

The effect of sport on computerized electrocardiogram measurements in college athletes

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Abstract

Background: Broad criteria for abnormal electrocardiogram (ECG) findings, requiring additional testing, have been recommended for preparticipation exams (PPE) of athletes. As these criteria have not considered the sport in which athletes participate, we examined the effect of sports on the computerized ECG measurements obtained in college athletes.

Methods: During the Stanford 2007 PPE, computerized 12-lead ECGs (Schiller AG) were obtained in 641 athletes (350 male/291 female, age 19.5 ± 2 years). Athletes were engaged in 22 different sports and were grouped into 16 categories: baseball/softball, basketball, crew, crosscountry, fencing, field events, football linemen, football other positions, golf, gymnastics, racquet sports, sailing, track/field, volleyball, water sports, and wrestling. The analysis focused on ECG leads V2, aVF and V5 which provide a three-dimensional representation of the heart's electrical activity. As marked ECG differences exist between males and females, the data are presented by gender.

Results: In males, ANOVA analysis yielded significant ECG differences between sports for heart rate, QRS duration, QTc, J-amplitude in V2 and V5, spatial vector length (SVL) of the P wave, SVL R wave, and SVL T wave, and RS_{sum} ($p < 0.05$). In females ECG differences between sports were found for heart rate, QRS duration, QRS axis and SVL T wave ($p < 0.05$). Poor correlations were found between body dimensions and ECG measurements ($r < 0.50$).

Conclusions: Significant ECG changes exist between college athletes participating in different sports, and these differences were more apparent in males than females. Therefore, sport-specific ECG criteria for abnormal ECG findings should be developed to obtain a more useful approach to ECG screening in athletes.

Keywords

Athletics, electrocardiography, preparticipation exam, screening for cardiovascular risk

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Introduction

Although the incidence of sudden death in athletes is relatively low, about 1 : 200 000,¹ the impact of such an event is high since athletes are considered to represent optimal health. To prevent sudden death, guidelines have proposed a preparticipation examination (PPE) in athletes that includes a cardiovascular-oriented history and physical examination.² The role of the electrocardiogram (ECG) within the PPE however, remains controversial.

The American Heart Association (AHA) does not recommend an ECG within the PPE, while the European Society of Cardiology (ESC) does.^{3,4} The

recommendation of the ESC originates from the long-standing experience in Italy, where a screening programme (including an ECG) for competitive athletes has been implemented since 1982. Since the implementation of the screening programme, the annual incidence of sudden cardiovascular death in athletes from

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one province in Italy with a high incidence of sudden death has decreased by 90%.⁵ However, several concerns remain regarding the widespread application of the ECG as a screening tool for athletic participation. For instance, the widely used computerized ECG analysis programmes often generate alarming output statements in athletes.

Another major concern with the application of the ECG as a screening tool is that currently recommended criteria for abnormal ECGs are the same for both genders, all ages, and all sports. While the ECG differences for age and gender have been reported and qualitative differences between sports have been described,^{6–10} there have been few quantitative studies of the ECG differences between sports.¹¹ The aim of this study was to demonstrate that sport-specific quantitative electrocardiographic measurements exist. In order to improve the screening characteristics of the electrocardiogram (reduction of false positives and false negatives), studies like ours need to become the basis for recognizing which athletes need further testing to identify those at risk of cardiovascular events.

Methods

Study population

The study population consisted of Stanford undergraduate students planning to compete in intercollegiate sports. During the 2007 preparticipation physical exams, the student athletes were offered an electrocardiogram. The addition of an ECG was approved by the Stanford Institutional Review Board and written informed consent was obtained from all athletes. More than 95% of the athletes agreed to participate in the ECG screening. A total of 653 athletes agreed to participate in the study.

Athletes were engaged in 22 different sporting disciplines including: baseball, basketball, crew/rowing, crosscountry, diving, fencing, field hockey, football, golf, gymnastics, lacrosse, sailing, softball, soccer, squash, swimming, synchronized swimming, tennis, track/field, volleyball, water polo, and wrestling. Sports were grouped based on similarity to form 16 different categories (Table 1): baseball and softball, basketball, crew/rowing, crosscountry, fencing, field sports (field hockey, lacrosse, and soccer), football linemen, football others, golf, gymnastics, racquet sports (squash and tennis), sailing, track/field, volleyball, water sports (diving, swimming, synchronized swimming, water polo), and wrestling.

ECG analysis

ECGs were recorded using Schiller ECG machines and the digital recordings were entered into a database

(SEMA, Schiller AG, Baer, Switzerland). The ECGs were also reviewed by cardiologists who entered the visual interpretation and selected visual measurements into a StudyTRAX database using a standardized form (Jacksonville, Florida). After data entry, all ECGs were again over read by two investigators particularly experienced in interpreting the ECGs of athletes (VVL and VF). Only athletes judged to have significant abnormalities by the senior investigator (VF) were recommended to undergo further testing, which included echocardiography and/or cardiac magnetic resonance imaging ($n=63$). ECGs exhibiting right bundle branch block ($n=6$) or Wolff–Parkinson–White syndrome ($n=2$) were excluded because of their established measurement characteristics.

Computerized ECG measurements included all intervals and durations in 12-leads. Values considered out of range were reread visually and corrected; waveform measurement algorithms most often failed for the P wave and T wave end. Intervals/durations are presented as milliseconds and amplitudes are presented in millivolts. In this paper we will focus on the ECG measurements in the leads V2, aVF and V5. The following ECG parameters were included:

major durations/intervals: PR interval, P wave duration, QRS duration, and QTc;
axis: P wave axis, QRS axis, and T wave axis;
J-amplitude in V2, aVF, and V5;
spatial vector length (SVL) for P wave, T wave, and QRS complex:

$$SVL_{QRS} = \sqrt{\left((R \text{ ampl. in } V2)^2 + (R \text{ ampl. in } V5)^2 \right) + (S \text{ ampl. in } aVF)^2}$$

$$SVL_P = \sqrt{\left((P_{\max} \text{ ampl. in } V2)^2 + (P_{\max} \text{ ampl. in } V5)^2 \right) + (P_{\max} \text{ ampl. in } aVF)^2}$$

$$SVL_T = \sqrt{\left((T_{\max} \text{ ampl. in } V2)^2 + (T_{\max} \text{ ampl. in } V5)^2 \right) + (T_{\max} \text{ ampl. in } aVF)^2}$$

P_{max} and T_{max} are maximum absolute amplitudes (either positive or negative in P and T wave, respectively;

the sum of the S wave in V2 and R wave in V5 (RS_{sum}).

