance athletes (OR 2.85, 95% CI 1.81-4.50) and non-endurance athletes (OR 2.19, 95% CI 1.43-3.55) were more likely to have sinus bradycardia than non-athletes. Non-endurance athletes were more likely to have elevated systolic BP than endurance athletes (OR 1.70, 95% CI 1.07-2.72) and non-athletes (OR 1.73, 95% CI 1.04- 2.87).
Conclusions: Young athletes mainly have similar ECG and BP findings independent of the sport. Particular physiological adaptations like sinus bradycardia, higher QRS amplitude and lower diastolic BP, commonly found in adult athletes, are visible also among adolescent athletes.

Key Words: electrocardiogram, blood pressure, pulse pressure, endurance athletes, non-endurance athletes

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Key Points:

- Young athletes exhibit similar ECG findings independent of the sport.
- Non-endurance athletes were more likely to have elevated systolic blood pressure than endurance athletes, but diastolic blood pressure and pulse pressure levels were similar independent of the sport.
- Particular physiological adaptations such as sinus bradycardia, higher QRS amplitude and lower diastolic BP, which reflect commonly found ECG and BP patterns in adult athletes, are visible already in adolescent athletes.
Regular exercise in athletes causes adaptive structural and functional changes within the heart. These consist principally of pronounced cardiac vagal tone and an increase in cardiac dimensions which are reflected on the surface 12 lead electrocardiogram (ECG) in the form of sinus bradycardia, left ventricular hypertrophy (LVH), and depolarisation and repolarisation changes along with other common electrical changes, especially in the anterior leads. However, there are few data assessing training-induced ECG changes in adolescent athletes. In a study of 1710 highly trained athletes aged 14-18 years, the PR-interval, QRS, and corrected QT duration were more prolonged in athletes than non-athletes. Furthermore, in the same study Sokolow-Lyon voltage criterion for LVH and sinus bradycardia were more common in athletes. Similarly, higher prevalence of LVH on voltage criteria and a lower resting heart rate (HR) were observed in 13-19 year old elite tennis players compared to non-athletes.

Regular exercise is also associated with reductions in blood pressure (BP) in the general population, however elevated BP is one of the most common cardiovascular abnormalities encountered in athletic populations. Highly trained young athletes may have “spurious systolic hypertension” characterized by an elevated brachial systolic BP and pulse pressure but a normal diastolic BP. This is still a non-pathologic finding resulting from an increased cardiac stroke volume combined with highly elastic arteries and a low peripheral vascular resistance. Previously, none of the 1710 highly trained 14-18 year old athletes had a systolic BP exceeding 120 mmHg or a diastolic BP exceeding 80 mmHg. Additionally, in another study highly trained 13-19 year old players actually had lower systolic and diastolic BP readings compared to controls.

Whereas there is a significant amount of information on ECG and BP changes in senior athletes, there is a striking lack of data on ECG and BP differences in adolescent athletes. Our aim was to define ECG and BP differences in adolescent endurance and non-endurance athletes and non-athletic age-matched controls.

METHODS

Between August 2013 and April 2014, 410 athletes and 164 non-athletes aged 14-16 years underwent a cardiac evaluation as part of the multicentre Finnish Health Promoting Sports Club (HPSC) study. The study concept and design have been previously reported in detail. Evaluation was comprised
of a validated health questionnaire relating to training activity and presence of cardiac symptoms; and cardiovascular examination including resting 12-lead ECG examination and BP measurements.

Ethical approval was received from the Ethics Committee of Health Care District of Central COUNTRY-XXX. Written informed consent was obtained from both a parent/guardian and the subject.

**Athletes**

A total of 240 youth sports clubs from 10 most popular sports disciplines in COUNTRY-XXX were targeted to produce a nationally representative sample of the most popular team and individual youth sports. Sports that have their main competition season in the winter were basketball, cross-country skiing, floorball, ice hockey and skating. Summer sports were soccer, gymnastics, orienteering, swimming, and track and field. Of the invited sports clubs, 154 agreed to participate in the study. In the present study, cross-country skiing, soccer, orienteering and swimming were categorized as “endurance sports” (n=169) and other disciplines as “non-endurance sports” (n=241).

The sampling of the athletes being a member of sports club was tailored separately to team and individual sports and had some differences between winter and summer sports depending on the timing of the data collection. Our aim was to collect both winter and summer sports data during competition periods. Some questions were related to the ongoing season and thus, specific goal was to time data collection after the midpoint of the competition period. Unfortunately, this did not always come true and we collected additional data just after the competition period.

