Electrocardiographic screening in paediatric and adolescent athletes: a 6-year prospective observational study from a Swiss mass-participation race

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Summary

INTRODUCTION: Pre-participation cardiovascular screening with resting 12-lead electrocardiography (ECG) is recommended by most sports societies to detect conditions associated with sudden cardiac death. While the ideal age to initiate screening remains controversial, an expert consensus paper written in Switzerland suggested starting ECG screening at 15 years of age. As part of the Swiss multicentre prospective ECG screening study (Swiss PAED), we initiated an ECG screening programme in 2018 in conjunction with the Course de l'Escalade, a popular Geneva running event attracting over 10,000 children and adolescents annually.

METHODS: This prospective observational study was conducted between 2018 and 2024 (excluding 2020 due to the COVID-19 pandemic) during the Course de l'Escalade in Geneva, Switzerland. Competitive athletes aged 8–17 years training ≥6 hours per week in organised sport and without known cardiac disease were invited to undergo pre-participation cardiovascular evaluation including medical history, physical examination and resting 12-lead ECG. ECGs were interpreted according to the 2017 international criteria for athlete ECG interpretation and classified as normal, borderline or abnormal. Abnormal ECGs were referred for specialist cardiology evaluation.

RESULTS: A total of 428 athletes (239 boys; mean age 12.9 [2.7] years) were enrolled. Normal variants were observed in 298/428 athletes (69.6%), most frequently sinus arrhythmia (183/428, 42.8%). Borderline findings in isolation occurred in 30/428 athletes (7.0%), most often right atrial enlargement (16/30, 3.7%). Abnormal findings were detected in 7/428 (1.6%) athletes, among whom 2/7 were subsequently found to have a condition associated with sudden cardiac death: Wolff–Parkinson–White pattern.

CONCLUSION: ECG-based screening during the Course de l'Escalade identified abnormal findings in 1.6% of young athletes among whom 2/7 were found to harbour a disease associated with sudden cardiac death. Current international interpretation criteria performed well in this population of young competitive athletes.

Introduction

Sudden cardiac death is the leading medical cause of death during physical activity in young athletes [1]. Sudden cardiac death incidence varies across populations, with the highest rates reported in adolescent football players, up to 1 in 14,800 athlete-years [1, 2]. Most cases of sudden cardiac death result from underlying cardiac diseases that predispose to malignant arrhythmia during exercise [1].

Resting 12-lead ECG screening, as recommended by most sports and medical societies [3–5], is intended to facilitate early detection of underlying disorders associated with sudden cardiac death, as the majority of these conditions manifest with ECG abnormalities [6]. However, athletic training induces benign structural, functional and electrical cardiac adaptations, collectively termed "athlete's heart", that may overlap with pathological findings [7]. International athlete-specific ECG interpretation criteria have been developed to distinguish physiological changes from abnormalities suggestive of underlying disease, thereby improving diagnostic accuracy, reducing false positives and enhancing cost-effectiveness – their most recent update was in 2017 [6, 8].

In Switzerland, participation in organised sports outside school physical education is high among youth aged 10–14 years, averaging 7.5 hours per week according to national surveillance data [9]. Despite this high level of participation, studies focusing on this age group remain limited. Swiss proposals recommend, on an empirical basis, preparticipation cardiovascular evaluation (PPCE) with history and examination from age 12, adding ECG in post-pubertal athletes or those older than 15 years, with the most recent update in 2017 [10]. Compared with adults, children and adolescents show distinct training-related cardiac adaptations, including less left ventricular hypertrophy and age-specific electrical patterns such as T-wave inversion in leads V1–V3 before age 16 [11]. Moreover, early screening is challenged by the low penetrance or incomplete phenotypic expression of sudden cardiac death-associated conditions before puberty, which increases the cost per diagnosis in children [12].

As part of the Swiss multicentre prospective ECG screening study (Swiss PAED), we initiated ECG screening at the Course de l'Escalade in Geneva in 2018, a mass-participation race involving more than 10,000 children and adolescents annually.

