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Resting Electrocardiogram and Blood Pressure in Young Athletes and Non-Athletes: A 4-year follow-up

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Summary

A follow-up data on electrocardiogram (ECG) and blood pressure (BP) changes in adolescent athletes are scarce. We compared ECG and BP between adolescent athletes and non-athletes in a 4-year follow-up. A total of 154 youth sports clubs (SC) in Finland and 100 secondary schools for comparison data participated in this observational follow-up study. Those who maintained or adopted SC participation are referred to as “Always athletes” (n=137), those who never participated in SC as “Never athletes” (n=108) and those who dropped out of SC during the follow-up as “Changers” (n=116). The mean age of the participants was 15.5 (0.6) years in all study groups at baseline. Resting ECG including heart rate, PR interval, QRS duration, QRS axis, QRS amplitude, T axis and QT interval and BP were measured from all participants at baseline and after follow-up. “Always athletes” had lower resting heart rate, more negative T-wave axis and higher QRS amplitude than “Never athletes” at baseline and at 4-years ($P < 0.05$). “Changers” had lower resting heart rate, more negative T-wave axis and higher QRS amplitude, systolic BP and pulse pressure than “Never athletes” at baseline ($P < 0.05$). None of the observed differences at baseline, were visible at 4-years ($P > 0.05$) except the difference in T-wave axis ($P = 0.028$). The significant group x time interaction between “Changers” and “Never athletes” was found for QRS amplitude ($P = 0.017$). Adolescent athletes have several training-induced cardiovascular adaptations, which return towards the levels of non-athletes after cessation of regular training.

Keywords: adolescent athletes, cardiovascular health, heart electric activity, sports clubs, multilevel modelling

INTRODUCTION

Certain structural and functional electrocardiographic (ECG) changes are regularly observed in adult athletes. Sinus bradycardia and arrhythmia, first-degree atrioventricular block, early repolarisation, incomplete right bundle branch block and voltage criteria for left ventricular hypertrophy (LVH) usually reflect benign structural and electrical remodelling of the heart which has developed as a result of regular and sustained training (Drezner et al., 2013). These functional and structural changes are less pronounced in adolescent athletes due to their shorter training history (Baumgartner et al., 2019).

However, certain cardiovascular adaptations to regular physical training are seen also in adolescent athletes. Regular and prolonged physical training is associated with bradycardia, repolarisation changes, atrial enlargement and LVH in pediatric and adolescent athletes (McClean et al., 2018). In 343 adolescent athletes aged 10-15 years, the ECG was normal in 64%, mildly abnormal in 31%, and distinctly abnormal in 4% (Koch et al., 2014). In a highly trained young athletes, the PR-interval, QRS, and corrected QT duration were more prolonged in athletes than non-athletes (Papadakis et al., 2009). Sinus bradycardia and LVH were also more common in athletes (Papadakis et al., 2009). Similarly, lower resting heart rate and higher prevalence of LVH on voltage criteria were observed in adolescent tennis players compared to non-athletes (Basavarajaiah et al., 2007). LVH is also common in children and adolescents with newly diagnosed hypertension (Brady et al., 2008).

Vigorous physical activity is associated with higher systolic BP and pulse pressure (PP) levels in healthy adolescents (Tsioufis et al., 2011). In a large cohort study, one-third of the athletes aged 13-35 years presented with BP levels above the current US guidelines’ thresholds for hypertension (Hedman et al., 2019). Elevated BP in youth is associated with significantly higher risk for subsequent cardiovascular disease later in life (Yano et al., 2018). In a previous study with 723 patients aged 10 to 23 years, transition from normotension to pre-hypertension and further to hypertension led to a graded increase in carotid intima-media thickness, arterial stiffness, and decrease in diastolic function (Urbina et al., 2011).

We recently reported that adolescent athletes mainly exhibit similar ECG findings BP levels independent of the sport, but differences emerge when compared to the non-athletes (Pentikäinen et al., 2021). Here we aim to extend our cross-sectional findings and compare ECG and BP between adolescent sports club (SC) participants and non-participants in a 4-year follow-up.

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 (Kokko et al., 2015). Cardiovascular examination including resting 12-lead ECG examination and BP measurements was performed. Ethical approval was received from the Ethics Committee of Health Care District of Central Finland. The ethical statement required written consent from the participating youth for the questionnaire data, and written consent from a guardian and the adolescent him/herself for the preparticipation screening. The adolescents were notified that they had the right to refuse to participate and could withdraw their consent later without giving a reason.

