Comparative analysis of international electrocardiographic criteria usage in young athletes

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doi: 10.18176/archmeddeporte.00195

Received: 18/04/2024
Accepted: 16/01/2025

Summary

Introduction and objectives: Electrocardiogram (ECG) screening in young individuals remains a matter of controversy due to relatively high false positive rates. In addition, validation of international criteria in athletes under 12 years of age has not yet been established. The intention of this study is to describe the prevalence of ECG findings in a sample of juvenile athletes aged 11-16 years.
Material and method: Retrospective cross-sectional descriptive study of 14608 athletes aged 11 to 16 years, establishing children aged 11 to 12 years and adolescents aged 13 to 16 years. To assess the athletes, questionnaires on relevant background information were used by means of an interviewer. In addition, anthropometric measurements and resting ECG were performed. To measure the primary findings of abnormal ECGs, the international recommendations for electrocardiographic interpretation in athletes were followed.
Results: Among the evaluated population of adolescent athletes, the vast majority howed results without pathological alterations in the ECG, with adaptive findings related to sports participation being more frequent among young adolescents and males. Of the total sample, 1.34% were diagnosed with a previously unknown cardiac pathology on ECG alone.
Conclusions: The information collected provides valuable data on the prevalence of normal, abnormal and borderline ECGs in a very large sample of young athletes. These findings serve as a reference in the detection of potentially serious cardiac abnormalities within this specific group, considering variations according to age and sex. Furthermore, our findings highlight the use of the refined Seattle criteria as a sensitive and specific technique for the detection of juvenile athletes, further improving the accuracy of ECG-based assessments.

Key words:
Athletes. Adolescent. Electrocardiogram. Sudden cardiac death. Sports medicine evaluation.

Análisis comparativo del uso de los criterios electrocardiográficos internacionales en deportistas jóvenes

Resumen

Introducción y objetivos: El electrocardiograma (ECG) en los exámenes en individuos jóvenes sigue siendo un tema de controversia debido a las tasas relativamente altas de falsos positivos. Además, aún no se ha establecido la validación de los criterios internacionales en deportistas menores de 12 años. La intención de este estudio es describir la prevalencia de los hallazgos del ECG en una muestra de deportistas infantojuveniles de entre 11 y 16 años.
Material y método: Estudio descriptivo trasversal retrospectivo de 14608 deportistas de entre 11 y 16 años, estableciendo niños de 11 a 12 años y adolescentes de 13 a 16. Para evaluar a los deportistas, se usó unos cuestionarios sobre antecedentes relevantes mediante un entrevistador. Además, se realizaron medidas antropométricas y ECG en reposo. Para medir los resultados primarios de los ECG anormales, se siguieron las recomendaciones internacionales para la interpretación electrocardiográfica en Deportistas.
Resultados: Entre la población evaluada de deportistas adolescentes, la gran mayoría mostró resultados sin alteraciones patológicas en el ECG, siendo los hallazgos adaptativos relacionados con la participación deportiva más frecuentes entre los adolescentes jóvenes y los hombres. El 1,34% de la muestra total fue diagnosticado de alguna patología cardíaca previamente desconocida únicamente a través del ECG.
Conclusiones: La información recopilada, aporta datos valiosos sobre la prevalencia de ECG normales, anormales y limítrofes en una muestra de deportistas jóvenes muy grande. Estos hallazgos sirven de referencia en la detección de alteraciones cardíacas potencialmente graves dentro de este grupo específico, considerando variaciones según la edad y el sexo. Además, nuestros hallazgos resaltan la utilización de los criterios refinados de Seattle como una técnica sensible y específica para la detección en deportistas infantojuveniles, mejorando aún más la precisión de las evaluaciones basadas en ECG.

Palabras clave:
Deportistas. Adolescente. Electrocardiograma. Muerte cardíaca súbita. Evaluación médica deportiva.