The primary outcome of this study was to determine the prevalence and distribution of normal, borderline and abnormal ECG findings according to the 2017 international athlete criteria in a cohort of paediatric athletes undergoing systematic screening. The secondary outcome was to detect cardiac conditions associated with sudden cardiac death confirmed after specialist evaluation.

Methodology

Data were collected over six years (2018–2024, excluding 2020 due to the COVID-19 pandemic) during the Course de l'Escalade in Geneva, one of the largest running events open to the public in Europe. In 2024, the event attracted more than 57,000 participants, including approximately 20,000 individuals aged below 18 years [13]. A dedicated 2000 m² tent with multiple stands and activities served as the study site.

Athletes were recruited on a voluntary basis at a dedicated cardiovascular screening stand during the Course de l'Escalade. Information about the screening programme was disseminated through the event website, local sports clubs and on-site announcements. Potential participants self-presented and were screened consecutively if inclusion criteria were met.

Eligible participants were those who were voluntary athletes aged 8–17 years, engaged in ≥6 hours per week of organised training outside of school sports, and without known heart disease (figure 1). This threshold corresponds to Swiss recommendations defining competitive youth athletes and was used to identify individuals more likely to exhibit training-related cardiac adaptations. Written informed consent was obtained from participants aged 14–17 years with additional parental consent and participant assent for those aged 8–13 years. The study was approved by the local Ethics Committee (Commission Cantonale d'Éthique de la Recherche sur l'être humain, ID 2018-00121).

Athletes (or their parents) completed a general health questionnaire covering demographics and medical history (table 1). A team of 4 doctors, 7 nurses and 1 medical student conducted assessments that included history-taking (sport type and volume, personal and family history of cardiac problems), anthropometric measurements, blood pressure, heart rate, cardiac auscultation and a 12-lead resting ECG performed either before the race or ≥1 hour afterwards to minimise acute exercise effects.

Table 1: Baseline characteristics by sex.

Variable, as mean ± SD or n (%)	Female	Male	Total	p-value
	n = 189	n = 239	n = 428	
Age (years)	13.18 ± 2.73	12.62 ± 2.70	12.87 ± 2.73	0.036
Weight (kg)	45.08 ± 12.13	43.44 ± 12.81	44.7 ± 12.53	0.177
Height (cm)	156.52 ± 12.03	155.61 ± 16.00	156.01 ± 14.37	0.519
Systolic blood pressure (mm Hg)	113.41 ± 9.48	112.49 ± 10.55	112.90 ± 10.01	0.347
Diastolic blood pressure (mm Hg)	69.26 ± 8.80	67.79 ± 7.79	68.44 ± 8.23	0.069
Mean arterial pressure (mm Hg)	81.18 ± 8.11	79.64 ± 7.23	80.32 ± 7.67	0.068
Body mass index (kg/m^2)	18.08 ± 2.98	17.51 ± 2.05	17.76 ± 2.52	0.020
Hours of sport per week	11.01 ± 5.95	9.71 ± 3.78	10.28 ± 4.89	0.036
Type of sport				0.073
... Skill	1 (0.5%)	4 (1.7%)	5 (1.2%)	
... Power	22 (11.8%)	28 (12.0%)	50 (11.9%)	
... Mixed	51 (27.3%)	87 (37.3%)	138 (32.9%)	
... Endurance	113 (60.4%)	114 (48.9%)	227 (54.0%)	

Data on type of sport were available for 420 participants (187 females and 233 males); percentages are calculated among participants with available data.

