# COMPARISON OF DIFFERENT PRE-PARTICIPATION ELECTROCARDIOGRAM SCREENING CRITERIA IN ATHLETES-IS GENDER IMPORTANT?

Tatjana Miljkovic[1,2,*], Aleksandra Milovancev[2], Marija Bjelobrk[1,2], Bojana Saroskovic[2], Nemanja Lakicevic[3], Mladen Mikic[4], Patrik Drid[4]

[1]Medical Faculty, University of Novi Sad, Serbia - [2]Institute of Cardiovascular Diseases of Vojvodina, Serbia - [3]Department of Psychology, Educational Science and Human Movement, University of Palermo, Palermo, Italy - [4]Faculty of Sport and Physical Education, University of Novi Sad, Novi Sad, Serbia

***ABSTRACT***

***Introduction:*** *Screening programs in athletes are aimed to reduce the incidence of sudden death during sports by identifying individuals that need further diagnostic procedures. The aim of this study was to investigate and compare the prevalence of electrocardiogram (ECG) abnormalities using different screening criteria (European society of Cardiology recommendations (ESC), Seattle and Refined criteria) and to evaluate ECG gender-related differences.*

***Materials and methods:*** *Prospective cross-sectional study included 80 active athletes aged 22.5±3.4 years, 59.5% males and 40.5% females. All study participants filled the questionnaire, underwent clinical examination, a 12-lead ECG and a transthoracic echocardiogram (TTE). Electrocardiogram abnormalities were then assessed according to three sets of criteria.*

***Results:*** *Prevalence of training related ECG changes (Type 1) were: ESC 70% vs. Seattle 62.5% vs. Refined 63.8%, p<0.01. The most frequent type 1 ECG changes were isolated left ventricular hypertrophy, sinus bradycardia and early repolarization. Females had significantly more sinus arrhythmia (31.9% vs. 4.3%, p=0.01) and sinus bradycardia (66.7% vs. 44.6%, p=0.03). The prevalence of type 1 changes was significantly associated to smoking ($\chi^2$=4.78, p=0.02), alcohol ($\chi^2$=4.36, p=0.04) and family history ($\chi^2$=3.58, p=0.05) in athletics and in years engaged in sport (p<0.01) and age (p=0.05) in basketball players. Abnormalities unrelated to training were significantly reduced according to Seattle and Refined criteria compared to ESC (respectively 6.2% vs. 3.8% vs. 22.5%, p<0.01) in males (6.3% vs. 4.3% vs. 19.1%, p<0.01) and females (6% vs. 3% vs. 27.3%, p<0.01). The most frequent type 2 abnormality was T wave inversion.*

***Conclusion:*** *Stricter criteria resulted in a significant reduction of all ECG abnormalities in all athletes of both genders. According to ESC recommending females had more ECG abnormalities compared to men, but when assessed with more specific and sensitive criteria males were more prevalent. The study highlights ECG gender specific differences among different screening protocols.*

***Keywords:*** *Athletes, cardiovascular screening, electrocardiography, male, female.*

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## Introduction

Fitness, athletic and medical screening is fundamental to ensure optimal health in athletes[1-3], being that sudden cardiac death (SCD) is the leading cause of mortality in athletes[4-6]. The majority of disorders associated with SCD (cardiomyopathy or channelopathy) can be detected on a resting 12-lead electrocardiogram (ECG)[7, 8]. Interpretation of ECG however, is not easy, as physiological adaptations to an athlete's heart as a result of exercise, can resemble changes seen in cardiomyopathies and channelopathies[9]. Criteria for interpreting ECG in athletes have gone through several revisions to improve the accuracy in detecting potentially life threatening cardiac disorders in athletes and lower the rate of false positive findings. In 2010, the European Society of Cardiology (ESC) published recommendations for interpretation of ECG in athletes[10].