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Introduction

Sudden cardiac death (SCD) among young, healthy populations is a matter of medical and social concern[1]. Its incidence in athletes is currently estimated to be around 1/50,000[2], but this figure varies depending on the registry due to differences in study methodologies and comparisons between heterogeneous populations[3]. Given the potential fatality of SCD, pre-participation evaluation (PPE) of athletes has been proposed to detect situations that may pose a life-threatening risk during physical exercise[4]. Early detection of potentially lethal diseases in athletes has been shown to reduce cardiovascular morbidity and mortality in some cases[5]. Hearts with structural and electrical cardiopathies, including myocardial diseases, ion channel diseases, coronary anomalies, acquired heart diseases and potential SCD, can be unmanageable without early detection[6]. Performing a 12 lead ECG can provide diagnostic information on underlying cardiopathies that could produce malignant arrhythmias, which may be related to SCD[7]. Italian studies have shown that PPE with ECG led to a reduction in the incidence of sudden cardiac death from 3.6/100,000 to 0.4/100,000 people/year, resulting in a 90% reduction in sports-related mortality[8,9]. To detect cardiopathies related to SCD, the expert consensus statement produced in Seattle in 2013[10] was proposed as a tool that allows for the identification of normal, borderline and pathological findings, as well as recommendations on the clinical management and assistance to athletes with abnormal findings. In 2017[11], the Seattle criteria were refined to increase the specificity of the ECG. The revised criteria incorporated a section addressing specific considerations for individuals aged 11–16 years, referred to as the juvenile pattern. However, it is important to note that this young-adolescent population is not represented and the criteria do not encompass paediatric children under the age of 11 years. Building on the publication of that consensus statement, the objective of this study was to clarify the prevalence of abnormal ECG findings within a sample of paediatric (child) athletes aged 11-12 years and adolescent athletes aged 13-16 years..

Material and Method

Participants

- Design: A retrospective cross-sectional descriptive study with an inferential component was conducted to analyse the reading and interpretation of ECGs performed on the athletes who participated in the study between 2018 and 2023.
- Sample population: The target population consisted of sports clubs in the province that requested health screening for athletes to be conducted using this method. Total participation amounted to 14,608 athletes of both genders engaged in 11 different sports: football, basketball, handball, volleyball, rugby, swimming, futsal, tennis, rhythmic gymnastics, padel and athletics. Written informed consent was obtained from the father, mother or legal guardian, as well as from the athletes themselves, in accordance with the requirements of the Data Protection Act. This study was approved by the corresponding provincial Ethics Committee and met the research criteria defined in the Declaration of Helsinki (amended by the 59th General Assembly of the WMA in Seoul, October 2008).

Procedures

The athlete assessment protocol was performed by a team of professionals who travelled to the exam location, usually a sports facility. The team consisted of four professionals: 1 doctor, 2 nurses and 1 physiotherapist. The medical equipment used was: 2 beds, a podoscope, a stadiometer, a weighing station, a stethoscope, a blood pressure monitor, an electrocardiograph, a metric tape, an otoscope, a pulse oximeter, a digital tablet with a Snellen[1] test app and a laptop. The circuit was made up by four stations or positions, where each professional conducted a series of tests, measurements and assessments:

- Station One: Review of the clinical history of the athlete, with a particular focus on personal and family backgrounds. This was conducted by nursing staff.

Table 1. Characteristics of the participants included in the study.

	Muestra (n = 14.608)	Children (11-12 years) (n = 3,580)	Adolescents (13-16 years) (n = 11,060)	Boys (n = 10,897)	Girls (n = 3,710)
Age	12.7 ± 3.18 years	11.7 ± 0.2 years	14.8 ± 0.5 years	12.6 ± 3.2 years	13.2 ± 1.7 years
Gender (boys/girls)	10,897 (74.59%) / 3,710 (25.39%)	2,784 (19.05%) / 763 (5.22%)	8,113 (55.53%) / 2,947 (20.17%)	-	-
Weight (kg)	50.1	44.5	61.3	50.8	51.8
Height (metres)	159.1	152.9	168.9	159.1	158.8
BMI (kg/m^2)	19.35	18.47	22.51	19.26	20.01
Systolic blood pressure (mmHg)	108	103	115.7	108	107.9
Diastolic blood pressure (mmHg)	60.1	59.5	64.5	61.2	62

Table 2. Electrocardiographic findings.

