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Original research

Resting ECG findings in male Brazilian soccer players of different ethnicities: Results from the B-Pro Foot ECG study

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ABSTRACT

Objectives: To compare the prevalence of training-related ECG findings in white, mixed-race, and black male Brazilian soccer players.
Design: Multicenter observational study.
Methods: This study involved athletes aged 15 to 35 years from 82 professional clubs across Brazil's five regions. It included athletes who underwent preparticipation cardiovascular screening between February 2002 and September 2023.
Results: A total of 6125 players (median age: 18) were included (2496 white, 2004 mixed-race, and 1625 black). Ninety-seven percent of the ECGs were normal. Sinus bradycardia was observed in 50.1 %, while left ventricular hypertrophy in 35.1 %, with a higher prevalence in black players (41.7 %) compared to white (31.7 %) or mixed-race (34.1 %) players. Early repolarization was most prevalent among black athletes (48.2 %) compared to white (34.3 %) and mixed-race (40.5 %) athletes. The mean PR interval was 153.0 ms, higher in black players (156.8 ms) than in white (150.6 ms) or mixed-race (152.8 ms) players. Black athletes had more first-degree AV block (4.1 %)

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compared to mixed-race athletes (2.7 %). Conversely, white athletes (15.4 %) had more incomplete right bundle branch block than mixed-race (11.4 %) or black (9.8 %) athletes. The 'African/Afro-Caribbean pattern' was found in 1.8 % of black players.

Conclusions: Ninety-seven percent of male Brazilian soccer players had normal ECG patterns. Training-related ECG findings were more common in black players compared to white or mixed-race players. The 'African/Afro-Caribbean pattern' was rare in black players.

Practical implications

- This study revealed the ECG characteristics of an ethnically diverse male Brazilian athletic population, showing a high (97 %) overall rate of normal ECG patterns.
- Black players had a higher prevalence of training-related ECG changes compared to their white and mixed-race counterparts.
- The 'African/Afro-Caribbean pattern' among black male Brazilian soccer players was significantly less prevalent than what has been observed in other international cohorts.
- These results have the potential to enhance the precision of ECG interpretations among athletes from diverse ethnic backgrounds, while also encouraging further research in this field.

1. Introduction

Participation in prolonged and intense physical training can induce remarkable physiological adaptations in the cardiovascular system, often recognized as 'athlete's heart'.[1] These adaptations become evident in the analysis of the 12-lead resting electrocardiogram (ECG), a valuable and cost-effective tool for preparticipation cardiovascular screening in athletes.[2–4]

Soccer occupies a prominent position as the most extensively played and loved sport in Brazil. Due to the remarkable ethnic diversity in Brazil, Brazilian athletes may have genetic variations that can influence ECG changes. In addition to this challenge, the existing guidelines for interpreting athletes' ECGs currently do not encompass the mixed-race ethnicity,[5] which further complicates the accurate assessment of these cardiovascular adaptations.

Numerous studies have explored the prevalence of training-related ECG changes among athletes worldwide.[6–13] Nevertheless, there is a noticeable gap in knowledge about the prevalence of such changes in male Brazilian soccer players and the potential influence of ethnicity on normal ECG results. Brazil is a highly miscegenated country with a significant proportion of mixed-race individuals. Consequently, relying on data from athletes from diverse continents to evaluate these mixed-race athletes can lead to potentially misleading interpretations. In this study, we aimed to investigate and compare the prevalence of training-related ECG findings in white, mixed-race, and black male Brazilian soccer players.

2. Methods

2.1. Study design and data sources

The B-Pro Foot ECG is a multicenter, observational study carried out in the five regions of Brazil (North, South, Northeast, Southeast, and Midwest), encompassing 18 states and 56 cities (Table S1). This study was approved by the Research Ethics Committee of the Research and Postgraduate Group of the Hospital de Clínicas de Porto Alegre, Brazil (GPPG-HCPA; number 2019-0050), and follows Resolution no. 466/12 of the National Health Council.