In 2013, the specificity of screening was improved by Drezner et al.[11] by publishing the Seattle criteria, which are the most widely cited guide-

lines[12]. Both criteria divide ECG changes in type 1 (normal training related changes) and type 2 (abnormal changes) according to different parameters. Both algorithms use the same criteria for male and female athletes except for the long QT interval criteria, which is gender-related[11]. Sheikh et al.[13] published "Refined criteria", which improved specificity without losing sensitivity particularly in black athletes, however, most of the screened athletes were male. Despite emerging evidence and efforts to improve cardiovascular screening protocols in athletes, most of the studies included male athletes and data about gender specific ECG screening differences are dearth.

The aim of this study was to investigate and compare the prevalence of ECG abnormalities using different screening criteria (ESC recommendations, Seattle and Refined criteria) and to evaluate ECG gender-related differences.

## Materials and methods

### *Subjects*

This is a prospective cross-sectional study which was conducted from November 2018 to November 2019 at The Institute of Cardiovascular diseases of Vojvodina. Study included 80 active athletes (performing intensive exercise more than 4 hours/week) aged 18 to 35 years.

There were 40 short distance runners and 40 basketball players. The mean (standard deviation (SD) athlete age was 22.5 (3.4) years (range, 19-33 years) with non-significant difference between males and females. There were 47 (59.5%) males (23 basketball players and 24 athletics) and 33 (40.5%) females (17 basketball players and 16 athletics).

They were all professional athletes taking part in sports competitions at national and international levels. According to Levine's categorization, short distance runners are categorized as middle dynamic and middle static sport category and basketball is categorized as high dynamic and moderate static sport category[14].

Exclusion criteria were previous medical history of chronic diseases and taking drugs that can influence ECG intervals. The study was performed according to the Declaration of Helsinki, and informed consent was obtained from all participants. The study was approved by the Ethics Committee of the Faculty of Medicine in Novi Sad and The Institute of Cardiovascular Diseases of Vojvodina (ethical approval number 240-1/12).

The participants filled the questionnaire about the years in sport, number of hours spent training on a weekly basis, cardiovascular risk factors: family history, smoking, alcohol and stimulants (doping) use. Average years engaged in sport were 9.2 years in males and 9.3 years in females (Table 1). Males spent more hours in training on a weekly basis (12.9 vs. 11) and had bigger family history prevalence of cardiovascular diseases (51% vs. 42.4%). Females were more often drinking alcohol (30% vs. 25.5%) and smoking cigarettes (9.4% vs. 8.5%). Males declared to use stimulants more often than females (6.4 vs. 6%). These differences were not significant.

| | Mean (SD) | | | Student t-test |
|---|---|---|---|---|
| Variable | All athletes N=80 | Males N=47 (59.5%) | Females N=33 (40.5%) | |
| Age | 22.5 (3.4) | 22.6 (3.3) | 22.5 (3.6) | NS |
| Years in sport | 9.3 (4.2) | 9.2 (4.0) | 9.3 (4.5) | NS |
| Number of hours spent training on a weekly basis | 12.2 (10) | 12.9 (12.4) | 11 (4.7) | NS |
| Risk factors for CVD | | | | Chi square test |
| Family history | 38 (47.5%) | 24 (51%) | 14 (42.4%) | $X^2$=0.4; NS |
| Smoking | 7 (8.7%) | 4 (8.5%) | 3 (9.4%) | $X^2$=0.01; NS |
| Alcohol | 22 (27.5%) | 12 (25.5%) | 10 (30%) | $X^2$=1.3; NS |
| Stimulants | 5 (6.3%) | 3 (6.4%) | 2 (6%) | $X^2$=0.0; NS |

**Table 1:** Participant characteristics and risk factors.
*Legend: CVD - Cardiovascular diseases; NS -non significant; SD- Standard deviation.*

### *Procedures*

All athletes underwent a standard resting 12-lead surface ECG recorded at a paper speed of 25 mm/s and gain of 10 mm/mV. The ECG was performed at least 12 h after the last intense physical activity in supine position after a 5-minute rest.