The targeted athletes were 15 year old (9th graders). The athletes were randomly sampled from a list of eligible subjects (based on age) of a given team. For individual sports, the athletes were similarly randomly sampled from a list of all eligible subjects. Randomization was performed so that every third subject from the list was picked. If the number of athletes was small (more typical in the individual sports than team sports), it was possible that almost everyone was invited. Initially, five boys and five girls per club were aimed for. This target was, however, reduced to three per gender in the individual sports clubs because of the insufficient number of eligible athletes in some clubs.
Based on responses ascertained from the health questionnaire, none of the athletes had prior symptoms suggestive of underlying cardiac disease, and none of the subjects were taking any medications relevant considering the present study.

**Non-athletes**

Comparison data for non-sports club participant controls was collected via secondary schools (9th grades) approximately within the same timeframe as with athletes. The schools were stratified as per: 1) size of school (large vs. small), and 2) area type (city vs. countryside). Initially, the aim was to convenience sample 10 schools over the strata separately in each six district of the Sports Medicine Centres. However, because of insufficient number of small or countryside-based schools willing to participate in the study in some districts, the goal of 60 schools could not quite be achieved. In each school, non-sport club participant controls from one randomly selected class of 9th graders were then asked to participate in the cardiac evaluation.

The non-athletes were healthy asymptomatic adolescents who were matched with athletes with respect to age based on the school class. Like the athletes, none of the non-athletes had prior symptoms suggestive of underlying cardiac disease, and none of the subjects were taking any relevant medications.

**12 lead electrocardiogram**

A standard 12-lead resting ECG was recorded from all subjects after a 5 min rest during quiet respiration in a supine position. The electrodes were placed carefully to ensure consistency in the precordial lead locations, and ECGs were recorded at a paper speed of 25 mm/s with a 10 mm/mV gain. Seven quantitative ECG measurements, that are believed to be correlates of heart rate, conduction, left ventricular mass, and repolarization, were extracted for each subject: heart rate (HR); PR interval; QRS duration and axis; the sum of S wave amplitude in lead V1 and the maximum R wave in lead V5 or V6; T axis; and QT interval. Amplitudes were recorded to the nearest 100th of a millivolt and times to the nearest millisecond. HR, QRS- and T axis, QRS duration and PR- and QT interval were analyzed digitally using each ECG recorder’s own software. The S wave in V1 and the R wave in V5 and V6 were measured using a millimeter ruler. The digital ECG measures were...
reviewed independently by a separate physician in each Sports Medicine Centre and manual measurements were taken using calipers and a ruler on demand.

Sinus bradycardia was defined as HR below 60 beats per minute. Prolonged and short PR intervals were defined as a PR interval longer than 200 milliseconds or shorter than 120 milliseconds, respectively. QRS complex was considered as abnormally widened if longer than 120 milliseconds.

Left and right QRS-axis deviations were defined as a QRS axis more negative than 0° or more positive than +110°, respectively. Left and right T axis deviations were defined as a T axis more negative than -15° or more positive than +105°, respectively. QT-interval was corrected for HR (QTc) using the Bazett’s formula. QTc interval was considered abnormally prolonged if longer than 460 milliseconds. LVH was identified using the Sokolow-Lyon voltage amplitude criterion: the sum of the S wave in V1 and higher of the R waves in V5 or V6 exceeding 3.5 mV.

**Resting blood pressure**

Resting BP was measured in a sitting position from the left arm after a 5 min rest. The measurement was performed with a similar validated, cuff-style oscillometric (automated) device (Omron M6W, Kyoto, Japan) in each Sports and Exercise Centre. A correct-sized brachial cuff was placed with the lower edge about two to three centimeters above the elbow crease. The device recorded the oscillations of pressure in a cuff during gradual deflation, and systolic and diastolic BP was estimated indirectly according to empirically derived algorithm. Two independent consecutive measurements were taken at interval of 1 min. If there was >10 mmHg difference in systolic or diastolic BP between the first and second measurements, the third reading was obtained after interval of 1 min. The pulse pressure (PP) was calculated as the difference between systolic and diastolic BP. Elevated BP was defined equal or higher than 120 mmHg or equal or higher than 80 mmHg for systolic and diastolic BP, respectively.