Since voltage criteria for the P, QRS, and T waves have traditionally been used to reflect abnormalities of cardiac chamber size and function, we represented these voltages in spatial terms since the individual ECG leads are affected by body morphology.

Table 1. Demographic characteristics of the collegiate athletes per sport for those involved in individual sports and team sports

Characteristic	Individual sports								
	Total (n = 641)	Crosscountry (n = 41)	Fencing (n = 13)	Golf (n = 16)	Gymnastics (n = 37)	Racquet sports (n = 29)	Track and field (n = 22)	Wrestling (n = 30)	
Age (years)	19.5 ± 2	19.8 ± 2	19.1 ± 1	19.1 ± 1	19.6 ± 1	19.4 ± 1	19.5 ± 2	19.3 ± 2	
Male/female (n)	350/291	21/21	7/6	9/7	17/20	8/21	6/16	30/0	
Ethnicity									
Caucasian	484 (74)	32 (76)	9 (69)	8 (50)	27 (73)	20 (69)	15 (68)	21 (70)	
Hispanic	43 (6)	5 (12)	1 (8)	0 (0)	1 (3)	3 (10)	0 (0)	5 (17)	
African-American	67 (10)	3 (7)	1 (8)	1 (6)	1 (3)	0 (0)	7 (32)	2 (7)	
Asian/Pacific islands	64 (10)	2 (5)	2 (15)	7 (44)	8 (21)	6 (21)	0 (0)	2 (7)	
Height (inches)	70.0 ± 4.7	69.3 ± 3.4	69.7 ± 3.9	68 ± 5.7	64.9 ± 3.3	68 ± 3.9	69.5 ± 2.7	69 ± 3	
Weight (lbs)	166.9 ± 40	144.2 ± 34	150.4 ± 25	155.6 ± 27	140.1 ± 17	146.2 ± 26	156 ± 25	168.9 ± 29	
BMI (kg/m ²)	23.7 ± 3.6	21.0 ± 3.4	21.7 ± 2.4	23.7 ± 2.9	23.3 ± 1.5	22.1 ± 2.4	22.8 ± 3.5	24.9 ± 3	
	Team sports								
	Baseball/ softball (n = 48)	Basketball (n = 29)	Crew (n = 66)	Field events (n = 93)	Football linesman (n = 22)	Football other (n = 45)	Sailing (n = 18)	Volleyball (n = 29)	Water sports (n = 103)
Age (years)	19.9 ± 2	19.1 ± 1	19.0 ± 1	19.5 ± 1	19.5 ± 2	20.2 ± 2	19.5 ± 1	19.3 ± 1	19.4 ± 1
Male/female (n)	30/18	16/13	31/34	31/62	22/0	45/0	6/12	17/12	54/49
Ethnicity									
Caucasian	34 (71)	15 (52)	53 (82)	78 (84)	15 (68)	25 (56)	16 (89)	21 (72)	85 (83)
Hispanic	7 (15)	3 (10)	3 (5)	6 (7)	1 (5)	0 (0)	1 (6)	2 (7)	4 (4)
African-American	3 (6)	11 (38)	2 (3)	4 (4)	5 (23)	19 (42)	0 (0)	2 (7)	3 (3)
Asian/Pacific islands	4 (8)	0	7 (11)	5 (5)	1 (5)	1 (2)	1 (6)	4 (14)	11 (11)
Height (inches)	71.3 ± 4.1	74.6 ± 4.7	70.6 ± 4.5	67.2 ± 3.8	76 ± 1.7	73.5 ± 2.3	68 ± 4.4	74.3 ± 3.7	70.4 ± 4.5
Weight (lbs)	182.6 ± 33	190.1 ± 30	165.3 ± 33	144.7 ± 22	262.5 ± 29	217.7 ± 42	139.3 ± 18	176.3 ± 29	164.2 ± 27
BMI (kg/m ²)	25.1 ± 3.2	24.0 ± 2.0	23.2 ± 3.1	22.5 ± 2.1	32.2 ± 3.1	28.5 ± 5	21.2 ± 2	22.4 ± 2.5	23.3 ± 19.4

Values are mean ± SD or n (%) unless otherwise indicated. BMI, body mass index.

Statistical analysis

Data were analysed using NCSS software (Kayesville, UT) and SPSS (version 16.0). Differences between the groups were compared using ANOVA. Since most of the ECG measurements were non-Gaussian distributed, all data are presented as medians and interquartile range (IQR), a measure of statistical dispersion, being equal to the difference between the third and first quartiles. Unlike the (total) range, the interquartile range is a robust statistic, having a breakdown point of 25%, and is thus often preferred to the total range. Half the IQR equals the median absolute deviation; this also facilitates setting boundaries for risk of being 'abnormal'. Correlations were determined using Pearson's product moment correlation. Correlations were calculated between body morphology and key ECG

variables to identify relationships that could be considered for normalizing ECG measurements. Age was not considered because of the narrow age range in this population. *p*-values <0.05 were considered statistically significant. When presenting the results for each measurement, the order of the sports was determined by the magnitude of the median value from lowest to highest.