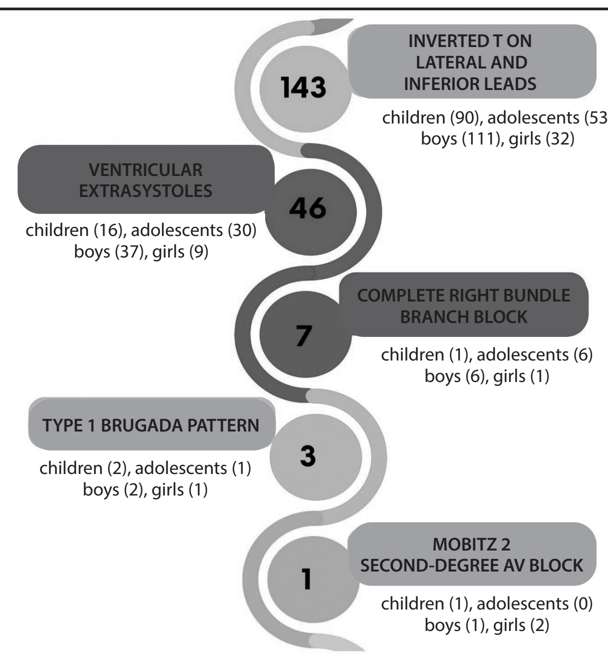
	Sample (n = 14,608)	Children (11-12 years) (n = 3,580)	Adolescents (13-16 years) (n = 11,060)	Boys (n = 10,897)	Girls (n = 3,710)
Normal findings					
Increased voltage	2,086 (14.27%)	1,390 (9.51%)	696 (4.76%)	1,782 (12.19%)	304 (2.08%)
Incomplete right bundle branch block	887 (6.07%)	183 (1.25%)	704 (4.81%)	546 (3.73%)	341 (2.33%)
Early repolarisation	847 (5.79%)	363 (2.48%)	484 (3.31%)	729 (4.99%)	118 (0.8%)
Juvenile population T-wave pattern	563 (3.85%)	409 (2.79%)	154 (1.05%)	413 (2.82%)	150 (1.02%)
Bradycardia and sinus arrhythmia	1,189 (8.13%)	701 (4.79%)	488 (3.34%)	799 (5.46%)	390 (2.66%)
Fewer than 2 ventricular extrasystoles in 10”	59 (0.40%)	22 (0.15%)	37 (0.25%)	46 (0.31%)	13 (0.08%)
Atrial or AV junctional rhythm	3 (0.02%)	0 (0.00%)	3 (0.02%)	2 (0.01%)	1 (0.001%)
First-degree AV block	85 (0.58%)	27 (0.18%)	58 (0.39%)	56 (0.38%)	29 (0.19%)
Mobitz 1 second-degree AV block	2 (0.01%)	1 (0.001%)	1 (0.001%)	1 (0.001%)	1 (0.001%)
Borderline findings					
Complete right bundle branch block	100 (0.68%)	26 (0.17%)	74 (0.50%)	71 (0.48%)	29 (0.19%)
Right axis deviation	756 (5.17%)	43 (0.29%)	713 (4.88%)	649 (4.44%)	107 (0.73%)
Left axis deviation	21 (0.14%)	0 (0.00%)	21 (0.14%)	18 (0.12%)	4 (0.02%)
Abnormal findings					
Mobitz 2 second-degree AV block	1 (0.001%)	1 (0.001%)	0 (0.00%)	0 (0.00%)	1 (0.001%)
T-wave inversion from V4	143 (0.97%)	90 (0.61%)	53 (0.36%)	111 (0.75%)	32 (0.21%)
Complete left bundle branch block	7 (0.04%)	1 (0.001%)	6 (0.04%)	5 (0.03%)	1 (0.001%)
Brugada pattern	3 (0.02%)	2 (0.01%)	1 (0.001%)	2 (0.01%)	1 (0.001%)
More than 2 ventricular extrasystoles in 10”	46 (0.31%)	16 (0.10%)	30 (0.2%)	37 (0.25%)	9 (0.06%)

Values presented in frequency (percentage). Differences via Fisher test or chi-squared test, as appropriate. LVH: left ventricular hypertrophy (according to Sokolow criteria). AV: atrioventricular. RBBB: Right bundle branch block.