ECG electrodes were positioned according to standard international recommendations. Examinations were performed in private screened compartments. In female athletes, electrodes were placed beneath clothing as required to ensure correct anatomical positioning while maintaining participant comfort and privacy. ECGs were recorded with the same device each year (Philips PageWriter TC70 cardiograph, Philips, Amsterdam, Netherlands) and analysed according to the 2017 international recommendations for ECG interpretation in athletes [6] with all 11 normal, 5 borderline and 16 abnormal criteria systematically assessed for each ECG. Normal findings were defined as ECG changes considered physiological adaptations to training. Initial ECG interpretation was performed by a final-year medical student trained in athlete ECG interpretation and was systematically reviewed and confirmed by an experienced sports cardiologist with more than 15 years of expertise in athlete ECG assessment (PM). Digitised ECGs in PDF format were reviewed with magnification tools to enhance interpretation accuracy. Automated ECG intervals and axes (PR interval, QRS duration and axis, QT interval, P-wave and T-wave) were systematically checked and manually corrected when necessary; P-wave duration was systematically measured. Athletes with abnormal ECG findings were referred for paediatric cardiology assessment including transthoracic echocardiography and additional investigations when indicated (Holter monitoring, exercise testing or electrophysiological study).

The study was conducted within the Swiss PAED programme and approved by the local Ethics Committee (ID 2018-00121). There was no public protocol registration.

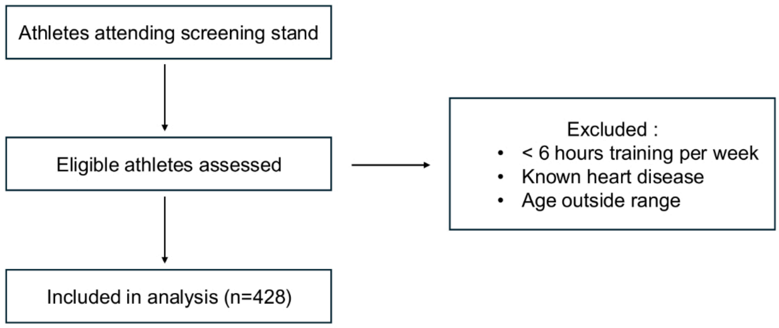
Statistical analysis

Descriptive statistics were used to characterise the study population. Continuous variables are presented as means (SD), given that distributions did not significantly deviate from normality, and categorical variables as absolute counts and percentages. Sex comparisons were performed using the independent Student's t-test for continuous variables, and the chi-squared or Fisher's exact test for categorical variables, as appropriate. Two-sided p-values <0.05 were considered statistically significant. Analyses were performed using IBM SPSS Statistics, version 28.0 (IBM Corp., Armonk, NY, USA).

Results

Over six years, 428 paediatric athletes participated in the screening programme (239 boys [56%], 189 girls; mean age 12.9 (2.7) years) (figure 1).

Figure 1: Flow diagram and inclusion/exclusion criteria. Athletes attending the cardiovascular screening station were assessed for eligibility. Exclusion criteria included training volume <6 hours per week, previously diagnosed cardiovascular disease or age outside the predefined study range (8–17 years). Athletes meeting all inclusion criteria were included in the final analysis (n = 428).



Normal findings

Ninety-two athletes (21.5%) had completely normal ECGs without any findings listed in the international athlete criteria. Normal ECG findings were identified in 298/428 athletes (69.6%), corresponding to 519 findings overall when excluding those present in athletes with borderline or abnormal ECGs (table 2).