Based on categorisation of SC participants (coded as 1) and non-participants (coded as 0), at baseline and follow-up *the change in SC participation* was formed through variable containing four groups 1) never participated SC (0,0), 2) dropped out of SC (1,0); 3) adopted SC participation (0,1); and 4) maintained SC participation (1,1). Because of low amount of cases in ‘3) adopted SC participation’ (n=2), the categories 3 and 4 were combined as one ‘maintained or adopted SC participation’. Those who maintained or adopted SC participation are referred as “Always athletes” (n=137), those who never participated SC as “Never athletes” (n=108) and those who dropped out of SC during the follow-up as

“Changers” (n=116). ECG data were missing for two subjects in the “Always athletes” group, for one subject in the “Never athletes” group, and for one athlete in the “Changers” group.

Athletes

A total of 240 youth sports clubs from the 10 most popular sports disciplines in Finland 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.

The sampling of the athletes being a member of SC 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, our 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. Randomisation 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 SC because of the insufficient number of eligible athletes in some clubs.

Non-athletes

Comparison data for non-SC 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.

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 standardised ECG measurements reflecting conduction, left ventricular mass, and repolarisation, 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 (Gorodeski et al., 2009). Amplitudes were recorded to the nearest 10th of a millivolt and times to the nearest millisecond. HR, QRS- and T axis, QRS duration and PR- and QT interval were analysed 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 separate physicians 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 (bpm). 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-wave axis deviations were defined as a T-wave 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. The ECG reference values were based on the Finnish guidelines (Jokinen 2005).

Resting blood pressure

Resting BP was measured in a sitting position from the left arm after a 5 min rest (Pickering et al., 2005). 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 (Pickering et al., 2005). The device recorded the oscillations of pressure in a cuff during gradual deflation, and systolic and diastolic BP was estimated indirectly according to an empirically derived algorithm (Pickering et al., 2005). Two independent consecutive measurements were taken at an 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 an interval of 1 min.

Elevated BP was defined equal or higher than 120 mmHg or equal or higher than 80 mmHg for systolic and diastolic BP, respectively. The PP was calculated as the difference between systolic and diastolic BP.

Statistical analysis

Means and standard deviations (SD) were calculated for continuous variables. The distribution of dichotomous variables are shown as frequencies and percentages. Left and right QRS axis deviation, left and right T-wave axis deviationand widened QRS complex were not analysed because of the low number of cases with these conditions.

Comparisons between study groups were performed by using multilevel modeling which was conducted by means of the linear and logistic mixed models in SPSS software, version 25 (SPSS Inc., Chicago, IL, USA). Multilevel modeling was used to appropriately allow for correlated data due to: 1) two repeated observations within subject; 2) cluster sampling design (sports for athletes, classes for non-athletes); and 3) different ECG recorders used in six Sports Medicine Centres.

Four-level data structure was constructed, separate observations being level 1, the subjects being level 2, the sports and control groups being level 3, and the Sports Medicine Centres being level 4.

As there are many choices among models to fit to a given data set with four-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 and BP variable as a dependent variable and we predeterminedly chose the model with the lowest BIC as our final model for a given outcome. That is, we did not force the four-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.

Study group (“Always athletes”, “Never athletes, “Changers”), sex, baseline body mass index (BMI) and time were used as fixed effects in all the models. As appropriate, the same variables were also tested as random effects when fitting the models. The possible number of different random effect combinations (including also the naïve model ignoring any clustering of data at any level) across four levels considered in the present study is 4096 for each outcome. Because of limited computational resources we did not explore each and every combination outcome-wise. Instead, we used a modified “step-up strategy” as described in more detail in Supplement 1. The final models chosen for each ECG and BP variable are shown in Supplement 1. The results of the final binary logistic models are presented as odds ratios (OR) and their 95% confidence intervals (CI).

Various covariance structures were explored at level 1 to adjust for the correlated observations within the subject. A variance component structure providing a single residual variance for two measurement occasions was found to be the best option for all the models considered based on BIC values observed.