- Station Two: Anthropometric assessment, with measurements of weight, height, body mass index, abdominal circumference, upper limb girth, upper and lower limb segments. A static footprint analysis was also performed using a podoscope, and the ankles, knees and back were examined. Finally, visual acuity was assessed using the Snellen[12] chart. Work at this station was carried out by a physiotherapist. The weight, height, heart rate and blood pressure measurements were obtained according to International Biological Programme recommendations and current guidelines from the European Society of Cardiology[13]. We used the DuBois and DuBois[14] formula to calculate body surface area (BSA). This role was performed by physiotherapy staff.
- Station Three: A full medical examination that encompassed osteoarticular assessment, cardiopulmonary auscultation, neurological assessment, peripheral pulse palpation, dermatology and general assessment of all the organs. The tests at this station were exclusively performed by a doctor specialising in sports medicine.
- Station Four: Cardiovascular examination using a digital ECG and monitoring of vital signs. This was conducted by nursing staff.

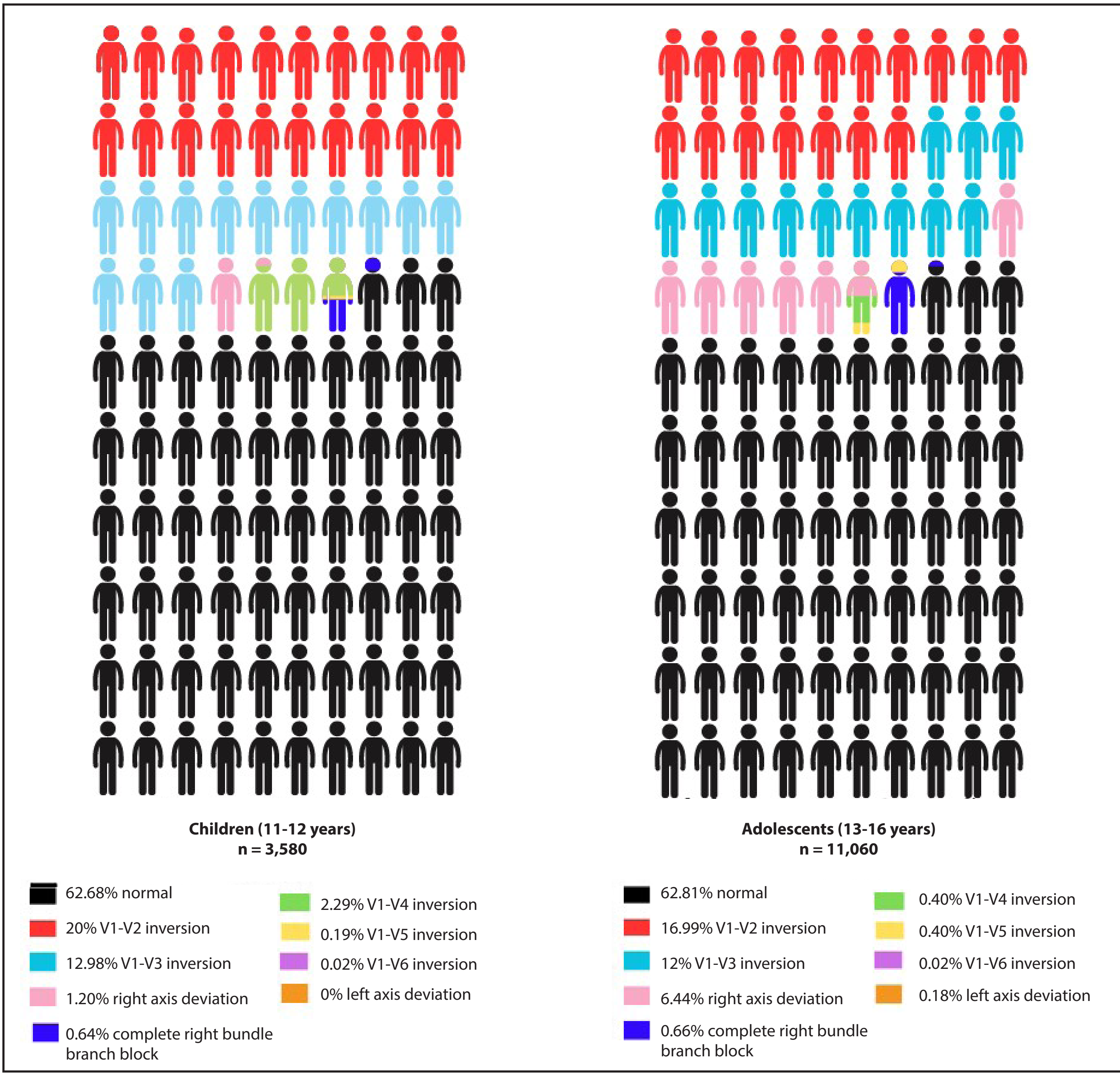
The 12-lead resting ECG was performed in the supine position according to internationally agreed criteria for the interpretation of ECGs in athletes. A Cardioline electrocardiograph (Touch ECG model) was used with a speed of 25 mm/s and an amplitude of 10 mV. To determine whether each ECG finding was normal or abnormal, we considered the criteria described in the guidelines from 2017[9], where at least one of the changes found was compatible with the criteria listed in Table