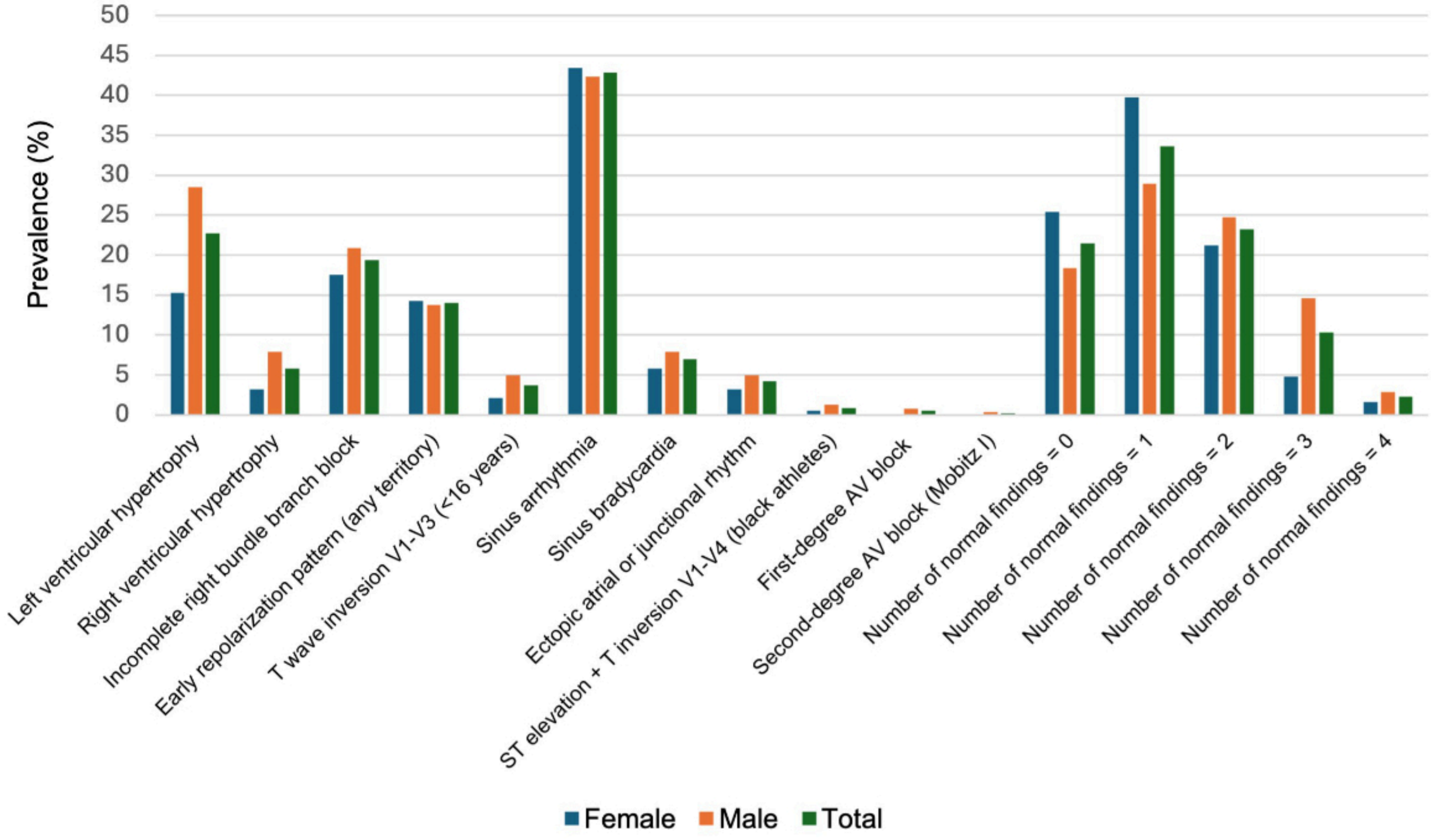
Table 2: Normal findings.

Variable n (%)		Female	Male	Total	p-value (female vs male)
		n = 189	**n = 239**	**n = 428**	
Left ventricular hypertrophy (voltage)		29 (15.3%)	68 (28.5%)	97 (22.7%)	0.002
Right ventricular hypertrophy (voltage)		6 (3.2%)	19 (7.9%)	25 (5.8%)	0.039
Incomplete right bundle branch block		33 (17.5%)	50 (20.9%)	83 (19.4%)	0.391
Early repolarisation pattern (any territory)		27 (14.3%)	33 (13.8%)	60 (14.0%)	0.890
ST elevation + T inversion V1–V4 (Black athletes)		1 (0.5%)	3 (1.3%)	4 (0.9%)	0.634
T-wave inversion V1–V3 (<16 years)		4 (2.1%)	12 (5.0%)	16 (3.7%)	0.131
Sinus arrhythmia		82 (43.4%)	101 (42.3%)	183 (42.8%)	0.844
Sinus bradycardia		11 (5.8%)	19 (7.9%)	30 (7.0%)	0.449
Ectopic atrial or junctional rhythm		6 (3.2%)	12 (5.0%)	18 (4.2%)	0.468
First-degree AV block		0 (0.0%)	2 (0.8%)	2 (0.5%)	0.506
Second-degree AV block (Mobitz I)		0 (0.0%)	1 (0.4%)	1 (0.2%)	1.000
Normal findings (≥1 among the predefined items)		128 (67.7%)	170 (71.1%)	298 (69.6%)	0.460
Number of normal findings	0	48 (25.4%)	44 (18.4%)	92 (21.5%)	0.097
	1	75 (39.7%)	69 (28.9%)	144 (33.6%)	0.023
	2	40 (21.2%)	59 (24.7%)	99 (23.2%)	0.420
	3	9 (4.8%)	35 (14.6%)	44 (10.3%)	<0.001
	4	3 (1.6%)	7 (2.9%)	10 (2.3%)	0.523