As all the missing data was assumed to be missing at random, no method was applied to impute missing values. No formal correction was performed for multiple comparisons because the linear and logistic mixed modelling naturally address the multiple comparisons problem by shifting point estimates and their corresponding confidence intervals toward each other (Gelman et al., 2012). In this way, estimates derived make comparisons appropriately more conservative without reducing statistical power to detect true differences.

For continuous variables, the validity of the assumption of normality of the residuals was verified by inspection of a quantile-quantile (or a normal probability) plot. Plotting residuals against fitted values was used for an assessment of linearity and homoscedasticity assumptions. All statistical analyses were two sided, and a probability value (P value) of less than 0.05 was considered significant.

RESULTS

Descriptive characteristics

Baseline and follow-up characteristics of the study groups are presented in Table 1. The mean age was 15.5 (0.6) years in all study groups at baseline. There were proportionally more boys (48.2%) in the “Always athletes” group than in the two other study groups (df = 2; $X^2(2) = 9.09$; P = 0.011). The mean BMI of the study population at baseline was 21.1 (2.68) without differences between the study groups (P > 0.05). Pubertal development (Toivo et al., 2018) and baseline height, weight and body surface area of the athletes according to sport discipline are presented previously (Pentikäinen et al., 2021).

“Always athletes” and “Changers” trained an average of 9.0-9.6 hours per week during the preparation and competitive periods at baseline. When comparing the training hours of “Always athletes” at baseline and at follow-up, they trained more during a preparation period at the follow-up than at baseline (9.6 vs. 10.8 hours per week, P = 0.011).**”Always athletes” and”Never athletes”**

“Always athletes” had on average 7 bpm lower resting heart rate (P < 0.001) than “Never athletes” at baseline. “Always athletes” also had more negative T-wave axis (P = 0.018) and 5 mm higher QRS amplitude (P = 0.002) than “Never athletes” at baseline. All the observed differences at baseline, were also visible at 4-years (P < 0.05). No significant group x time interactions were found between “Always athletes” and “Never athletes” (P > 0.05 for all interaction analyses).

“Always athletes” were more likely to have sinus bradycardia at baseline (OR = 2.32; 95% CI = 1.26-4.29) and at 4 years (OR = 3.02; 95% CI = 1.62-5.65) than “Never athletes”. No significant group x time interactions were found in dichotomous variables.

“Changers” and “Never athletes”

“Changers” had on average 3 bpm lower resting heart rate (P = 0.023) than “Never athletes” at baseline. “Changers” also had more negative T-wave axis (P = 0.014) and 3.2 mm higher QRS amplitude (P = 0.012) than “Never athletes” at baseline. In addition, “Changers also had on average 4 mmHg higher systolic BP (P = 0.006) and 4 mmHg higher PP (P = 0.008) than “Never athletes” at baseline. None of the observed differences at baseline, were visible at 4-years (P > 0.05) except the between-group difference in T-wave axis (P = 0.028). The QRS amplitude decreased 1.2 mm in the “Changers” group and increased 1.2 mm in the “Never athletes” group (P = 0.017 for group x time interaction, Fig. 1). No other interactions were found.

No differences in dichotomous variables were found between “Changers” and “Never athletes” at baseline or at the end of the follow-up. No significant group x time interactions were found in dichotomous variables.

“Changers” and “Always athletes”

“Changers” had on average 4 bpm higher resting heart rate than “Always athletes” at baseline (P = 0.023) and at 4-years (P = 0.007). “Changers” also had 2 mmHg higher diastolic BP (P = 0.035) and 3.1 mm lower QRS amplitude (P = 0.067) than “Always athletes” at 4-years. The PP decreased 2.6 mmHg in the “Changers” group and increased 0.7 mmHg in the “Always athletes” group (P = 0.022 for group x time interaction, Fig. 2).

“Always athletes” were more likely to have sinus bradycardia at baseline (OR = 2.18; 95% CI = 1.20-3.97) and at 4 years (OR = 2.03; 95% CI = 1.12-3.67) than “Changers”. No significant group x time interactions were found in dichotomous variables.