Figure 1. Prevalence of abnormal findings on the ECG based on 2017 international consensus.



Total sample, n = 14,608
Boys (n = 10,897); Girls (n = 3,710)
Children 11-12 years (n = 3,580); Adolescents 13-16 years (n = 11,060).
Abnormal electrocardiograms found (n = 74, 0.5%)
Boys (n = 55); Girls (n = 18)
Children 11-12 years (n = 12); Adolescents (n = 62)

Figure 2. Prevalence of repolarisation disorders by age and borderline findings.

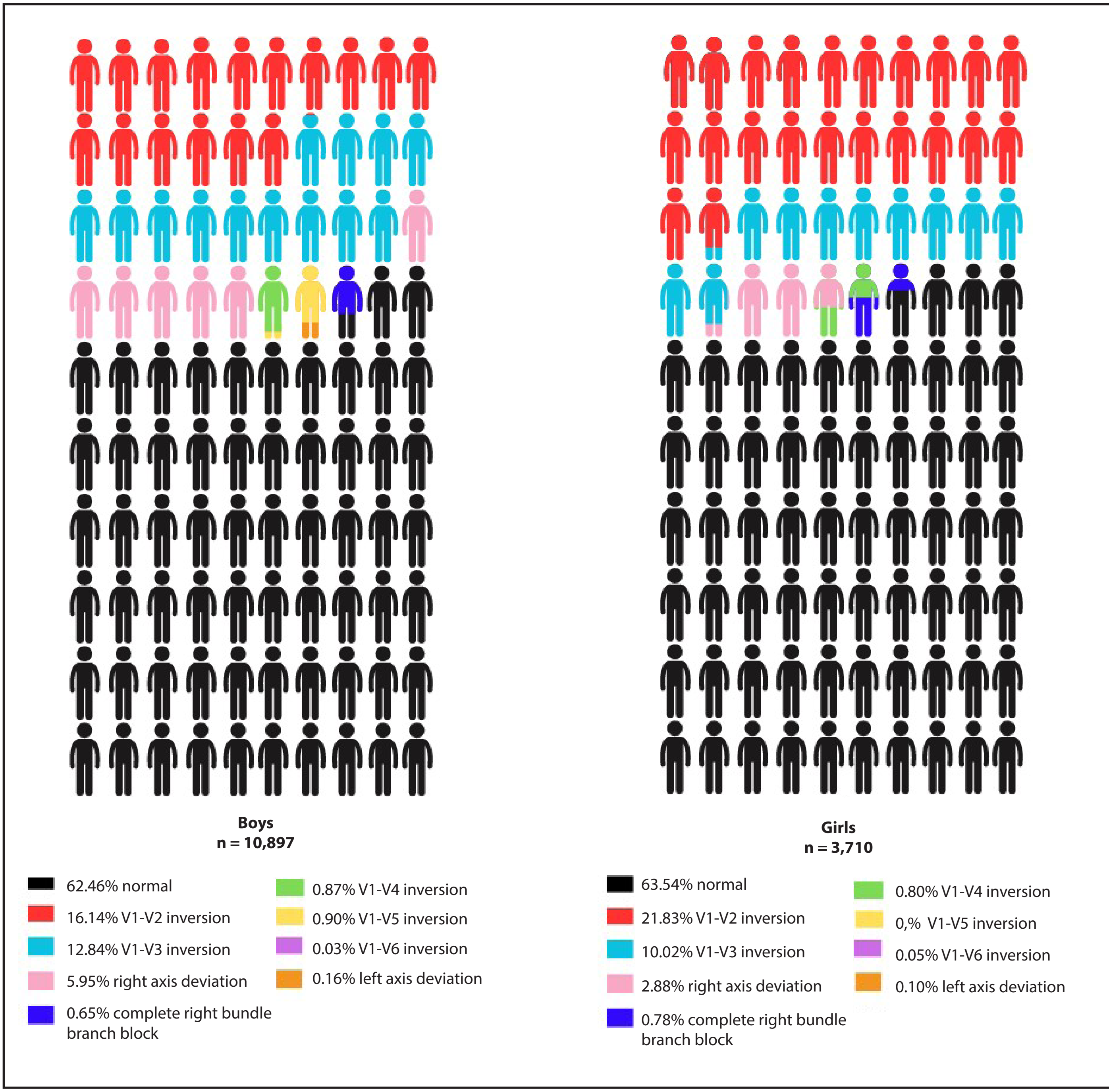


1, as abnormal, or two or more of the changes considered borderline were found.

The following variables were measured:

- Gender: dichotomous qualitative variable. Male/Female.
- Sport: categorical qualitative variable: football, basketball, handball, volleyball, rugby, swimming, athletics, futsal, padel and tennis.
- Age: quantitative variable.
- Prior cardiac diseases: dichotomous qualitative variable. Yes/No.
- Family history: categorical qualitative variable: cancer, diabetes, high blood pressure and cardiopathies.
- Blood pressure: continuous quantitative variable.
- Weight, height and body mass index: continuous quantitative variable.
- Heart rate: continuous quantitative variable.
- SEATTLE 2017 criteria: increased voltage, incomplete right bundle branch block, early repolarisation, juvenile population T-wave

Figure 3. Prevalence of repolarisation disorders by gender and borderline findings.