The ECG parameters were manually measured by using a graduated lens. Each ECG was interpreted by one cardiologist trained in the interpretation of ECGs of trained athletes with the three sets of analysis criteria: The ESC recommendations[10], the Seattle criteria[11] and Refined criteria[13]. ECGs were then classified for the peculiarities/abnormalities discovered. ECGs were classified as type 1 or type 2 depending on the peculiarities/abnormalities they presented using the ESC recommendations and Seattle criteria. Using refined criteria ECG's were first divided in three categories: training related normal variants, borderline variants and training unrelated variants. The borderline abnormality variants were than reclassified, if present in isolation the ECG was reclassified as training related normal variant, if there were two or more borderline variants the ECG was reclassified as

training unrelated abnormality. Transthoracic, two-dimensional, M-mode, and Doppler echocardiographic studies were performed using a General Electric Vivid E IX and Vivid E IX XD clear with a 1.5-4.6 MHz transducer by one ultrasonography-experienced cardiologist who was unaware of ECG or other data of the participants. With the athletes set in a left lateral position, images based on three consecutive heart cycles were obtained from standard views. Ventricular size and wall thickness measurements were performed using established guidelines[15].

### *Statistical analysis*

Continuous variables were presented by mean and standard deviation, and categorical variables by percentages. Normality was assessed by the Kolmogoroff-Smirnoff test. Differences were tested by student t-test, and chi-square test.

Logistic multivariable analysis was used to model the dependence of ECG abnormalities according to ESC recommendation and according to Seattle criteria on several dependent variables: age, sex, years in sport, number of hours spent training on a weekly basis, family history, alcohol and stimulants (doping) use, p-value less than 0.05 was considered significant. Statistical software Statistica, Statistica 13.5 Ultimate Academic Bundle, StatSoft (Europe), GmbH, Poßmoorweg 1, Hamburg, University licence for University of Novi Sad was used for all analysis.

## Results

### *Training related ECG changes (type 1)*

Type 1 ECG changes were found in 70% according to ESC and in 62.5% of athletes according to Seattle criteria (p=0.016) (Table 2). When we compared genders, type 1 abnormalities were more prevalent in females than in males (ESC criteria 75. 8% vs. 66%, p=0.24; Seattle criteria 66. 7% vs. 59. 6%, p 0. 41), which however did not display any statistically significant difference. The prevalence of type 1 changes was significantly reduced with the Seattle criteria in male and female groups.

| | Type 1 | | P | Type 2 | | p |
|---|---|---|---|---|---|---|
| | ESC | Seattle | | ESC | Seattle | |
| All athletes (N=80) | 56 (70%) | 50 (62.5%) | 0.016 | 18 (22.5%) | 5 (6.3%) | 0.001 |
| Males (N=47) | 31 (66%) | 28 (59.6%) | 0.001 | 9 (19.1%) | 3 (6.3%) | 0.030 |
| Females (N=33) | 25 (75.8%) | 22 (66.7%) | 0.040 | 9 (27.3%) | 2(6%) | 0.010 |

**Table 2:** Prevalence of ECG abnormalities assessed by ESC and Seattle criteria.
*Legend: ESC- European society of cardiology, Seattle- Seattle criteria.*

The most frequent type 1 peculiarity (Table 3) was Sinus bradycardia which was present in 53.8% of athletes. It was significantly more prevalent in females according to ESC criteria (66.7% vs. 44.6%, p=0.03); Left ventricular hypertrophy (LVH) was found in 12.5% of all athletes according to ESC criteria and in 11.2% according to Seattle criteria. It was more prevalent in males 17% of males, 6% of females according to ESC criteria and 14.9% of males, 6.2% of females according to Seattle criteria; Sinus arrhythmia was present in 11.2%, Seattle criteria, females had significantly more sinus arrhythmia than males (31.9% vs. 4.3%, p=0.01). Early repolarization in 2.5% by ESC criteria. In the group of athletics the prevalence of type 1 changes according to the Seattle criteria were significantly associated to smoking ($\chi^2$=4.78, p=0.02), alcohol ($\chi^2$=4.36, p=0.04) and family history ($\chi^2$=3.58, p=0.05). In the basketball players group the years engaged in sport (p=0.009) and age (p=0.05) were significantly associated to type 1 changes assessed by ESC recommendations.