DISCUSSION

During a 4-years follow-up with adolescent athletes and non-athletes, our main finding was that the QRS amplitude decreased in those who dropped out of SC activities (i.e. “Changers”) compared to those who never participated SC activities (i.e. “Never athletes”). This suggests that decrease in QRS amplitude emerge relatively fast after dropping out from SC activities. We observed several differences in ECG and BP at baseline between those who dropped out of SC and those who never participated in SC activities including different levels of QRS amplitude, T-wave axis, heart rate, systolic BP and PP. None of these differences were seen after 4 years follow-up except the difference in T-wave axis. Although the change between groups was significant only in QRS amplitude, this indicates that many of the training-induced cardiovascular adaptations return towards the levels of those who have not regularly participated in sport activities during adolescence. From a clinical point of view, divergent ECG findings in an adolescent which appear years after involvement in regular training warrant caution, because they may not be attributed to previous training history.

At baseline, those who continued to participate in SC activities (i.e. “Always athletes”) during 4-years follow-up and also those who dropped out of SC had higher QRS amplitude than those who never participated in SC activities. When this difference was still seen between “Always athletes” and “Never athletes” after 4 years, there was no difference in QRS amplitude between “Changers” and “Never athletes” at the end of the follow-up. This indicates that QRS amplitude recovers in a relatively short period of time after quitting active participation to sports. This was further emphasised by the marginal (although not statistically significant) difference in QRS amplitude at the end of the follow-up between “Changers” and “Always athletes”. Although there was a significant difference in change of QRS amplitude between “Changers” and Never athletes” when explored as a continuous variable, we did not see a difference in LVH changes between these groups. This is not surprising considering that the number of participants fulfilling the criteria for LVH was relatively low. The change of QRS amplitude in many participants may emerge inside normal levels without fulfilling the LVH criteria.

Those who continued to participate in SC activities and also those who dropped out of SC had more negative T-wave axis at both time points than those who never participated in SC activities. It seems that adolescent athletes have a more negative T-wave axis and it does not recover as soon as several other ECG and BP adaptations after dropping out SC activities. Anterior T-wave inversions are more common among young white athletes than in nonathletes (Malhotra et al., 2017). An athlete’s age, sex and ethnicity and their interaction with training history has an effect on the prevalence of T-wave inversions, with recent evidence suggesting that anterior T-wave inversions appear harmless, while lateral T-wave inversions always need further evaluation (Wilson et al., 2017).

We observed a substantial decrease in PP in those who dropped out of SC compared to those who continued to participate in SC activities. This suggests that while PP likely continues to rise in those who maintain SC participation and keep up physical training, PP returns to lower levels in those who cease regular training. This was further supported by the fact that “Always athletes” had higher PP than “Never athletes” at 4-years, when this difference was not seen at baseline. The rise of PP in healthy older adults probably relates to fall in systemic arterial compliance, whereas elevation of PP in the young may relate to increases in stroke volume (Berge et al., 2013; Alfie et al., 1999). Increases in stroke volume and PP are likely to emerge in those who maintain SC participation and keep up physical training, when stroke volume together with the PP probably return to lower levels after cessation of regular training.

“Always athletes” had sinus bradycardia more often than “Never athletes” at both measurements, which is a expected finding (McClean et al., 2018; Papadakis et al., 2009). “Always athletes” also had sinus bradycardia more often than “Changers” at both time points. It is difficult to find explanation for this, because both groups were involved in SC activities at baseline. However, it is possible that the proportion of endurance athletes was higher in “Always athletes” group and there were more power athletes included in the “Changers” group. “Changers” had higher systolic BP than “Always athletes” at baseline, but this difference between groups vanished completely during follow-up supporting this explanation. Power athletes usually have higher systolic BP values than endurance type athletes (Berge et al., 2015).

All the observed differences at baseline between those who continued to participate in SC and those who never participated in SC, were sustained through the follow-up period. The myocardium is particularly adaptive to training during the late phase of adolescence (Pressler et al., 2009). Our findings in this age group suggests that particular physiological adaptations such as a lower resting heart rate, a higher QRS amplitude and a more negative T-wave axis are visible already in adolescent athletes. These adaptations are commonly found ECG patterns in adult athletes and our results provide additional evidence that the heart starts to adapt to regular training at an early stage.

Strengths and limitations

The major strength of this study is a representative and relatively large sample from different regions of Finland including the 10 most popular sport disciplines in Finland. The prospective nature of this study allowed us to explore changes in ECG and BP in study groups over time. However, this observational study can only identify associations between independent variables and outcomes of interest rather than causality. We used multilevel modeling which accounts clustering of observations inside separate sports and control groups, as well as possible clustering inside six separate Sports Medicine Centres. Furthermore, linear mixed models provides valid results despite the randomly missing data, and accounts for the correlation among repeated measurements on the same participants.