pattern, bradycardia and sinus arrhythmia, fewer than 2 ventricular extrasystoles in 10'', atrial or AV junctional rhythm, 1st degree AV block, Mobitz 1 2nd degree AV block, right bundle branch block, right axis deviation, left axis deviation, Mobitz 2 2nd degree AV Block, V4 T-wave inversion, left bundle branch block, type 1 Brugada pattern, more than 2 ventricular extrasystoles in 10''. Categorical qualitative variable.

Statistical Analysis

To summarise the data, quantitative variables were expressed as averages alongside their standard deviation while qualitative variables were reported as frequencies and percentages. In terms of graphics, pictograms were used as ancillary data representation tools. The data from analysis of the ECGs were recorded as one ordinal qualitative variable and categorised as normal, borderline or pathological.

Results

The sample for this study included 14,608 athletes (74.59% men and 25.41% women), of whom over 97% were of Caucasian ethnicity. These athletes were engaged in federated sports in Spain, with football and basketball being the most commonly played sports (90%). The athletes were of ages between 11 and 16 years (11 years, n = 1,191; 12 years, n = 2,389; 13 years, n = 1,682; 14 years, n = 940; 15 years, n = 6,963; 16 years, n = 1,475).

Table 2 shows detailed information about the anthropometric measurements and other characteristics of the study population.