Results

Study population

A total of 653 college athletes participated in this study. Twelve athletes could not be categorized within one single sport, leaving 641 athletes for further study. Detailed information about the demographics characteristics per sport are given in Table 1. Most of our

Table 2. Electrocardiogram findings of the collegiate athletes per sport for those involved in individual sports and team sports

Finding	Individual sports								
	Total (n = 641)	Crosscountry (n = 41)	Fencing (n = 13)	Golf (n = 16)	Gymnastics (n = 37)	Racquet sports (n = 29)	Track and field (n = 22)	Wrestling (n = 30)	
ICRBBB	84 (13)	4 (9.8)	2 (15.4)	1 (6.2)	2 (5.4)	5 (17.2)	0	7 (23.3)	
RBBB	9 (1.4)	1 (2.4)	0	1 (6.2)	1 (2.7)	0	0	0	
Preexcitation	2 (0.3)	0	0	0	0	0	0	0	
ARVD/CECG	6 (0.1)	0	0	0	0	0	1 (4.5)	0	
ST elevation V2 ≥2 mm	83 (13)	10 (24)	0 (0)	2 (13)	0 (0)	0 (0)	2 (9)	2 (7)	
ST depression V5 <0 mm	165 (26)	5 (12)	4 (31)	4 (25)	11 (30)	9 (31)	3 (14)	16 (53)	
Right axis deviation	99 (15)	11 (27)	2 (15)	1 (6)	3 (8)	5 (17)	3 (14)	4 (30)	
Abnormal Q wave (V5 or aVF ≥0.04 sec)	4 (0.6)	1 (2)	0	0	0	0	0	0	
Finding	Team sports								
	Baseball/ softball (n = 48)	Basketball (n = 29)	Crew (n = 66)	Field events (n = 93)	Football linesman (n = 22)	Football other (n = 45)	Sailing (n = 18)	Volleyball (n = 29)	Water sports (n = 103)
ICRBBB	4 (8.3)	2 (6.9)	15 (22.7)	11 (11.8)	6 (27.3)	3 (6.7)	3 (16.7)	6 (20.7)	12 (11.7)
RBBB	0	0	0	4 (4.3)	0	0	0	2 (6.9)	0
Preexcitation	0	0	0	0	0	2 (4.4)	0	0	0
ARVD/CECG	3 (6.2)	0	0	1 (1.1)	0	0	0	1 (3.4)	0
ST elevation V2 ≥2 mm	5 (10)	6 (21)	12 (18)	12 (13)	3 (14)	7 (16)	1 (6)	1 (3)	20 (19)
ST depression V5 <0 mm	14 (29)	9 (31)	20 (30)	22 (24)	5 (23)	7 (16)	4 (22)	8 (28)	24 (23)
Right axis deviation	6 (13)	5 (17)	14 (21)	9 (10)	5 (23)	6 (13)	3 (18)	3 (10)	19 (18)
Abnormal Q wave (V5 or aVF ≥0.04 sec)	1 (2)	0	0	1 (1)	0	0	0	1 (3)	0

Values are *n* (%). ARVD/CECG, arrhythmogenic right ventricular dysplasia cardiomyopathy electrocardiogram; ICRBBB, incomplete right bundle branch block; RBBB, right bundle branch block; preexcitation, Wolff–Parkinson–White pattern.

athletes were Caucasian (74%). Visual analysis by two experienced cardiologists found no significant difference in the prevalence of abnormal ECGs between the races represented in our sample.¹² Furthermore, detailed analysis of the computerized measurements including those considered in this paper, failed to demonstrate any clinical meaningful differences between the races. Eleven athletes judged to have complete right bundle branch block (*n* = 9) and Wolf–Parkinson–White syndrome (*n* = 2) were excluded from further analyses (Table 2).

ECG variables

All ANOVA *p*-values between sports for male and female athletes are listed in Table 3. Resting heart

rate differed significantly between sports for male (*p* < 0.001; Figure 1A) and female athletes (*p* < 0.01; Figure 1B). Both male and female crosscountry athletes had the lowest resting heart rates (49, 44–57 bpm and 47, 43–51 bpm, respectively). Male sailors and female fencers showed the highest resting heart rates (Figure 1).

No significant differences between sports were found in P wave duration and PR-interval in either gender group. QRS duration (QRSd), however, differed between sports for both male and female athletes. The longest QRSd was found in volleyball players (males 108, 104–116 ms; females 95, 88–102 ms) and the shortest QRSd was found in gymnasts (males 93, 89–99 ms; females 82, 80–92 ms; Figure 2). Four athletes had abnormal Q wave durations (Table 2). QTc duration

Table 3. ANOVA *p*-values between sports for male and female athletes

Variable	Male athletes	Female athletes
Heart rate	0.00	0.01
Major duration/intervals		
PR interval	0.28	0.14
P wave duration	0.17	0.43
QRS duration	0.00	0.04
QTc	0.005	0.23
Axis		
P axis	0.08	0.37
QRS axis	0.81	0.04
T axis	0.66	0.09
J-amplitude/ST level		
V2	0.00	0.20
aVF	0.32	0.73
V5	0.00	0.08
Spatial vector length		
P wave	0.001	0.10
R wave	0.00	0.07
T wave	0.00	0.004
Summations		
Rv5 and Sv2	0.00	0.34

differed significantly between sports in male athletes ($p < 0.01$) but not in female athletes ($p = 0.23$). QTc duration was the longest in sailors (414, 402–420 ms) and shortest in field event athletes (380, 373–387 ms; Figure 3).

No differences between sports were found for P wave axis and T wave axis. In female athletes, QRS axis was most vertical in crew and basketball athletes (83 degrees) and most leftward in golfers (65 degrees; $p < 0.05$). No significant differences between sports in QRS axis were found in male athletes ($p = 0.81$). Right axis deviation was apparent in 15.5% of the study population (17% in males and 13% in females; Table 2).

In male athletes, differences between sports in J amplitude were found in V2 (Figure 4A) and V5 (Figure 4B), but not in aVF. In female athletes, no significant differences in J amplitude in V2, V5, or aVF were found between sports. ST elevation was apparent in 13% of all athletes, with the highest prevalence seen in crosscountry athletes (24%). ST-depression (J amplitude $V5 < 0$) was found in 26% of all athletes, with the highest prevalence in wrestlers (53%; Table 2). When using a less strict definition of ST depression (J amplitude $V5 < -0.05$), only 13 athletes displayed ST depression.

SVL for P wave, R wave, and T wave differed significantly between sports for male athletes (Table 2;

Figure 5). Crosscountry athletes exhibited the largest amplitudes for SVL for P wave, R wave, and T wave. In female athletes, only T wave SVL amplitude differed significantly between sports ($p = 0.004$), with the largest median found in crosscountry athletes (0.80, 0.53–0.92 mV).

The sum of the S wave in V2 and the R wave in V5 (RS_{sum}) differed significantly between sports in male athletes ($p < 0.0001$; Figure 6), but not in female athletes ($p = 0.34$). RS_{sum} amplitude was the greatest in crosscountry athletes (4.8, 3.9–5.8 mV) and the smallest in sailors (3.1, 2.7–4.1 mV). The mean ECG of the male crosscountry athletes and sailors is depicted in Figure 7.