**Statistical analysis**

Means and standard deviations (SD) were calculated for continuous variables. The distribution of dichotomous variables are shown as frequencies and percentages. The mean body surface area was calculated using the formula of Du Bois and Du Bois.
Comparisons between endurance and non-endurance athletes, between endurance athletes and non-athletes, and non-endurance athletes and non-athletes were performed by using multilevel modeling which was conducted by means of the mixed models linear and binary logistic multilevel analysis in SPSS software, version 25 (SPSS Inc., Chicago, IL, USA). Multilevel modeling was used to appropriately allow for correlated data due to: 1) cluster sampling (clubs for athletes, classes for non-athletes); and 2) different ECG recorders used in six Sports Medicine Centres. Three-level data structure was constructed, the subjects being level 1, the clubs and classes being level 2, and the Sports Medicine Centres being level 3. As there are many choices among models to fit to a given data set with three-level data structure, we used Bayesian information criterion (BIC) as a measure of model adequacy. The BIC number penalises the likelihood of the observed data based on the total number of parameters in a model with a lower BIC indicating a better model with a better balance between complexity and good fit. We fitted several models for each continuous and dichotomous ECG variable as a dependent variable and we predeterminedly chose the model with the lowest BIC as our final model for a given variable. That is, we did not force the three-level data structure to our model in case when it did not improve the model fit but instead brought on unnecessary complexity to the model. The final models chosen for each ECG and BP variable are shown in Supplements 1a and 1b. The results of the final binary logistic models are presented as odds ratios (OR) and their 95% confidence intervals (CI).

The assumption of normal distribution was confirmed by visual inspection for each continuous variable. All statistical analyses were two sided, and a probability value (P value) of less than .05 was considered significant.

RESULTS

The mean age of the athletes was 15.5 ± 0.6 years, they competed mostly at the national (52.6%) or regional (26.4%) level, and 51.5% of them were female. The mean amount of training per athlete was similar during the preparation and competitive periods; approximately 9.5 hours of training per week. The mean age of the non-athletes was also 15.5 ± 0.5 years and 66.5% of them were females.

Height, weight and body surface area of the endurance and non-endurance athletes according to sport discipline are shown in Table 1. There was no difference in height between endurance and non-
endurance athletes, but non-endurance athletes were on average 3.1 cm taller than non-athletes (P < .05, 95% CI 1.3-5.0). Non-endurance athletes were on average 2.5 kilograms heavier than endurance athletes (P < .05, 95% CI 0.3-4.8). The mean body surface area of non-endurance athletes (1.73 m$^2$) was larger (P < .05) when compared to endurance athletes (1.69 m$^2$) and non-athletes (1.69 m$^2$) (Table 1).

**Electrocardiogram in athletes and non-athletes**

Resting ECG characteristics of endurance athletes, non-endurance athletes and non-athletes are presented in Table 2. There were no differences in the mean resting heart rate, PR interval, QRS duration, QRS axis, QRS amplitude, T axis or in corrected QT interval between endurance and non-endurance athletes (P > .05). The resting heart rate of endurance (P < .001) and non-endurance (P < .001) athletes was lower than in non-athletes. The PR interval was longer in endurance athletes than in non-athletes (P = .05). The QRS amplitude was higher in non-endurance athletes (P = .03) but not in endurance athletes (P = .06) when compared to non-athletes (Table 2).

Sinus bradycardia (OR 0.77, 95% CI 0.52-1.14), LVH (0.94, 0.60-1.48), short PR interval (1.33, 0.85-2.10), prolonged PR interval (0.97, 0.61-1.52), left QRS axis deviation (0.69, 0.27-1.77), right QRS axis deviation (0.96, 0.61-1.52), prolonged corrected QT interval (1.09, 0.69-1.72), widened QRS complex (1.02, 0.65-1.61), left T-axis deviation (1.02, 0.65-1.61), left anterior hemiblock (0.97, 0.62-1.53) and left posterior hemiblock (0.99, 0.63-1.56) were equally prevalent among endurance and non-endurance athletes. Endurance athletes (2.85, 1.81-4.50) and non-endurance athletes (2.19, 1.43-3.35) were more likely to have sinus bradycardia than non-athletes (Table 2).

**Interaction analyses**

We also studied the modifying effect of gender on the differences in ECG variables between study groups. We performed three different interaction analyses per variable to study whether gender modifies the difference between endurance athletes and non-endurance athletes, the difference between endurance athletes and non-athletes and the difference between non-endurance athletes and non-athletes. Gender modified the difference in resting heart rate between non-endurance athletes and non-athletes (P = .04). The mean difference in resting heart rate between non-endurance athletes and non-athletes was 7.5 (± 1.6) and 2.6 (± 1.6) beats per minute in males and females, respectively.
Similarly, gender modified the difference in bradycardia between non-endurance athletes and non-athletes (P = .03). No other interactions were found. ECG characteristics in boys and girls are presented in Supplement 2.