There were no statistically significant differences between athletics and basketball players in the prevalence of training related ECG changes (respectively ESC 76.9% vs. 65%, p 0.24; Seattle 64.1% vs. 62.5%, p 0.88).

| Type 1 peculiarities (ESC) | | | | |
|---|---|---|---|---|
| | All athletes n=80 | Males n=47 | Females n=33 | p |
| Sinus bradycardia | 43 (53.8%) | 21 (44.6%) | 22 (66.7%) | 0.030 |
| 1°AV block | 4 (5%) | 3 (6.3%) | 1 (3%) | 0.516 |
| LV hypertrophy | 10 (12.5%) | 8 (17%) | 2 (6%) | 0.157 |
| Early repolarization/ST segment elevation | 2 (2.5%) | 1 (2.1%) | 1 (3%) | 0.781 |
| Type 2 peculiarities (ESC) | | | | |
| T wave inversion | 11 (13.8%) | 4 (8.5%) | 7 (21.8%) | 0.09 |
| Pathologic Q wave | 4 (5%) | 2 (4.2%) | 2 (6.2%) | 0.691 |
| Left atrial enlargment | 3 (3.8%) | 3 (6.4%) | 0 (0%) | 0.145 |
| Right ventricule hypertrophy | 2 (2.5%) | 1 (2.1%) | 1 (3%) | 0.222 |
| Type 1 peculiarities (Seattle) | | | | |
| Sinus bradycardia | 43 (53.8%) | 24 (51%) | 19 (59.4%) | 0.466 |
| Sinus arrhythmia | 9 (11.2%) | 2 (4.3%) | 7 (31.9%) | 0.015 |
| 1°AV block | 1 (1.2%) | 1 (2.1%) | 0 (0%) | 0.406 |
| LV hypertrophy | 9 (11.2%) | 7 (14.9%) | 2 (6.2%) | 0.235 |
| Incomplete right bundle branch block | 3 (3.8%) | 2 (4.3%) | 1 (3%) | 0.796 |
| Type 2 Peculiarities (Seattle) | | | | |
| T wave inversion | 3 (3.8%) | 2 (4.3%) | 1 (3.1%) | 0.796 |
| Left axis deviation | 1 (1.2%) | 0 (0%) | 1 (3.1%) | 0.222 |
| Left atrial enlargment | 1 (1.2%) | 1 (2.1%) | 0 (0%) | 0.406 |
| Right atrial enlargment | 1 (1.2%) | 0 (0%) | 1 (3.1%) | 0.222 |

**Table 3:** Prevalence of type 1 and type 2 ECG peculiarities.
*Legend: LV-Left ventricle, AV- Atrioventricular, ESC- European society of cardiology, Seattle- Seattle criteria.*

***Abnormal peculiarities unrelated to training (type 2)***

Seattle criteria significantly reduced the number of type 2 peculiarities when compared to ESC criteria in all athletes (6.3% vs. 22.5%, p=0.001) in males (6.3% vs. 19.1%, p=0.03) and females (6% vs. 27.3%, p=0.01). The observed differences between males and females were statistically non-significant (ESC criteria: females 27.3% vs. males 19.1%, p=0.19, Seattle criteria males 6.3% vs. females 6%, p=0.481). The most frequent type 2 peculiarity was T wave inversions (TWI), which was detected in 13.8% of ECG-s according to ESC criteria and reduced to 3.8% when assassed through the Seattle criteria. Females had more TWI according to ESC criteria (21.8% vs 8.5%, p=0.09), unlike Seatlle criteria where TWI was more prevalent in men (4.3% vs 3.1%, p=0.8).

There were no statistically significant differences between the athletics and basketball players groups in the prevalence of training unrelated abnormalities (respectively ESC 25.6% vs. 20%, p 0.55; Seattle 7.7% vs. 5%, p=0.62).

***Refined criteria***

According to Refined criteria, 24 (30%) of the ECG of the athletes were considered normal in 9 (27.2%) females and 15 (31.9%) males. Initially, 44 (55%) of ECG's were classified as training related normal variants, 7 (8.7%) were classified as borderline variants and 3 (3.8%) were classified as training unrelated variants. After reclassifications, we had 51 (63.8%) of training related normal variants (21 females (63.6%), 30 males (63.8%)) and 3 (3.8%) training unrelated variants. One (3%) female athletic had TWI and left atrial enlargement and two (4.3%) males (one athletic and one basketball player) had pathologic Q waves.