Correlations

To investigate the relationships that could be considered for normalizing ECG measurements, we correlated the ECG measurements with body dimensions. In both male and female athletes, the anthropomorphic variables showed poor correlations with ECG findings ($r \leq 0.30$). In both males and females, the highest correlation between body dimensions and ECG measurements was found between height and QRSd ($r = 0.30$ and $r = 0.20$ respectively). Poor correlations were also found between vagal tone (PR interval), ST elevation or depression, and heart rate ($r < 0.50$).

Discussion

This investigation was designed as an observational study of computerized ECG measurements in college athletes without the intent to validate the role of the ECG as a screening tool for cardiovascular disorders in athletes. We found that ECG differences between sports were more apparent in male than in female athletes. In male athletes, heart rate, QRS duration, QTc, J amplitude in V2 and V5, SVL of P wave, SVL R wave, SVL T wave, and RS_{sum} differed significantly between sports. In female athletes, ECG differences between sports were found for heart rate, QRS duration, QRS axis, and SVL T wave. Poor correlations existed between body dimensions and ECG measurements.

To our knowledge, the current study is the first to demonstrate the effects of sport on computerized ECG measurements in athletes. In 1993, Bjørnstad et al. compared visual ECG measurements in endurance athletes, ball players, strength athletes, gymnasts, and controls.¹¹ Compared to our findings, they found relatively few differences in ECG measurements between sports. In males, they reported differences between sports for heart rate and maximal T wave amplitude. In females, heart rate, Q amplitude, R amplitude in V1, ST elevation (max ST elevation in precordial leads), and

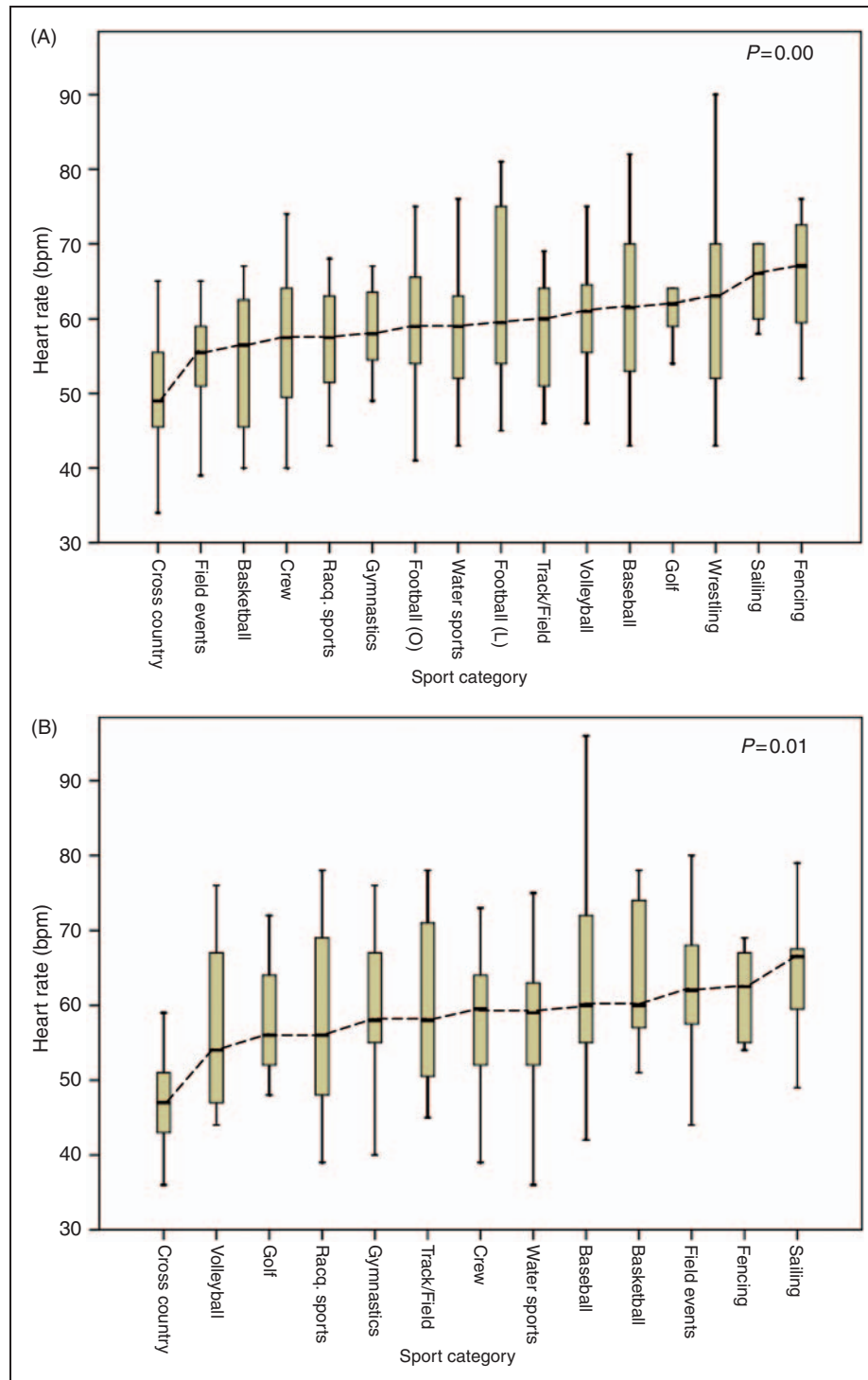


Figure 1. Heart rate per sport in (A) male and (B) female athletes.

T wave frontal plane axis differed between sports. The discrepancy between their results and our findings are likely the result of the different ECG analysis methods used (visual vs. computerized). In addition, the mean age of the athletes in the study of Bjørnstad et al. was higher than in our athletes, 24.8 vs.

19.5 years. Therefore, the athletes in the study of Bjørnstad may have had more years of training, which could have influenced training-related cardiac remodelling.¹³ If this was the case, however, one would expect more ECG differences between sports, given the additional 5 years of training.