**Blood pressure in athletes and non-athletes**

The resting BP of endurance athletes, non-endurance athletes, and non-athletes is presented in Table 3. In endurance athletes, systolic BP varied from 88 to 145 mmHg and diastolic BP from 45 to 82 mmHg. Corresponding values in non-endurance athletes were from 82 to 145 mmHg and from 43 to 86 mmHg. In non-athletes, systolic BP varied from 90 to 145 mmHg and diastolic BP from 48 to 90 mmHg. Pulse pressure varied from 11 to 77 mmHg in endurance athletes, and the corresponding values for non-endurance athletes and non-athletes were from 21 to 84 mmHg and from 19 to 83 mmHg.

There were no differences in systolic BP, diastolic BP or pulse pressure between endurance and non-endurance athletes (P > .05) (Table 3). Systolic BP was higher in non-endurance athletes than in non-athletes (P = .04). Diastolic BP in endurance (P = .002) and non-endurance (P = .02) athletes was lower than in non-athletes. The pulse pressure in non-endurance athletes was higher than in non-athletes (P = .04), but there was no difference between endurance athletes and non-athletes (P = .07).

Non-endurance athletes were more likely to have elevated systolic BP than endurance athletes (OR 1.70, 95% CI 1.07-2.72) and non-athletes (OR 1.73, 95% CI 1.04- 2.87). There was no difference in the prevalence of elevated diastolic BP between groups (Table 3). Gender did not modify the difference in any of the BP variables (P >.05).

**DISCUSSION**

The results of the present study suggest that ECG findings in adolescent athletes are similar regardless of the sport. However, resting heart rate was lower in endurance and non-endurance athletes than in non-athletes and both endurance and non-endurance athletes had sinus bradycardia more often than non-athletes. Furthermore, non-endurance athletes had a higher QRS amplitude compared to non-athletes. Endurance athletes had a longer PR interval than non-athletes.

Adolescent non-endurance athletes were more likely to have elevated systolic BP compared to endurance athletes and non-athletes. Diastolic BP was lower in both endurance and non-endurance...
athletes when compared to non-athletes. Pulse pressure was higher in non-endurance athletes than in non-athletes. A recent review including mostly young athletes reported lower systolic and diastolic BP in endurance-trained athletes compared to strength-trained athletes. Although non-endurance athletes in our study do not represent solely strength-trained athletes, our results are mainly in line with the review. However, in contrast to our findings, there was no significant difference in BP between athletes and non-athletes. In the same review, a trend towards a higher BP in athletes training more than 10 hours per week compared to those who trained less was seen.

The findings of this study yield further information for the professionals interpreting ECG and blood pressure findings of the young athletes. It is already known that young athletes have different ECG findings than non-athletes. Changes in the athletes ECG result mainly from the cardiac hypertrophy due to pressure and volume overload. According to current knowledge, these differing findings are thought to result mainly from endurance-type training. However, results of this study suggest that besides endurance athletes, changes in ECG may be visible also in adolescents participating other than endurance-type sports. While healthcare professionals should take into account the athlete status itself, the nature of the sport discipline may be less important. Importantly, due to the observational nature of the present study, we are not able to provide guidelines to classify particular ECG finding as abnormal guiding further evaluation or granting safe clearance for participation.

**ECG findings**

Resting heart rate did not differ between endurance and non-endurance athletes, but was significantly lower in both groups when compared to non-athletes. The latter finding is consistent with previous observations in young athletes. In the present study, sinus bradycardia was more prevalent in endurance and non-endurance athletes than in non-athletes. The most pronounced ECG features have usually been seen in endurance athletes and bradycardia was expected in that group. However, non-endurance athletes also exhibited bradycardia. This is not surprising considering that some sport disciplines categorized as non-endurance sports included “endurance-like” characteristics. Up to half of male adult athletes have been shown to exhibit Sokolow-Lyon voltage criteria for LVH and LVH has been commonly seen in young athletes also. In the present study, LVH was
more prevalent in athletes than non-athletes, but the difference was not statistically significant. However, non-endurance athletes had higher QRS amplitudes compared to the non-athletes and the association was on borderline significance also between endurance athletes and non-athletes. This suggests that also adolescent athletes exhibit thickening of the left ventricular myocardium. Our finding that adolescent endurance athletes had longer PR intervals than non-athletes is consistent with previous findings in adolescents \(^1\)\(^{,18} \)\(^{,19} \) as well as in pre-pubertal children \(^{19} \)\(^{,20} \). We did not see difference in QRS duration or in QT interval between athletes and non-athletes. There is inconsistency in the literature concerning QRS duration and QT interval: some studies have found differences \(^3\)\(^{,16} \)\(^{,17} \) between athletes and non-athletes while others have not \(^{17-19} \)\(^{,18-20} \). While this is the first study to compare the ECG findings between adolescent endurance athletes and non-endurance athletes, ECG findings have been extensively studied in adult athletes. Over half of the adult athletes demonstrate ECG changes such as sinus bradycardia, sinus arrhythmia, first-degree atrioventricular block, early repolarisation, incomplete right bundle branch block and voltage criteria for LVH \(^2\). Compared to adult athletes, young athletes more rarely present distinctly abnormal ECGs \(^{20-21} \). ECG findings observed in adult athletes may reflect structural changes which have developed as a result of long-term training, while such prominent changes probably do not occur in adolescent athletes with fewer years of training.