Refined criteria significantly reduced the number of type 1 changes when compared to ESC recommendations in all athletes (63.8% vs. 70%, p=0.05), males (63.8% vs. 66%, p=0.03) and females (63.6% vs. 75.8%, p=0.01). Type 2 abnormalities by Refined criteria were significantly reduced compared to ESC criteria in all athletes 3.8% vs. 22.5%, p=0.01, in males (4.3% vs. 19.1, p <0.01) in females (3% vs. 27.3%, p<0.01).

***Predictors of ECG changes***

We conducted the multivariate logistic regression analysis and demonstrated how different factors affected the occurrence of adaptive ECG changes. Results can be found in Table 4 (as our study group is relatively small the values of significance did not reach the statistical value, so they are not listed in the table). Each year of training increased the occurrence probability of training-related ECG peculiarities (by 7.5% according to ESC criteria and 5.9% according to Seattle criteria) and the training-unrelated abnormalities (by 2.3% according to ESC and 15.7% according to Seattle criteria).

The number of hours spent on training/weekly increased the probability of type 1 changes by ESC criteria but decreased the probability of type 2 ECG abnormalities. Males had greater chance of reveling type 1 changes and type 2 abnormalities according to ESC, but women had greater chance of revealing ECG abnormalities according to the Seattle criteria. Family history was associated with a greater probability of having ECG abnormalities.

| Variable | ESC Type 1 | ESC Type2 | Seattle Type 1 | Seattle Type 2 |
|---|---|---|---|---|
| | ODDS (95%CI) Exp (B) (Lower; Upper) | ODDS (95%CI) Exp (B) (Lower; Upper) | ODDS (95%CI) Exp (B) (Lower; Upper) | ODDS (95%CI) Exp (B) (Lower; Upper) |
| Age | 0.814 (0.648; 1.022) | 0.869 (0.675; 1.119) | 0.839 (0.677; 1.039) | 0.909 (0.555; 1.489) |
| Years in sport | 1.075 (0.896; 1.289) | 1.023 (0.840; 1.246) | 1.059 (0.890; 1.259) | 1.157 (0.787; 1.701) |
| Hours spent on training/ weekly | 1.019 (0.950; 1.094) | 0.987 (0.924; 1.054) | 1.031 (0.950; 1.118) | 0.884 (0.673; 1.162) |
| Gender male vs. female | 1.983 (0.668; 5.881) | 1.585 (0.538; 4.671) | 1.687 (0.618; 4.607) | 0.772 (0.102; 5.861) |
| Alcohol | 1.181 (0.348; 4.007) | 1.203 (0.324; 4.469) | 0.460 (0.415; 1.415) | 3.368 (0.415; 31.854) |
| Stimulants | 2.068 (0.196; 21.867) | 0.871 (0.081; 9.344) | 1.289 (0.193; 8.582) | 2.776 (0.183; 41.825) |
| Family history | 1.207 (0.403; 3.615) | 0.856 (0.269; 2.717) | 1.195 (0.426; 3.352) | 3.534 (0.307; 40.744) |

**Table 4:** Multivariate logistic regression analysis on how different factors affected the occurrence of type 1 and type 2 ECG peculiarities.
*Legend: ESC- European society of cardiology, Seattle- Seattle criteria, ODDS-Odds ratio, CI- Confidence interval.*

***Echocardiography***

We had 9 (11.2%) athletes with abnormal echocardiographic findings, 6 (7.5%) athletes (4 athletic and 2 basketball players) demonstrated LVH on echocardiography, one (1.3%) had left ventricular dilatation and two (2.5%) had mild to moderate valvular insufficiency. There was no significant difference in detecting LVH by transthoracic echocardiography (TTE) or by ECG (by Seattle criteria 15% vs. 12.8%, $\chi^2$=0.199, p=0.655).