In this study, data were collected from players who underwent preparticipation cardiovascular screening at 82 professional soccer clubs from February 18, 2002 to September 18, 2023 (Fig. 1). The sample included athletes from all 20 first division soccer teams and from 18 out of the 20 s division soccer teams, all actively participating in the 2023 Brazilian soccer championship.

The International Federation of Football Association and the Brazilian Football Confederation adhere to policies that advocate an annual preparticipation exam for all athletes, as recommended by the Brazilian Society of Cardiology.[14] This screening protocol includes a cardiovascular-focused history, a physical examination, and an ECG.

2.2. The 12-lead resting ECG

The standardized ECG recordings were conducted using a Wincardio System (Micromed, DF, Brazil), EP 12 digital apparatus (Dixtal, SP, Brazil), or a digital ECG PC (TEB, version 5.0, MG, Brazil), at a paper speed of 25 mm/s and a voltage of 10 mm/mV. The analysis was carried out in accordance with the most recent International Criteria for Electrocardiographic Interpretation in athletes.[5]

The initial interpretation of the ECGs was conducted by a researcher (F.F.) with extensive training in interpreting athletes' ECGs. Subsequently, two cardiologists (A.D.S. and R.S.) with significant expertise in sport cardiology independently reviewed the ECGs, remaining blinded to the athletes' characteristics, including ethnicity. To increase the accuracy of the analysis, factors such as the duration and amplitudes of waves, axes, segments, J point, and intervals were meticulously examined by scanning and magnifying the ECGs on a computer. All variables were systematically recorded and documented in a standardized Microsoft Excel spreadsheet.

Various parameters were collected from the ECGs, including sinus bradycardia, left ventricular hypertrophy (LVH), atrioventricular block (AV) (first-degree, or second-degree Mobitz I), incomplete right bundle branch block (RBBB), T-wave inversion in leads V1 to V4 preceded by convex ST-segment elevation (in black players), and early repolarization. Lastly, the parameters considered "borderline" (complete RBBB, left or right axis deviation, and right or atrial enlargement) were classified as 'normal' only if present in isolation.[5] Table 1 details the specific criteria used for identifying normal and borderline ECG findings.

2.3. Participants

We collected fully anonymized data from male Brazilian soccer players aged from 15 to 35 years. In addition to demographic information such as ethnicity, the athletes' height, body weight, and field position were assessed. The main exclusion criteria encompassed players of nationalities other than Brazilian or those for whom there was no information on age or ethnicity. The researchers determined ethnicity by assessing skin color and phenotypic characteristics, including nose shape and hair texture.[15] Athletes with parents of different racial backgrounds (e.g., one parent is black and the other is white) were classified as mixed-race.[15,16]

2.4. Statistical analysis

Continuous variables were described as mean ± standard deviation or median and quartiles as appropriate, while categorical variables were presented as absolute and relative frequencies. The normality of the data was assessed by visual inspection of the histograms. The Poisson