**Blood pressure and pulse pressure findings**

Resting systolic and diastolic BP were mostly at a low-normal level in endurance and non-endurance athletes consistently with previously studied young athletes \(^13\). On the other hand, children reporting more endurance type physical activity have displayed higher systolic BP and pulse pressure levels compared to sedentary children \(^{21} \)\(^{,22} \). Especially intense physical activity correlated directly to systolic BP and pulse pressure \(^{21} \)\(^{,22} \), yet opposite results exist \(^13\).

A low prevalence of elevated BP in the present study is in line with a recent report which showed a low (3%), prevalence of hypertension in young adults who were engaged in competitive sports \(^{22} \)\(^{,23} \). In general population, elevated BP was reported in 11% of young adults \(^{23} \)\(^{,24} \), largely related to family history and overweight. The prognostic significance of high BP in athletes is still unknown \(^13\).
although a high-normal level of resting blood pressure predisposed for future hypertension in middle-aged men with exaggerated increase of BP during exercise \(^{24, 25}\).

As expected, average pulse pressure was normal in all study groups, while there were some high values also. Although physical activity play an important role in the prevention of high pulse pressure, the dose-response relation between physical activity and BP in adolescents is unknown \(^{21, 22}\). Within optimal BP values pulse pressure remains approximately between 40 to 45 mmHg showing good elasticity of large arteries in adults. Pulse pressure typically rises gradually due to stiffening of large arteries during aging which predicts risk of coronary heart disease \(^{25, 26}\).

**Strengths and limitations**

The major strength of this study is a representative and relatively large sample from different regions of COUNTRY-XXX including 10 most popular sport disciplines in COUNTRY-XXX. The number of athletes in the study was greater than the amount of non-athletes because we wanted to include participants of both summer and winter sports as well as individual and team sports. Further, we used multilevel modeling which accounts clustering of observations inside separate clubs for athletes and classes for non-athletes, as well as possible clustering inside six separate Sports Medicine Centres. The use of regular single-level regression techniques to address multilevel issues is liable to errors originating from various violations of the regression assumptions which may lead to poorly estimated results. Our robust classification to categorize sport disciplines as “endurance sports” and “non-endurance sports” allowed us to compare ECG findings in adolescent athletes across the different types of sports. However, this study encompasses only ten the most popular sports for youth in COUNTRY-XXX and our results are not generalizable beyond them. Other limitations include the cross-sectional nature of this study which does not make it possible to draw any inferences about causality. In addition, the present study was partly based on self-reported questionnaire data. There is a possibility for recall bias, because with retrospective designs the ability of the subject to remember and report the information correctly is a potential issue.

The findings of this study yield further information for the professionals interpreting ECG and blood pressure findings of the young athletes. It is already known that young athletes have different ECG findings than non-athletes \(^{3, 4}\). While it is important to be aware of the athlete status itself, the results of
this study suggests that the nature of the sport discipline may be less important. However, this study encompasses only ten the most popular sports for youth in COUNTRY-XXX and our results are not generalizable beyond them. Please see the modified version of this paragraph at the beginning of the discussion section.