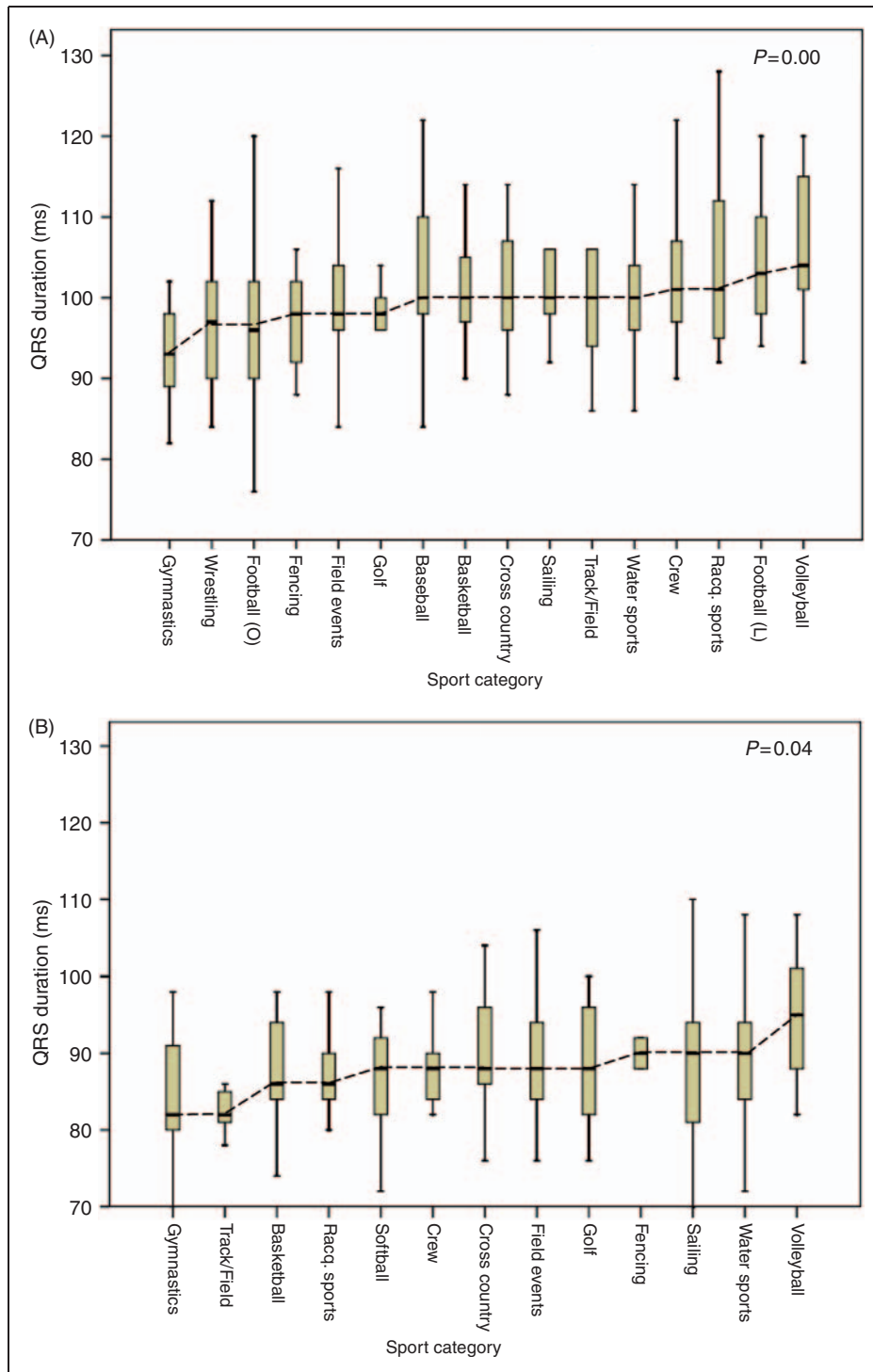


Figure 2. QRS duration per sport in (A) male and (B) female athletes.

It is a common finding that athletes frequently have ECG abnormalities.^{6,7,14} In our population, ST depression (J amplitude V5 <0 mm) was the most frequently found abnormality (26%; Table 2) and the highest prevalence of this abnormality was found in wrestlers (53%). This overall high prevalence may be the result of

both our relatively strict definition of ST depression as well as the computerized ECG analysis method, given that, in most of the athletes, ST depression was not noticed at first visual inspection. When using a less strict criterion for ST depression (J amplitude V5 < -0.05 mV), we found that only 13 athletes

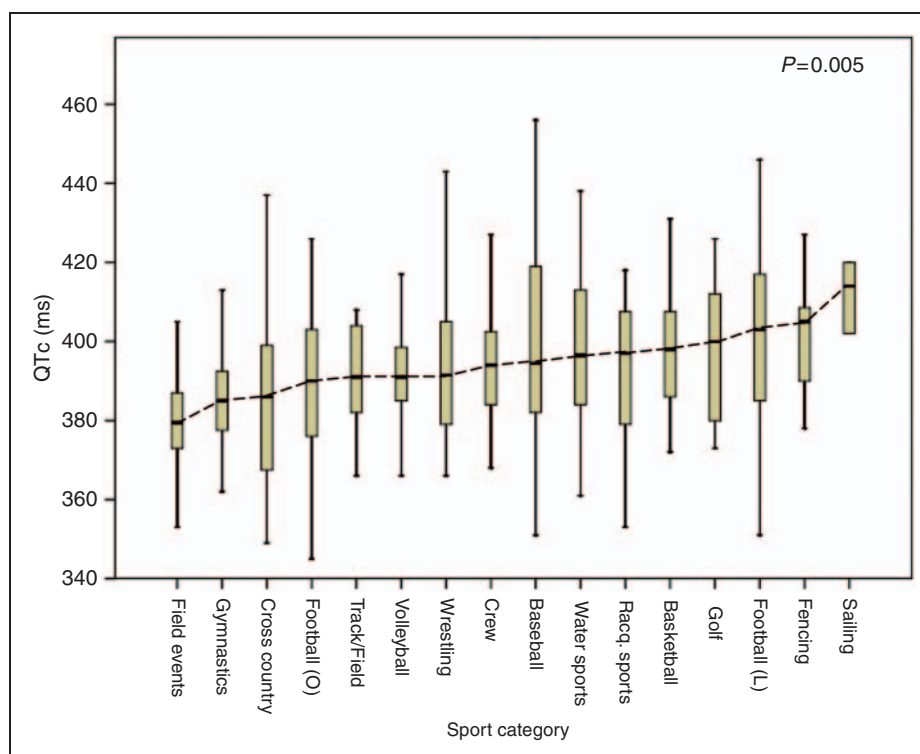


Figure 3. QTc per sport in male athletes.