AV block: atrioventricular block

The most frequent finding was sinus arrhythmia (42.8%), followed by left ventricular hypertrophy by voltage criteria (22.7%) and incomplete right bundle branch block (19.4%). Anterior T-wave inversion in leads V1–V3 in athletes younger than 16 years was observed in 16 athletes (3.7%). Males were more likely to show left ventricular hypertrophy ($p = 0.002$), right ventricular hypertrophy ($p = 0.039$) and to exhibit three normal findings ($p < 0.001$), whereas females more frequently had only one normal finding ($p = 0.023$). Exploratory age stratification (<12 vs ≥12 years) did not reveal a significant association between age group and the number of normal ECG findings. The prevalence of normal findings is shown in figure 2.

Figure 2: Bar chart of the prevalence of ECG findings classified as normal according to the 2017 international athlete criteria. Bar chart showing the prevalence of each normal ECG finding in females (blue), males (orange) and in the overall sample (green). The y-axis represents prevalence expressed as a percentage and the x-axis lists each ECG finding and shows the number of normal findings per individual (0–4). Participants presenting any borderline or abnormal ECG findings were excluded from the calculation of normal prevalence. Abbreviations: AV: atrioventricular; LVH: left ventricular hypertrophy; RVH: right ventricular hypertrophy.



Borderline findings

Borderline ECG findings were identified in 30 athletes (7.0%), accounting for a total of 31 findings (table 3). One athlete presented with two coexisting borderline findings (right axis deviation and right atrial enlargement) and was therefore classified as abnormal. Right atrial enlargement was the most common borderline finding (3.7%), followed by right axis deviation (1.9%). Complete right bundle branch block was observed in five athletes, with QRS duration ranging from 122 to 138 ms. No left atrial enlargement was detected. No sex-related differences were observed.

Table 3: Isolated borderline findings.

Variable n (%)	Female	Male	Total	p-value (female vs male)
	n = 189	n = 239	n = 428	
Left axis deviation	0 (0.0%)	2 (0.8%)	2 (0.5%)	0.506
Left atrial enlargement	0 (0.0%)	0 (0.0%)	0 (0.0%)	1.000
Right axis deviation	5 (2.6%)	3 (1.3%)	8 (1.9%)	0.310
Right atrial enlargement	4 (2.1%)	12 (5.0%)	16 (3.7%)	0.131
Complete right bundle branch block	0 (0.0%)	5 (2.1%)	5 (1.2%)	0.070
Borderline findings (=1 among the predefined items)	9 (4.8%)	21 (8.8%)	30 (7.0%)	0.128

Abnormal findings

Abnormal ECGs were found in 7 athletes (1.6%) (table 4). These included two cases of pathological Q waves (one in the inferior leads and one in the anterior leads), two cases of ventricular pre-excitation, one case of atrial tachyarrhythmia, and one case of ST-segment depression in leads V3–V4. Abnormal ECGs were more frequent in females (5/189; 2.6%) than in males (2/239; 0.8%).

No additional clinically significant abnormalities were identified through physical examination or questionnaire screening beyond those detected on ECG.