In conclusion, young athletes mainly exhibit similar ECG findings as well as blood pressure and pulse pressure levels independent of the sport, but differences emerge when compared to the non-athletes. Particular physiological adaptations such as sinus bradycardia, higher QRS amplitude and lower diastolic BP, which reflect commonly found ECG and BP patterns in adult athletes, are visible already in adolescent athletes.
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Table 1. Height, Weight and Body Surface Areas of the Endurance and Non-Endurance Athletes According to a Sport Discipline

| Sport discipline          | No. (%) | Height, cm | Weight, kg | Body Surface area, m² |
|---------------------------|---------|------------|------------|-----------------------|
| Endurance sports          |         |            |            |                       |
| Cross-country skiing      | 38 (9.3)| 169.1 ± 6.5| 57.7 ± 8.3 | 1.66 ± 0.14           |
| Soccer                    | 50 (12.2)| 170.9 ± 8.0| 59.1 ± 8.5 | 1.69 ± 0.15           |
| Orienteering              | 41 (10.0)| 169.4 ± 7.3| 58.4 ± 8.1 | 1.67 ± 0.13           |
| Swimming                  | 40 (9.8)| 171.6 ± 5.9| 64.4 ± 8.9 | 1.76 ± 0.14           |
| Non-endurance sports      |         |            |            |                       |
| Basketball                | 39 (9.5)| 177.6 ± 8.5| 67.5 ± 8.3 | 1.84 ± 0.15           |
| Floorball                 | 42 (10.2)| 175.7 ± 7.0| 64.0 ± 9.0 | 1.78 ± 0.15           |
| Ice hockey                | 39 (9.5)| 174.1 ± 6.1| 65.1 ± 9.2 | 1.78 ± 0.14           |
| Skating                   | 34 (8.3)| 165.1 ± 6.1| 57.1 ± 7.2 | 1.62 ± 0.12           |
| Gymnastics                | 45 (11.0)| 165.4 ± 7.0| 58.0 ± 8.8 | 1.63 ± 0.14           |
| Track and field           | 42 (10.2)| 171.9 ± 7.9| 62.6 ± 8.2 | 1.74 ± 0.14           |

Values are number (%) or mean ± SD.
Table 2. Resting Electrocardiogram Characteristics in the Endurance Athletes, Non-Endurance Athletes and Non-Athletes

| ECG variable                | Endurance Athletes (n=169) | Non-Endurance Athletes (n=241) | Non-Athletes (n=164) |
|-----------------------------|-----------------------------|--------------------------------|----------------------|
| Continuous variables        |                             |                                |                      |
| Heart rate, beats/min       | 60.0 ± 8.9                  | 61.0 ± 10.7                    | 66.6 ± 12.1          |
| PR interval, ms             | 150.6 ± 20.5                | 148.9 ± 22.4                   | 146.2 ± 19.0         |
| QRS duration, ms           | 91.4 ± 9.2                  | 92.0 ± 10.2                    | 89.4 ± 8.3           |
| QRS axis, degrees           | 64.6 ± 32.4                 | 65.0 ± 21.9                    | 65.1 ± 26.6          |
| T axis, degrees             | 35.7 ± 16.6                 | 36.7 ± 14.8                    | 38.2 ± 15.7          |
| Corrected QT interval, ms   | 415.2 ± 25.6                | 413.4 ± 34.7                   | 414.2 ± 23.7         |
| QRS amplitude, mm           | 27.0 ± 8.3                  | 27.2 ± 8.3                     | 23.6 ± 7.1           |
| Dichotomous variables       |                             |                                |                      |
| Sinus bradycardia, n (%)    | 89 (52.7)                   | 111 (46.1)                     | 46 (28.0)            |
| Prolonged PR interval, n (%)| 4 (2.4)                     | 4 (1.7)                        | 1 (0.6)              |
| Widened QRS complex, n (%)  | 0 (0.0)                     | 1 (0.4)                        | 0 (0.0)              |
| Left QRS axis deviation, n (%)| 7 (4.1)                     | 4 (1.7)                        | 3 (1.8)              |
| Right QRS axis deviation, n (%)| 2 (1.2)                    | 1 (0.4)                        | 0 (0.0)              |
| Left T axis deviation, n (%)| 0 (0.0)                     | 1 (0.4)                        | 0 (0.0)              |
| Prolonged corrected QT interval, n (%)| 9 (5.3) | 17 (7.1)                  | 4 (2.4)              |
| Left ventricular hypertrophy, n (%)| 26 (15.4)        | 34 (14.1)                   | 14 (8.5)             |
| Short PR interval, n (%)    | 2 (1.2)                     | 17 (7.1)                       | 9 (5.5)              |
| Left anterior hemiblock, n (%)| 1 (0.6)                     | 0 (0.0)                        | 0 (0.0)              |
| Left posterior hemiblock, n (%)| 1 (0.6)                    | 1 (0.4)                        | 0 (0.0)              |