exhibited significant ST depression. Hence, most athletes with ST depression only had ST depression < -0.05 mV. Therefore, one should be cautious with computerized ECG measurements, as this method frequently interprets an ECG as abnormal while visual analysis would not detect these abnormalities. Furthermore, although 53% of the wrestlers showed a J amplitude in V5 < 0 mV, this is likely an effect of their training regimen (more isometric). Therefore, this is unlikely a pathophysiological abnormality; rather, it most likely represents a normal variant common in wrestlers.

Besides the high prevalence of ST depression we found a surprisingly high prevalence (25%) of alarming statements generated by the ECG machine, including 'acute myocardial infarction', 'pathological hypertrophy', and 'myocardial damage'. However, after visual inspection, it was concluded that all of these were false-positive statements. As a result, we did not offer the athletes a copy of the standard computerized output from our ECG machine for their own records. Hence, before computerized output from the ECG machines can be used without a substantial amount of physician editing, the software should be refined to allow interpretation specific to athletes' ECGs.

As expected we found that differences in ECG measurement between sports were more pronounced in male than in female athletes, particularly in ECG

measurements that reflect cardiac morphology. While this has not been noted in prior ECG studies, it is consistent with echocardiographic studies. In 1996, Pellicia et al. reported that training was related to more distinct cardiac changes in males than in female athletes.¹⁵ They found that female athletes had a significantly smaller wall thickness (23% lower) and left ventricular cavity dimension (11% lower) and, hence, a smaller left ventricular mass (31% lower) than male athletes. Also, in none of the female athletes did the left ventricular wall thickness exceed the borderline gray zone for left ventricular mass.¹⁵ Similar findings were reported by Sharma et al.¹⁶ One of the explanations for these sex-specific morphologic changes may be the higher circulating concentrations of androgenic hormones in males. Furthermore, it is known that different sport disciplines, e.g. endurance and strength training, cause divergent cardiac adaptations.^{8,16} As female athletes have less exercise-induced cardiac changes than males, it is likely that different sport disciplines cause less divergent adaptations. Hence, ECG differences between sports would likely also be less distinct in female athletes than in male athletes, as suggested by this study.

Ethnicity can be of influence on the ECG in professional athletes. For instance, electrocardiographic abnormalities have been found to be more common in African-American than in Caucasian football players.¹⁷ In our sample, we did not find

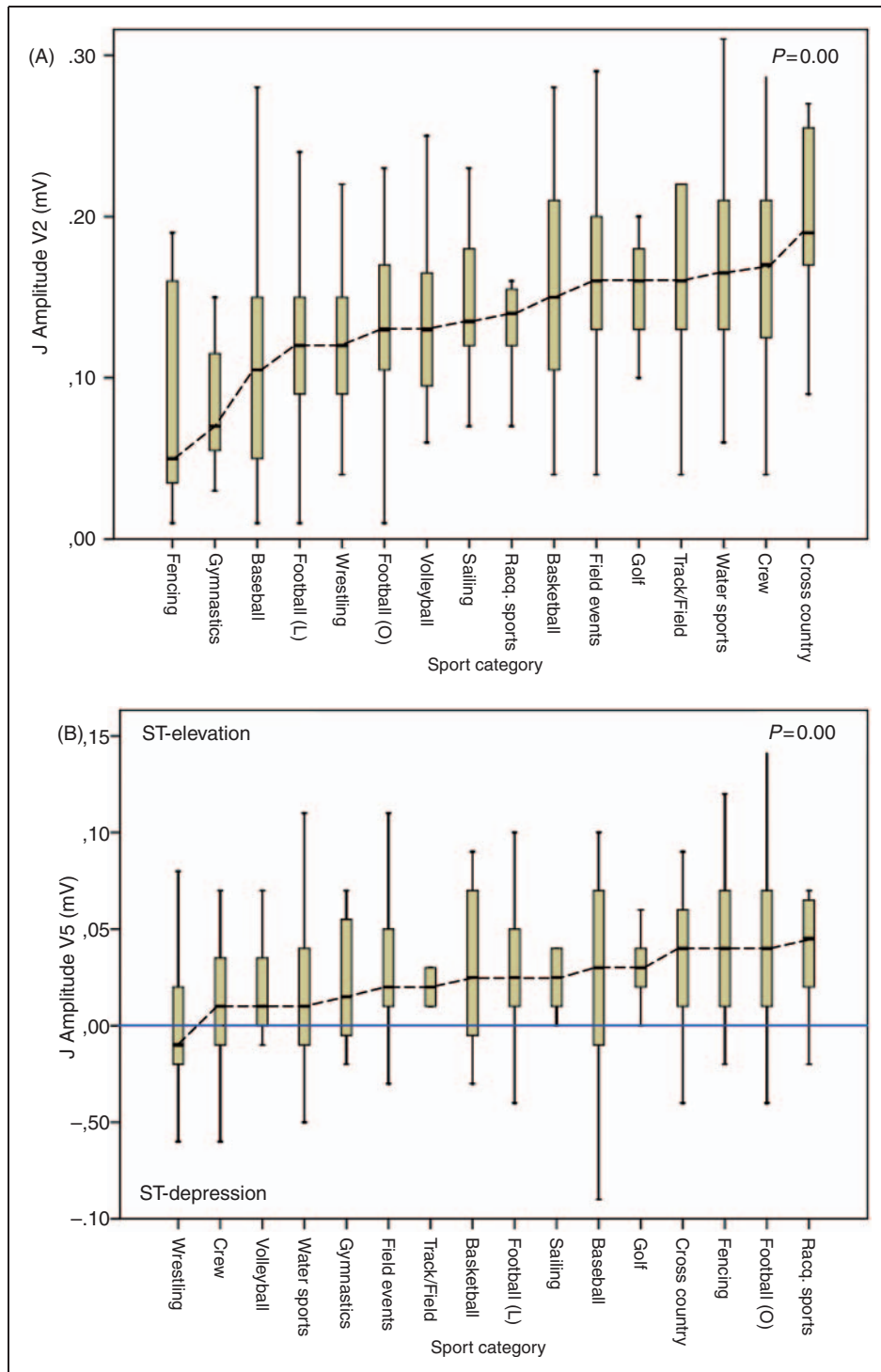


Figure 4. J amplitude in (A) V2 and (B) V5 per sport in male athletes.