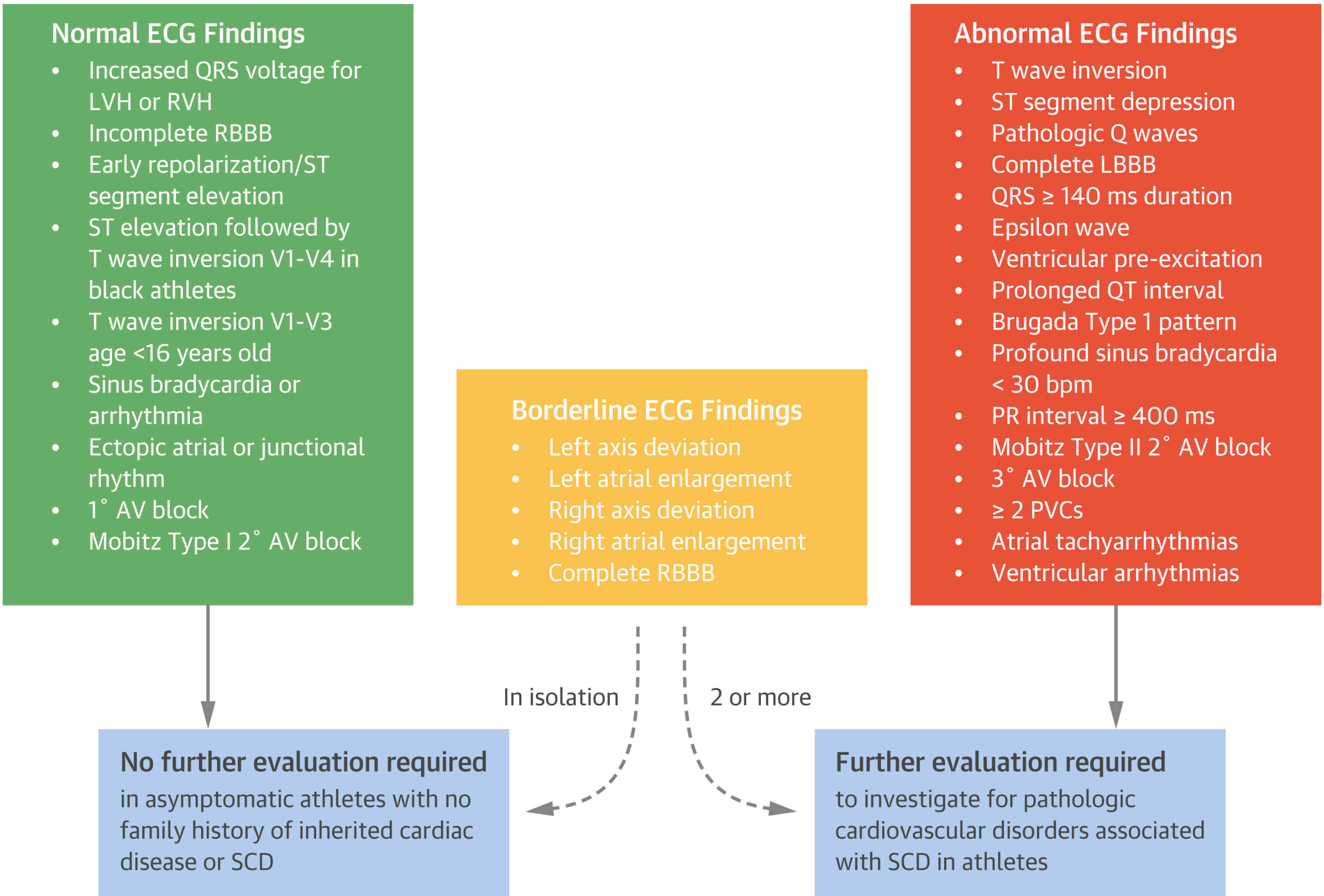
Table 4: Abnormal findings.