Values are mean ± SD or number (%).
Table 3. Resting Blood Pressure in the Endurance Athletes, Non-Endurance Athletes, and Non-Athletes

|                          | Endurance Athletes (n=169) | Non-Endurance Athletes (n=241) | Non-Athletes (n=164) |
|--------------------------|----------------------------|-------------------------------|---------------------|
| Continuous variable      |                            |                               |                     |
| Systolic blood pressure, mmHg | 114.3 ± 9.7                | 115.7 ± 10.6                  | 113.5 ± 10.2        |
| Diastolic blood pressure, mmHg | 64.1 ± 7.1                 | 64.8 ± 7.8                    | 66.1 ± 7.8          |
| Pulse pressure, mmHg      | 47.4 ± 9.8                  | 48.0 ± 10.0                   | 44.9 ± 9.7          |
| Dichotomous variable     |                            |                               |                     |
| Elevated systolic blood pressure, n (%) | 42 (24.9)                  | 87 (36.1)                     | 41 (25.0)           |
| Elevated diastolic blood pressure, n (%) | 4 (2.4)                    | 7 (2.9)                       | 6 (3.7)             |

Values are mean ± SD or number (%).
Supplement 1a. Bayesian Information Criterion-Based Model Selection for Continuous Variables in the Present Study

| Variable | Naive model† | Random intercept at the club / class level‡ | Random intercept at both the club / class and the Center level†† |
|----------|--------------|---------------------------------|-------------------------------------------------------------|
| heart rate | X | | |
| PR interval | X | | |
| QRS duration | X | | |
| QRS axis | X | | |
| T axis | X | | |
| corrected QT interval | X | | |
| the sum of the S wave in V1 and the higher of R waves in V5 or V6 (QRS amplitude) | | X | |
| Diastolic blood pressure | | | X |
| Systolic blood pressure | | X | |
| Pulse pressure | | | X |

† any clustering of data ignored; ‡ the observations of subjects clustered within clubs / classes; †† the observations of subjects clustered within clubs / classes and the observations within clubs / classes clustered in Sports Medicine Centers.

In addition, the following models were tested, but they were not the best models in any of the analyses:

Random intercept at the Center level (the observations of subjects clustered within Sports Medicine Centers)

Random intercept at both the club / class and the Center level and random slope at the Center level (the observations of subjects clustered within clubs / classes and the observations within clubs / classes clustered in Sports Medicine Centers, additionally the difference between athletes and non-athletes allowed to fluctuate between Centers)

Random intercept at the club/class level and random slope at the Center level (the observations of subjects clustered within clubs / classes and the difference between athletes and non-athletes allowed to fluctuate between Centers)

Random intercept at the Center level and random slope at the Center level (the observations of subjects clustered within Sports Medicine Centers and the difference between athletes and non-athletes allowed to fluctuate between Centers)
Supplement 1b. Bayesian Information Criterion-Based Model Selection for Dichotomous Variables in the Present Study (See Methods Section for Definitions of Dichotomous Variables)

| Variable                                | Naive model† | Random intercept at the club / class level‡ |
|-----------------------------------------|--------------|---------------------------------------------|
| Sinus bradycardia                       |              | X                                          |
| Prolonged PR interval                   | X            |                                             |
| Widened QRS complex                     | X            |                                             |
| Left QRS axis deviation                 | X            |                                             |
| Right QRS axis deviation                | X            | X                                          |
| Left T axis deviation                   | X            |                                             |
| Prolonged corrected QT interval         | X            |                                             |
| Left ventricular hypertrophy            | X            |                                             |
| Short PR interval                       | X            |                                             |
| Left anterior hemiblock                 | X            |                                             |
| Left posterior hemiblock                | X            |                                             |
| Elevated systolic blood pressure        | X            |                                             |
| Elevated diastolic blood pressure       | X            |                                             |

† any clustering of data ignored; ‡ the observations of subjects clustered within clubs / classes

In addition, the following models were tested, but they were not the best models in any of the analyses:

Random intercept at the Center level (the observations of subjects clustered within Sports Medicine Centers)

Random intercept at both the club / class and the Center level (the observations of subjects clustered within clubs / classes and the observations within clubs / classes clustered in Sports Medicine Centers)

Random intercept at both the club / class and the Center level and random slope at the Center level (the observations of subjects clustered within clubs / classes and the observations within clubs / classes clustered in Sports Medicine Centers, additionally the difference between athletes and non-athletes allowed to fluctuate between Centers)

Random intercept at the club/class level and random slope at the Center level (the observations of subjects clustered within clubs / classes and the difference between athletes and non-athletes allowed to fluctuate between Centers)