Table 1 shows the electrocardiographic findings that were considered non-pathological, borderline and abnormal in this population. These findings encompass a broad spectrum of electrical manifestations related to the physiological changes associated with the practice of sport and specific characteristics of the age.

The most common normal finding observed in our study was repolarisation disorder (14.27%) according to the Sokolow criteria[15], respiratory sinus arrhythmia and sinus bradycardia, representing 8.13% of cases and incomplete right bundle of His block (6.07%). The prevalence of these normal findings varied according to gender and age (Figure 1). The majority of athletes exhibited negative T-waves in the precordial leads, this being most prevalent in the V1-V2 leads (20% in children and 16.99% in adolescents). Another sub-group showed negative T-waves that extended to the V1-V3 leads, known as the juvenile pattern. Both findings were similar in the two age groups (12.98% in children and 12% in adolescents), with minimal differences between genders (12.84% in boys and 10.02% in girls). A small percentage of athletes (0.86%) presented negative T-waves that extended to the V4 (127 cases) and V5 (12 cases) leads. Furthermore, ST segment depression was not present in the participants (Figure 2).

Discussion

This study seeks to provide valuable information about the findings from ECGs among paediatric and young adolescent athletes in Spain, with a specific focus on comparing results based on age and gender. It is important to note that only limited data is currently available in literature about this specific population and the international criteria for under-11 athletes have yet to be validated for optimising pre-participation evaluations in young athletes[16]. The low prevalence of abnormal findings in the ECG (1.34%) observed in this population further emphasises the importance of using the refined Seattle criteria as a sensitive and specific technique for effective detection in young athletes.

The findings from this study revealed that a proportion of athletes presented non-pathological electrocardiographic readings that were appropriate for their age[17]. Furthermore, differences were observed between the different age groups and genders[10]. More specifically, within our sample, the adaptive findings related to participation in sport were more common among young adolescents and boys[18], the majority of whom are athletes. It is important to mention that the repolarisation alterations showed low specificity in the detection of cardiac diseases due to its high prevalence among young healthy athletes[19]. In particular, the study revealed a low prevalence of bradycardia in the sample. The adaptive alterations related to participation in sport were more common in adolescents, potentially due to the increased volume of exercise performed. Examples of such findings include: sinus bradycardia, first-degree atrioventricular (AV) block and early repolarisation.

On the other hand, the normal findings that predominantly appeared in the paediatric group were associated with the young age of the athletes, such as sinus arrhythmia and the juvenile T-wave pattern.

The presence of ECG anomalies in under-12 federated athletes justifies a careful interpretation before attributing them to physiological adaptations of the heart in the athlete. This is particularly important given their low prevalence (1.34%), as shown in Figure 1. Significant differences were observed in our study between age groups and genders. Nonetheless, this may be biased due to the low prevalence of these anomalies. Most of these anomalies (72.58%) were repolarisation irregularities in precordial leads that extended beyond V3 to V4 and V5, more frequent in males (77.62%).

This study sought to investigate the prevalence of abnormal ECG findings in adolescent athletes in Spain. Part of this analysis was focused on the presence of negative T-waves in specific leads and their correlation with pathology. Specifically, the prevalence of negative T-waves extending to the V1-V3 leads was assessed, known as the juvenile pattern[20]. The study also examined possible differences based on age and gender. The majority of athletes exhibited negative T-waves to the V1-V3 leads (12.06%), in accordance with the juvenile pattern[21]. In particular, these findings were more prevalent among male children and adolescents. Despite the relatively high prevalence of these findings, they were considered within normal range given that their association with cardiac pathology has shown a poor correlation in several studies[22].

A small percentage of athletes (0.86%) showed negative T-waves that extended to the V4 (127 cases) and V5 (12 cases) leads, which required further investigation and cardiological monitoring to exclude possible diseases of the myocardium[23].