Abnormal finding	**Sex**	**Age (years)**	**Physical exam**	**Follow-up**
Pathological Q waves in inferior leads	Male	8	Normal	Normal transthoracic echocardiogram; last phone contact in October 2025; continues competitive running, asymptomatic.
Pathological Q waves in leads V1 and V2	Female	10	Normal	Normal transthoracic echocardiogram. Last phone contact in October 2025; continues competitive soccer, asymptomatic.
Ventricular pre-excitation	Female	11	Normal	Confirmed accessory pathway; normal transthoracic echocardiogram and 24-h Holter. Pre-excitation disappeared on exercise test. Electrophysiological study showed proximity of the pathway to the atrioventricular node, with no inducible arrhythmias. Ablation not performed. Last phone contact in October 2025; continues competitive roller hockey, asymptomatic.
Atrial tachyarrhythmia	Female	11	Normal	Normal transthoracic echocardiogram. Normal 24-h Holter. Last phone contact in October 2025; continues competitive running, asymptomatic.
Two borderline findings: right axis deviation, right atrial enlargement	Male	11	Normal	Normal transthoracic echocardiogram. Last phone contact in October 2025; continues competitive running, asymptomatic.
ST-segment depression (horizontal) in leads V3 and V4	Female	13	Normal	Last follow-up in November 2025; Normal ECG and transthoracic echocardiogram; continues competitive artistic gymnastics, asymptomatic.
Ventricular pre-excitation	Female	14	Normal	Confirmed accessory pathway; normal transthoracic echocardiogram and 24-h Holter. Pre-excitation disappeared on exercise test. Last phone contact in October 2025; continues competitive swimming, asymptomatic; ablation under discussion.

Discussion

We have presented the results of a 6-year, prospective ECG screening study in 428 paediatric athletes aged 8–17 years, performed during the Course de l'Escalade, one of the largest youth sports events in Switzerland. Unlike previous studies, our cohort includes a broad range of young athletes, many of them pre- or early-pubertal, evaluated with a fully standardised methodology using the same digital ECG system and an experienced cardiology team across all editions. ECGs were interpreted according to the 2017 International Recommendations for ECG Interpretation in Athletes [6] (figure 3).

Figure 3: International consensus standards for electrocardiographic interpretation in athletes. Classification of electrocardiographic (ECG) findings in athletes according to the International Recommendations for ECG Interpretation in Athletes. ECG patterns are categorised as normal, borderline or abnormal. Isolated borderline findings in asymptomatic athletes without a family history of inherited cardiac disease or sudden cardiac death generally do not require further evaluation, whereas ≥2 borderline findings or any abnormal finding warrant additional cardiovascular assessment.Abbreviations: AV block: atrioventricular block; LBBB: left bundle branch block; LVH: left ventricular hypertrophy; PVC: premature ventricular contraction; RBBB: right bundle branch block; RVH: right ventricular hypertrophy.Reproduced with permission from the International Recommendations for Electrocardiographic Interpretation in Athletes [6].



Normal ECG variants were highly prevalent, detected in 69.6% of participants, with a mean of 1.5 (1.18) normal variants per male athlete and 1.1 (0.93) per female. These results confirm the ubiquity of physiological ECG adaptations in youth, consistent with prior reports describing sinus bradycardia, early repolarisation and incomplete right bundle branch block as the most frequent patterns [14, 15]. The application of modern interpretation criteria remains crucial to correctly distinguish these benign adaptations from pathological findings [6].

Borderline findings were observed in 7% of athletes, most commonly right atrial enlargement and axis deviation. When isolated, such findings are generally benign, but in combination they warrant further investigation to exclude underlying disease [6]. Their prevalence in our study was relatively low and comparable to earlier reports in Swiss paediatric athletes [8, 12]. Sex differences were not significant, although complete right bundle branch block tended to be more frequent in males. The limited number of cases prevents firm conclusions, but our data provide descriptive benchmarks for this age group.