The clinical relevance of our findings is that adolescents who have stopped being active athletes many years ago, should be considered as having pathological ECG while being found with a typical athlete's ECG. In conclusion, adolescent athletes have several training-induced cardiovascular adaptations. These adaptations, however, return towards the levels of non-athletes after cessation of regular training.

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Conflict of Interest

The authors have no conflicts of interest.

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Table 1. ECG and BP of the study groups

	Always athletes (N=135)		**Never athletes (N=107)**		**Changers (N=115)**	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
Continuous ECG variable						
Heart rate, beats/min	59.7 (9.7)	58.8 (9.5)	66.5 (12.7)	63.4 (10.9)	63.2. (10.7)	62.6 (10.7)
PR interval, ms	149.3 (23.1)	153.9 (25.3)	146.5 (20.7)	148.1 (21.1)	147.4 (22.4)	150.1 (22.3)
QRS duration, ms	91.4 (9.6)	94.3 (11.1)	89.2 (8.2)	91.5 (9.9)	91.3 (9.8)	93.8 (11.6)
QRS axis, degrees	64.3 (23.9)	64.1 (24.0)	66.6 (20.3)	65.3 (20.4)	65.0 (21.8)	62.5 (22.1)

T-wave axis, degrees	35.3 (14.3)	35.3 (15.4)	38.7 (15.7)	38.2 (16.0)	34.0 (17.0)	34.0 (16.5)
Corrected QT interval, ms	414.0 (29.4)	414.1 (22.8)	413.8 (24.9)	411.4 (25.0)	420.6 (34.9)	415.6 (26.6)
QRS amplitude, mm	28.2 (8.4)	28.5 (8.5)	23.2 (7.1)	24.6 (7.3)	26.4 (9.0)	25.4 (7.3)
Dichotomous ECG variable						
Sinus bradycardia, n (%)	74 (54.8)	78 (59.1)	30 (28.0)	40 (37.7)	42 (36.5)	46 (40.4)
Short PR interval, n (%)	7 (5.2)	7 (5.3)	8 (7.5)	7 (6.6)	5 (4.3)	8 (7.0)
Prolonged PR interval, n (%)	4 (3.0)	6 (4.5)	1 (0.9)	2 (1.9)	3 (2.6)	3 (2.6)
Prolonged corrected QT interval, n (%)	8 (5.9)	2 (1.5)	3 (2.8)	2 (1.9)	9 (7.8)	8 (7.0)
Left ventricular hypertrophy, n (%)	22 (16.3)	24 (18.2)	8 (7.5)	9 (8.5)	20 (17.4)	11 (9.6)
Continuous BP variable	**N=137**		**N=108**		**N=116**	
Systolic BP, mmHg	114.9 (10.3)	119.5 (11.0)	112.5 (9.7)	117.5 (11.9)	116.5 (10.6)	118.7 (13.5)
Diastolic BP, mmHg	65.0 (7.5)	69.7 (7.8)	65.6 (7.8)	71.8 (8.3)	65.5 (7.4)	71.6 (8.8)
Pulse pressure, mmHg	46.9 (10.2)	47.6 (9.2)	44.4 (9.3)	43.6 (9.9)	47.9 (9.7)	45.3 (11.4)
Dichotomous BP variable						

Elevated systolic BP, n (%)	35 (25.5)	59 (43.1)	23 (21.3)	38 (35.2)	36 (31.0)	44 (37.9)
Elevated diastolic BP, n (%)	4 (2.9)	8 (5.8)	3 (2.8)	15 (13.9)	1 (0.9)	18 (15.5)

Values are mean (SD) or number (%).

ECG data were missing for two subjects in the "Always athletes" group and for one subject in a "Never athletes" and in a "Changers" group.

Left and right QRS axis deviation, left and right T-wave axis deviationand widened QRS complex were not analyzed because of the low number of cases with these conditions.