Random intercept at the Center level and random slope at the Center level (the observations of subjects clustered within Sports Medicine Centers and the difference between athletes and non-athletes allowed to fluctuate between Centers)
### Supplement 2. ECG characteristics in boys and girls

|                         | Endurance athletes | Non-endurance athletes | Non-athletes | P value for interaction |
|-------------------------|--------------------|------------------------|--------------|-------------------------|
|                         | Boys (n=75)        | Girls (n=94)           | Boys (n=127) | Girls (n=114)           | Boys (n=56) | Girls (n=108) |
| **Continuous variables**|                    |                        |              |                         |
| Heart rate, beats/min   | 58.0 (7.2)         | 61.6 (9.9)             | 57.6 (9.9)   | 64.9 (10.5)             | 65.1 (10.0) | 67.5 (13.8)   | .04*          |
| PR interval, ms         | 153.6 (18.6)       | 148.3 (21.9)           | 150.5 (23.5) | 147.9 (21.0)            | 145.7 (19.0) | 146.6 (19.3)  | Ns.           |
| QRS duration, ms        | 95.1 (9.3)         | 88.6 (8.1)             | 96.6 (9.7)   | 86.6 (7.4)              | 94.0 (7.8)  | 87.2 (7.8)    | Ns.           |
| QRS axis, degrees       | 62.3 (41.6)        | 66.0 (23.3)            | 63.8 (24.0)  | 65.7 (20.0)             | 62.5 (36.5) | 66.7 (19.8)   | Ns.           |
| T axis, degrees         | 38.7 (16.5)        | 33.7 (16.1)            | 39.4 (16.0)  | 33.4 (12.9)             | 45.8 (15.2) | 34.4 (14.6)   | Ns.           |
| Corrected QT interval, ms | 406.3 (21.1)     | 422.5 (26.6)           | 400.6 (30.3) | 427.8 (34.6)            | 404.3 (24.0) | 420.1 (21.4)  | Ns.           |
| QRS amplitude, mm       | 30.8 (7.8)         | 24.0 (7.0)             | 30.3 (8.6)   | 23.9 (6.9)              | 27.7 (7.4)  | 21.6 (6.1)    | Ns.           |
| **Dichotomous variables**|                    |                        |              |                         |
| Sinus bradycardia, n (%)| 49 (65.3)          | 40 (42.6)              | 74 (58.3)    | 37 (32.5)               | 17 (30.4)   | 29 (26.9)     | .03**         |
| Prolonged PR interval, n (%) | 1 (1.3)            | 3 (3.2)                | 3 (2.4)      | 1 (0.9)                 | 0 (0.0)     | 1 (0.9)       | Ns.           |
| Short PR interval, n (%) | 0 (0.0)            | 2 (2.1)                | 11 (8.7)     | 6 (5.3)                 | 3 (5.4)     | 6 (5.6)       | Ns.           |
| Widened QRS complex, n (%) | 0 (0.0)            | 0 (0.0)                | 1 (0.8)      | 0 (0.0)                 | 0 (0.0)     | 0 (0.0)       | Ns.           |
|                           | n (%)  |
|---------------------------|--------|
| Left QRS axis deviation, n (%) | 6 (8.0) 1 (1.1) 3 (2.4) 1 (0.9) 2 (3.6) 1 (0.9) Ns. |
| Right QRS axis deviation, n (%) | 2 (2.7) 0 (0.0) 0 (0.0) 1 (0.9) 0 (0.0) 0 (0.0) Ns. |
| Left T axis deviation, n (%) | 0 (0.0) 0 (0.0) 1 (0.8) 0 (0.0) 0 (0.0) 0 (0.0) Ns. |
| Prolonged corrected QT interval, n (%) | 0 (0.0) 9 (9.6) 3 (2.4) 14 (12.3) 1 (1.8) 3 (2.8) Ns. |
| Left ventricular hypertrophy, n (%) | 19 (25.3) 7 (7.4) 27 (21.3) 7 (6.1) 10 (17.9) 4 (3.7) Ns. |
| Left anterior hemiblock, n (%) | 1 (1.3) 0 (0.0) 0 (0.0) 0 (0.0) 0 (0.0) 0 (0.0) Ns. |
| Left posterior hemiblock, n (%) | 1 (1.3) 0 (0.0) 0 (0.0) 1 (0.9) 0 (0.0) 0 (0.0) Ns. |

Values are mean ± SD or number (%).

* Gender modified the difference in resting heart rate between non-endurance athletes and non-athletes

** Gender modified the difference in sinus bradycardia between non-endurance athletes and non-athletes