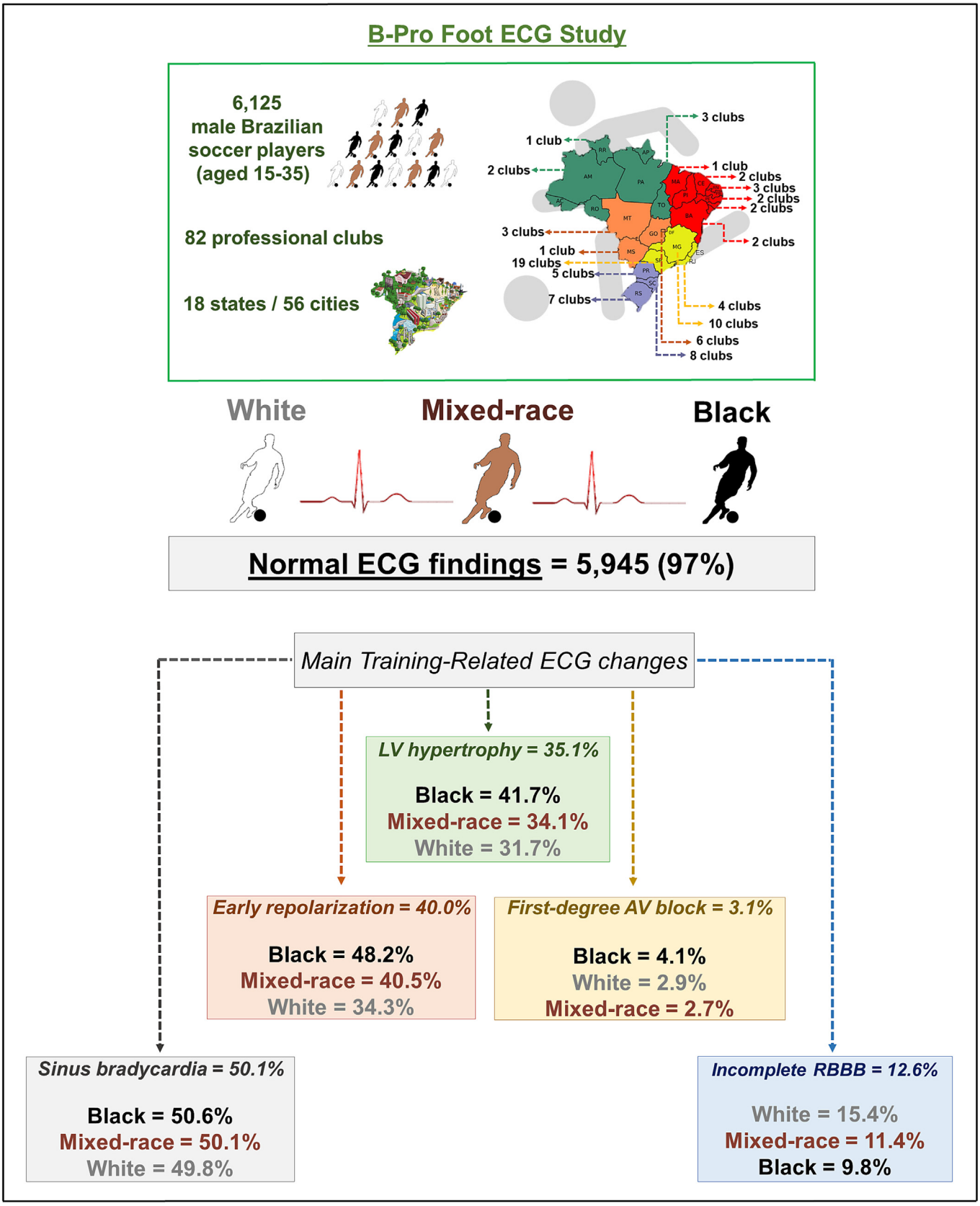

Fig. 1. The B Pro-Foot ECG.
Legend: AV, atrioventricular; LV, left ventricular; RBBB, right bundle branch block.

Table 1
Normal ECG findings.

Normal ECG findings	Definition
Sinus bradycardia	Heart rate <60 and >30 beats per minute
Early repolarization	J-point by ≥0.1 mV associated with a late QRS slurring or notching (J-wave) in inferior and/or lateral leads
Incomplete right bundle branch block	RSR' pattern in V1 to V3 with QRS duration of 100 to 119 ms
Left ventricular hypertrophy	S wave in V1 plus R wave in V5 or V6 ≥35 mm (Sokolow-Lyon criteria)
First-degree atrioventricular block	PR interval of 201 to 399 ms
African/Afro-Caribbean pattern in black athletes	J-point elevation and convex ST-segment elevation followed by T-wave inversion in leads V1 to V4
Mobitz type I second-degree atrioventricular block	PR interval progressively lengthens until there is a non-conducted P-wave with no QRS complex; the first PR interval after the dropped beat is shorter than the last conducted PR interval
Borderline ECG findings[a]	**Definition**
Left axis deviation	−30° to −90°
Right axis deviation	>120°
Left atrial enlargement	P wave duration ≥120 ms in DI or DII or Morris index (P wave ≥1 mm in depth and ≥40 ms in duration in lead V1)
Right atrial enlargement	P wave amplitude ≥0.25 mV in DII, DIII or AVF
Complete right bundle branch block	rSR' pattern in V1 to V3 with QRS duration ≥120 ms