Left ventricular dilatation was significantly correlated with electrocardiographic signs of LVH ($\chi^2$=4.932, p=0.026). There was a statistically significant relationship between echocardiography detect-

ed LVH and type 1 changes (ESC criteria $\chi^2$=63.3, p=0.0005; Seattle criteria $\chi^2$=56.4, p=0.0005) and type 2 abnormalities according to ESC criteria ($\chi^2$=5.6, p=0.018), but not with the Seattle criteria ($\chi^2$=0, p=1.0) in basketball players.

In the athletic group there was also a significant relationship between echocardiography demonstrated LVH and type 1 changes (ESC criteria $\chi^2$=90, p=0.0005; Seattle criteria $\chi^2$=44, p=0.0005), but not type 2 abnormalities according to the ESC criteria ($\chi^2$=3.3, p=0.018), Seattle criteria ($\chi^2$=1.4 p=0.2). Left ventricular dilatation was detected in 2.6% of athletes and was statistically correlated to type 1 changes (ESC $\chi^2$=121.3, p=0.0005; Seattle $\chi^2$=64.1, p=0.0005) and type 2 according to the ESC criteria.

## Discussion

This study showed that ESC recommendations for electrocardiographic interpretation in athletes are accountable for higher rate of ECG training related changes when compared with Seattle and refined criteria (respectively 70% vs. 62.5% vs. 63.8%, p=0.01). Dores et al.[16] reported that application of more restrictive criteria (Seattle and Refined criteria) for the interpretation of athletes ECG was associated with a two-thirds reduction in the rate of false-positive cases when compared to the ESC recommendations.

Frequently present ECG changes related to intensive training, defined as type 1 changes, can be found in up to 80% of athletes, depending on the practiced sport[10]. Maillot et al.[17] studied impact of the dynamic and static component of the sport for ECG analysis in screening athletes and reveled 62-71% of type 1 changes for the ESC, Seattle and Refined criteria algorithms (p<0.001). Type 2 abnormalities were not correlated with the type of sport. We observed same result in our study. The most frequent type 1 ECG changes in our study were isolated LVH, sinus bradycardia and early repolarization. Females had significantly more sinus arrhythmia and sinus bradycardia.

Males had more LVH and AV (atrioventricular) block but statistically insignificant. Wasfy et al.[18] described gender related differences in training-related ECG changes between male and female competitive rowers. Males had higher amounts of early repolarization and more isolated QRS voltage criteria for LVH, woman had more sinus arrhythmia like in our study. Pelliccia et al.[19] demonstrated in a population of adult female professional athletes lower left ventricular thicknesses, diameters and mass, with less frequent training related ECG changes. Pela et al.[20] found that being male was a strongly and independently predicting ECG-based LVH and ST elevation, which was also related to the TTE based left ventricular mass. Therefore, sex was a determinant not only of structural, but also of electrical LV remodeling in early adolescent athletes. Corici et al.[21] reported that sinus bradycardia was more commonly seen in male athletes and sinus arrhythmia occurred more frequently in female athletes. Bessem et al.[22] showed that there are significant gender related differences in ECG. Male athletes had significantly higher amounts of sinus bradycardia, incomplete right bundle branch block, early repolarization and isolated QRS voltage criteria for LVH. They also showed differences between QRS duration and suggested different gender based cut off values[22].

The prevalence of abnormalities unrelated to training assessed by ESC criteria were significantly reduced by Seattle and refined criteria (22.5% vs. 6.3% vs. 3.8%, p<0.001) in our study. This has been reported in several studies since the publication of the Seattle criteria. Brosnan et al.[23] showed a similar reduction in the false-positive rate using Seattle criteria vs. ESC recommendations (4.5% vs. 17.3%; p<0.001). Sheikh et al.[13] reported that refined criteria significantly reduced the number of positive ECG-s changes compered to ESC and Seattle criteria and reduced the burden of false positive ECGs in athletes, particularly in black athletes without compromising sensitivity. Different authors reported that Seattle criteria and subsequent revisions significantly improved the specificity and lowered the false-positive rate for ECG screening[11, 23-26].