Abnormal ECGs were found in 7 athletes (1.6%), in line with prior paediatric cohorts [12]. These included pathological Q waves, ventricular pre-excitation, atrial tachyarrhythmia and ST-segment depression. Two athletes were ultimately diagnosed with ventricular pre-excitation (Wolff-

Parkinson-White pattern), consistent with its predominance among cardiac disorders associated with sudden cardiac death in a large cohort of over 11,000 adolescent soccer players, where it accounted for 61% of all diagnoses [2]. The other five abnormal cases were not associated with a cardiac diagnosis upon thorough paediatric cardiology assessment at follow-up. Although numbers are small, these results highlight the clinical value of resting ECG to identify potential sudden cardiac death substrates in young athletes.

Our results also confirm known sex differences in ECG expression. Males showed more left and right ventricular hypertrophy and were more likely to present with multiple normal findings, reflecting greater physiological cardiac adaptation compared to females. By contrast, borderline findings did not differ significantly between sexes, possibly due to sample size limitations. Abnormal ECGs were more frequent in female athletes (2.6%) than in males (0.8%). However, this difference did not reach statistical significance and may reflect the small number of cases. Whether sex-related differences in abnormal ECG patterns exist in the paediatric athletes is not well established in the literature. Unlike normal and borderline findings, abnormal findings are not linked to training-induced adaptation but may reflect intrinsic pathology. Their detection justifies further evaluation and, in selected cases, restriction from competitive sports.

Comparisons with previous Swiss data are reassuring. In a retrospective analysis, 75.4% of athletes showed normal variants, comparable to our prospective rate of 69.6% [12]. Borderline findings were slightly more frequent in our study (7.0% vs 4.3%), although small numbers preclude definitive conclusions. Overall, the distribution of normal and borderline ECG features in paediatric athletes appears consistent across Swiss cohorts.

Sudden cardiac death in athletes, although rare, remains the leading cause of death during exercise, with an incidence of 1 per 14,800 athlete-years reported in adolescent football players [2]. In our study, two athletes (0.5%) were identified with a condition associated with sudden cardiac death: Wolff–Parkinson–White syndrome in both. While this number is small, it demonstrates the potential of early ECG screening to detect conditions predisposing to sudden cardiac death before symptoms occur. Although our study was not designed to determine the optimal age for initiation of ECG screening, the identification of sudden cardiac death-associated conditions in athletes younger than 15 years suggests that clinically relevant abnormalities may occur before mid-adolescence. These findings support consideration of ECG-based screening in competitive youth athletes before the age currently suggested in some national recommendations. This study has several limitations. Recruitment at a single event may have underrepresented athletes from power- or skill-based sports; however, the Course de l'Escalade attracts more than 10,000 children and adolescents across multiple disciplines, so the cohort was not restricted to running specialists. Training hours were self-reported and may have been overestimated. Pubertal staging and hormonal status were not assessed, limiting interpretation of sex-related differences and mechanistic inferences. Although the cross-sectional nature of the screening assessment limits longitudinal evaluation of outcomes, follow-up phone calls were conducted for participants with abnormal ECGs. Finally, the timing of ECGs around the race may have introduced minor residual effects of exertion, although most were performed ≥1 hour post-race. A major strength is the methodological consistency: the same equipment, standardised digital ECG acquisition and largely the same medical team were used across six years, ensuring robust and reproducible data quality.

Conclusion

ECG-based screening during six editions of the Course de l'Escalade identified abnormal ECG findings in 1.6% of paediatric athletes, with two cases of ventricular pre-excitation (Wolff-Parkinson-White pattern) detected. The prevalence and distribution of ECG findings were consistent with previous reports in young athletes. These results support the applicability of current international ECG interpretation criteria in paediatric populations and highlight the potential value of ECG screening in competitive youth athletes.

Data sharing statement

The datasets generated and analysed during the current study, including all deidentified individual participant data (including ECG classifications and demographic variables) are available from the corresponding author upon reasonable request for academic research purposes, subject to institutional approval and data protection regulations. Data will be available for 5 years following publication.

Financial disclosure

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Potential competing interests

All authors have completed and submitted the International Committee of Medical Journal Editors form for disclosure of potential conflicts of interest. No potential conflict of interest related to the content of this manuscript was disclosed.

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