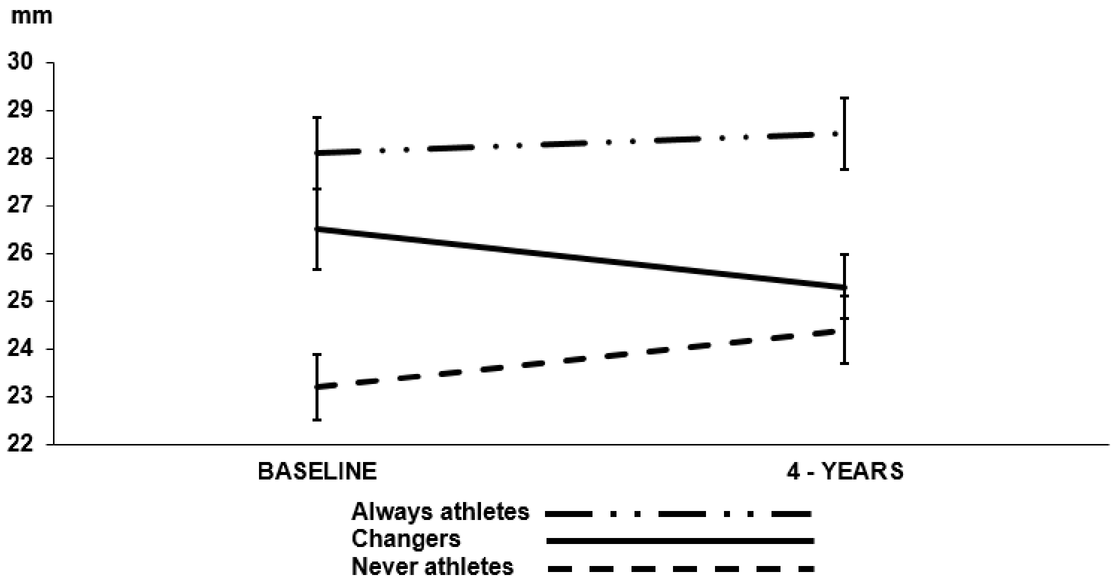

Figure 1. The mean (standard error) change of QRS amplitude between study groups during 4 years follow-up.

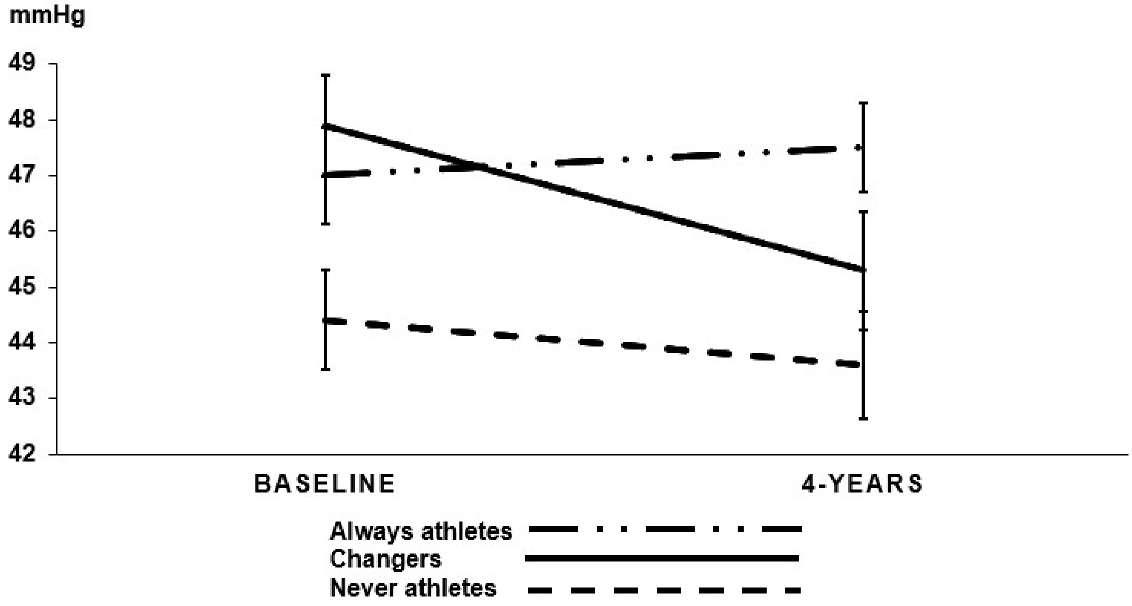

Figure 2. The mean (standard error) change of pulse pressure between study groups during 4 years follow-up.