African-American athletes to exhibit more ECG abnormalities than other ethnic groups.¹¹ Also, in our study population, detailed analysis of the computerized measurements failed to demonstrate any clinically meaningful differences between the different races. The reason for the discrepancy between our studies is not clear.

Perhaps differences in the ECG between races are more pronounced in professional athletes than in college athletes. However, Crouse et al. also found, in a small study population of college athletes, that electrocardiographic abnormalities were more common in African-American than in Caucasian football players.¹⁸

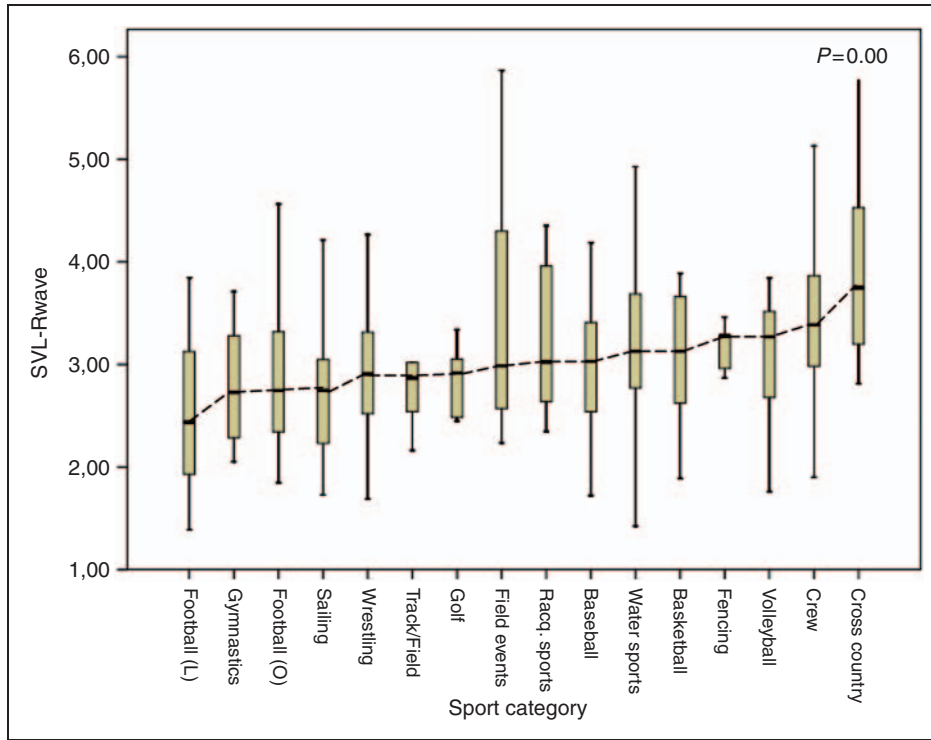


Figure 5. R wave per sport in male athletes.

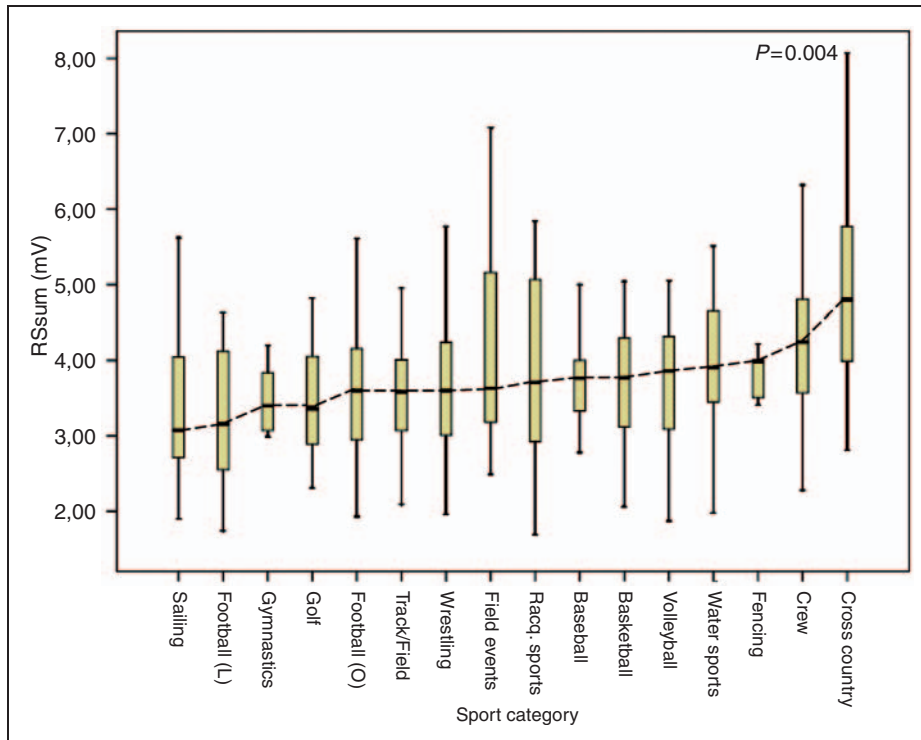


Figure 6. Spatial vector length for RS_{sum} per sport in male athletes.