These findings raise concerns about the possibility of underlying cardiac pathologies, such as latent cardiomyopathy or myocarditis. In an exhaustive study involving 2,765 Italian children subjected to pre-participation detection tests, it was determined that the prevalence of right precordial T-wave inversion was 5.7% and that this prevalence fell after puberty. In particular, 2.5% of those children with T-wave inversion were diagnosed with cardiomyopathy. These findings emphasise the critical importance of conducting additional assessments in cases of T-wave inversion to effectively prevent sudden cardiac death during sports activities[24]. Furthermore, the combination of J-point elevation and T-wave inversion restricted to the V1-V4 leads offers a reliable method for precisely distinguishing between "physiological" and "cardiomyopathic" anterior T-wave inversion in athletes of diverse ethnic origin. On the other hand, the presence of ST segment elevation without prior J-point elevation in anterior T-wave inversion may serve as an indication of underlying cardiomyopathy[25]. Appearance of a QRS duration >120 milliseconds was rare in this study[26], with right bundle branch block being the most frequent (0.6%). However, this is considered a borderline finding under the latest international criteria when it is an isolated finding and unrelated to other abnormalities[27].

Significant abnormal findings in resting ECGs on this 11-16 year-old population differ from those of the general population of athletes and are rather uncommon, presenting in only 1.34%[28]. In general, the incidence of pathological findings in this study is low. However, the possibility of underlying heart disease should not be ignored, especially in those cases in which additional risk factors also exist.

Nonetheless, recent publications have posed questions regarding the effectiveness of ECG screening in young athletes. A number of studies have not found any anomalies in the ECG associated with sudden death in 891 athletes who were subjected to detection tests[29]. Although this raises concern, it is important to highlight a significant finding in our sample: 1.34% of children presented abnormal ECG findings. This emphasises the importance of ECG screening in young athletes, from paediatric age[30]. It suggests that early detection via detection exams is valuable as it can identify cardiac anomalies that would otherwise go unnoticed. In general, and while the debate around the effectiveness of ECG screening continues, our study provides valuable evidence to back the usefulness of ECG screening in young athletes, particularly among the paediatric age group.

Although the ECG serves as a detection technique for channelopathies and cardiomyopathies that can cause SCD, its usefulness in young people remains widely debated, in part due to the high rates of false positives. With only 1.34% of abnormal ECGs in our sample, we can conclude that the false positives are low and similar to those from older athletes[30], indicating that general criteria can be used in this age group. This same percentage was also reported in a Swiss cohort study[31] and slightly higher in a study on Italian footballers[32], which is important to note because the abnormal findings included such alterations as RBB and negative T-wave in V1-V3. A higher percentage was also reported in a 2017 article by Graziol, *et al.*[33], but the refined Seattle criteria were not applied in this study for interpretation; only the previous criteria published in 2013.

The interpretation of ECG values must consider the age and characteristics of the athlete[34], according to available literature and the findings from this study. The differences observed in ECG results between paediatric and young adolescent athletes and the general population have practical implications for clinical decision-making, such as assessment of sports aptitude, suspected pathology, the performance of complementary cardiology tests and monitoring.

One limitation of this study is the lack of a control group (i.e. non-trained adolescents) for comparison purposes. However, similar results were reported in previous studies that also lacked control groups. Other limitations include the high percentage of male participants, the predominance of footballers and the uniformity of the sample in terms of race/ethnicity. Furthermore, this study was conducted at only one medical centre, is cross-sectional and strictly descriptive, which excludes causal inferences with regard to the link between training type, sports history and the findings observed in the ECG. For future lines of action, it would be interesting to conduct bi- and multi-variable analyses on the data in order to produce solid evidence for some of the hypotheses supported in this text.

Conclusion

In short, this study provides an exhaustive analysis of the typical ECG findings in paediatric and young adolescent athletes, as well as rare abnormalities that may indicate an underlying heart disease. These findings can be compared with similar populations consisting of 11-16 year-old age and gender groups. The low prevalence of abnormal findings in this population (1.34%) supports use of the refined Seattle criteria as a sensitive and specific technique for detection in paediatric and young adolescent athletes.

These ECG findings are especially valuable for decision-making in young athletes of both genders, similar to those included in this study. The results of this study may help to steer future research and inform clinical practice, ultimately promoting the health and safety of paediatric and young adolescent athletes.

Conflict of Interest

The authors declare no conflict of interest whatsoever.

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