The number of studies in screening programs for athletes is increasing. International criteria are the most recent consensus-based statement of the ESC and the American Heart Association and American College of Cardiology which include criteria for different ethnicities and younger athletes from 12-16 years[9]. Panhuyzen-Goedkoop et al.[27] recently published a study about ECG criteria for the detection of high-risk cardiovascular conditions in master athletes aged ≥35 years. Data about gender differences are scarce and conflicting. In our study abnormalities unrelated to training according to ESC criteria were found more in females but with no statistical difference, when assessed according to Seattle criteria the relative frequencies were similar between genders. T wave inversion was the most prevalent type 2 abnormality assessed by ESC criteria 21.8%

females and 8.5% males. The grater prevalence of TWI in our study could be explained by younger age. In juvenile ECG TWI could be observed more frequently[28]. But when striker criteria for TWI (Seattle) were applied the relative prevalence dropped to 4.3% in males and 3.1% in females.

Pelliccia et al.[29] found that left atrial enlargement, left axis deviation, and TWI were more prevalent in men than women assessed by ESC criteria. In a study performed on 1005 athletes who were participating in 38 sporting disciplines[29], a significantly larger proportion of male athletes had either distinctly (17% versus 8%; p=0.001) or mildly abnormal (28% versus 14%; p=0.001) ECGs compared to female athletes. Conversely, the vast majority of female athletes showed normal and ECGs with minor alterations (78%) compared to male athletes (55%; p=0.001). Logistic regression analysis confirmed that a greater probability for an abnormal ECG pattern was associated with male sex and younger age. Male athletes had greater maximum R or S wave voltages compered to female athletes; and more frequently abnormal Q waves.

Seattle criteria suggests statistically non-significant difference between genders[11]. The lack of gender difference seen in the Seattle compared to the ESC criteria is largely explained by the "stricter re-definition" of abnormal T wave inversions (TWI), QTc interval. Corici et al[21] demonstrated gender-related differences in ECGs of trained athletes and suggested that should be considered in their cardiovascular screening. However, there are studies about observed ECG gender differences. Ne gender cut off criteria but QT is included in all observed ECG screening criteria (ESC, Seattle and refined criteria). In our study ECG was correlated to TTE, good diagnostic tool in predicting LVH in athletes. Left ventricular remodeling in athletes is induced by exercise and is accompanied with increase in ventricular size, wall thickness and left ventricular mass[30]. Training-induced increase in left ventricular mass, wall thickness, and atrial and ventricular dilatation observed in competitive athletes may mimic the pathological remodelling of pathological hypertrophy.

In our study, age and male gender was significantly associated with training related ECG changes in the basketball group. Predictors that significantly affected the occurrence of adaptive changes in the study of Jakubiak et al.[31] were the age of the athlete, training duration (in years), and male gender.

Our study presents some limitation. The study enrolled a relative small number of subjects that were all of the same ethnicity. As ethnicity affects ECG changes in athletes, conclusions can be made only for white athletes. Long-term follow-up would be valuable in detecting any possible long-term sport implications on cardiovascular diseases. Finally, maybe it would be useful if we used most recently published International criteria for ECG interpretation in athletes and compared it with ESC, Seattle and Refined criteria.

However, the study was designed and planned before International criteria were published. Nevertheless, the study the focus was to evaluate gender related ECG differences on screening criteria. None of the recommendations for ECG screening protocols in athletes published so far involved data regarding gender comparison and gender specific cut off values (except QT interval) in pre-participation screening programs.

## Conclusion

This study determined that Seattle and Refined criteria significantly reduced the number of training related and unrelated ECG abnormalities in all athletes and in both genders.

According to the ESC recommendations females had more ECG abnormalities compared to men, but when assessed with stricter criteria abnormalities in males were more prevalent.

The study highlighted ECG gender specific differences among different screening protocols. More studies are needed to establish better cut off values between genders and to evaluate possible implications for screening criteria in detecting ECG abnormalities.

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*Corresponding Author:*
Tatjana Miljkovic
Faculty of Medicine, University of Novi Sad Hajduk Veljkova 3
21000 Novi Sad, Serbia
Email: tatjana.miljkovic@mf.uns.ac.rs
*(Serbia)*