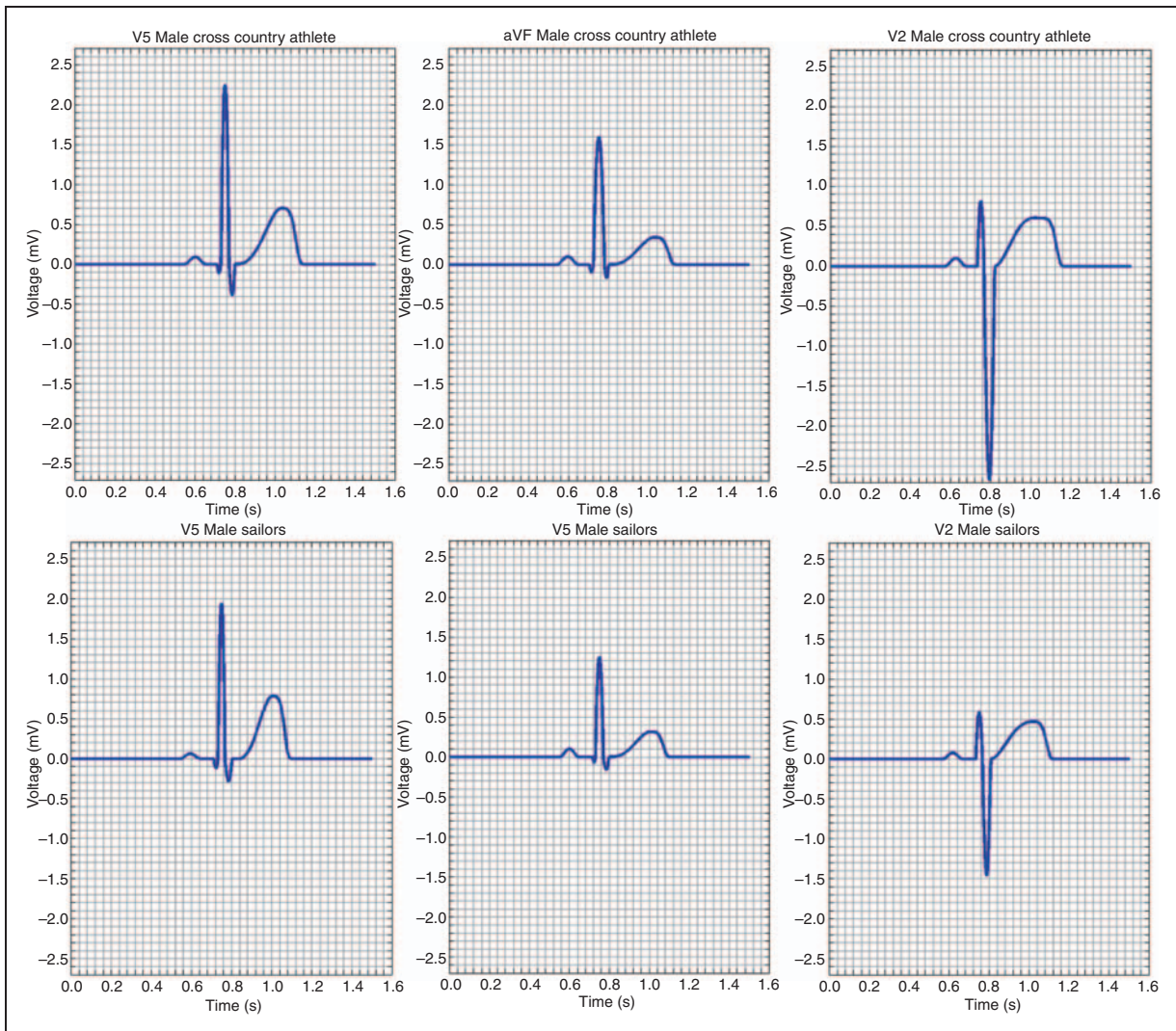


Figure 7. Mean electrocardiograms for male crosscountry athletes and sailors.

More studies are needed to investigate the influence of ethnicity on the ECG of athletes. As in our study population, most of our athletes had the same ethnic background (71% Caucasian) and we did not find clinical differences between the different races, we do not believe that race had a significant impact on our findings. Furthermore, we found a poor correlation between the ECG measurements and body dimensions. There are several possible reasons for the lack of association between anthropomorphic variables and surface potential. First, while there is a clear association between body size and heart mass, the association between heart mass and surface potential is more complex, primarily because thoracic impedance varies with body composition and body size. Thus, while larger subjects have the largest heart mass, they also have greater impedance due to a larger amount of tissue between myocardial surface and skin surface; thus

impedance also varies with body morphology. Furthermore, Rudy et al. have demonstrated mathematically that in some forms of left ventricular hypertrophy with normal cavity size, a cancellation effect may be present such that a hypertrophied heart exhibits normal surface voltages.¹⁹ This led us to conclude that the ECG measurements could not be meaningfully normalized by body size. However, we could not consider lean body mass since we did not systematically measure percent body fat in this population.

This descriptive study, which shows that ECG differences exist between sports, is a pioneering step toward the development of sport-specific criteria for abnormal ECG findings. The recognition of the existence of differences in ECG measurements between sports opens the door for further research which should link these ECG changes with structural cardiac changes. Although the significance of these differences

in ECG measurements between sports are not known, it is important to bear in mind the existence of these differences when testing athletes. For instance, ST depression in a wrestler could simply be an innocent physiological variant, whereas the same abnormality in a tennis player could be a more serious pathophysiological anomaly. A proper distinction between physiological and pathophysiological abnormalities should be the main goal of future research on ECG differences in athletes. In addition, the available ECG analysis programmes need to be refined to allow proper interpretation of the ECGs of athletes. Hopefully, data sets such as this one will catalyse efforts to make this happen.

Limitations

Our study did not include a control group. However, the study was designed as an observational study to assess the differences in ECG measurements between sports. It was not our objective to compare ECG changes between athletes and sedentary students. Additionally, we did not include echocardiography or other quantitative measurements of the heart. Therefore, we cannot relate the differences between sports in ECG measurements with structural cardiac differences.

Conclusions

Type of sport has significant impact on computerized ECG measurements obtained in college athletes. This impact is more pronounced in male than in female athletes. In particular, ECG patterns of left ventricular morphology were more evident between sports in males than in females. In male athletes, heart rate, QRS duration, QTc, J amplitude in V2 and V5, SVL of P wave, SVL R wave, SVL T wave, and RS_{sum} differed significantly between sports. In female athletes, type of sport affected heart rate, QRS duration, QRS axis, and SVL T wave. Therefore, sport-specific criteria for abnormal ECG findings should be developed to obtain a more useful approach of ECG screening in athletes.

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Conflict of interest

None

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