[a] Only if present in isolation.

regression model with robust variance was used to compare prevalences and a linear model was used to compare the mean values of ECG parameters between ethnicities. Thus, the results of the association were expressed as prevalence ratios and mean differences adjusted by age (categorized as 15 to 17, 18 to 25, and 26 to 35 years), body mass index (≤22 kg/m^2 or >22 kg/m^2), and field position (goalkeeper, center-back, wing-back, midfielder, and forward), with a 95 % confidence interval (CI). A P value <0.05 was considered significant. Statistical analyses were performed using R software, V.4.3.2.

3. Results

3.1. Baseline characteristics

The overall sample consisted of 6125 male Brazilian soccer players with a median age of 18 years (16 to 23). Among these athletes, the majority were white (2496; 40.8 %), followed by mixed-race (2004; 32.7 %) and black (1625; 26.5 %). In terms of field positions, the sample included 588 goalkeepers, 1131 center-backs, 852 wing-backs (right or left), 1992 midfielders, and 1562 forwards. Table 2 details the demographic characteristics of the players.

3.2. ECG

In total, 5945 players showed normal ECG patterns, making up 97 % (95 % CI, 96.6 to 97.5) of the sample (Fig. 1). In the entire sample, the prevalence of sinus bradycardia was observed in 50.1 %. The mean PR interval was 153.0 ms, revealing significant differences between ethnic groups. Specifically, black athletes showed a longer PR interval (156.8 ms) compared to white (150.6 ms) and mixed-race (152.8 ms) athletes, and mixed-race athletes had a longer PR interval than white athletes. Overall, the mean QRS duration was 93.4 ms, with white (94.3 ms) athletes showing a longer QRS duration than mixed-race (93.2 ms) and black (92.4 ms) athletes. The mean corrected QT interval was 401.8 ms, and no significant differences were observed between the three ethnic groups (Table 3).

3.3. Training-related ECG changes

The prevalence of LVH was found to be 35.1 %, and higher in black players than in white (41.7 % vs. 31.7 %, adjusted PR [aPR]: 1.3; 95 % CI, 1.2 to 1.5; $P < 0.0001$) and mixed-race players (41.7 % vs. 34.1 %, aPR: 1.2; 95 % CI, 1.1 to 1.4; $P = 0.0001$). The prevalence of early repolarization was 40.0 %, and was higher in black athletes compared to white (48.2 % vs. 34.3 %, aPR: 1.4; 95 % CI, 1.2 to 1.5; $P < 0.0001$) and mixed-race athletes (48.2 % vs. 40.5 %, aPR: 1.2; 95 % CI, 1.1 to 1.3; $P = 0.003$). In addition, it was higher in mixed-race athletes than in white athletes (40.5 % vs. 34.3 %, aPR: 1.2; 95 % CI, 1.1 to 1.3; $P = 0.005$).

The prevalence of incomplete RBBB was 12.6 %, with a higher occurrence in white players compared to mixed-race (15.4 % vs. 11.4 %, aPR: 1.3; 95 % CI, 1.1 to 1.6; $P = 0.0004$) and black players (15.4 % vs. 9.8 %, aPR: 1.6; 95 % CI, 1.3 to 1.9; $P < 0.0001$). The prevalence of first-degree AV block was 3.1 %. It was higher in black athletes compared to mixed-race athletes (4.1 % vs. 2.7 %, aPR: 1.5; 95 % CI, 1.0 to 2.2; $P = 0.03$). Second-degree Mobitz I was rare (0.07 %) and found in two mixed-race athletes and two black athletes. Among 1625 black athletes,

Table 2
Demographic characteristics of male Brazilian soccer players.

Variable	Normal ECG patterns				Abnormal ECG patterns			
	Total	White	Mixed-race	Black	Total	White	Mixed-race	Black
	N = 5945	N = 2426	N = 1946	N = 1573	N = 180	N = 70	N = 58	N = 52
Age (years)	18 (16–23)	18 (16–23)	18 (16–23)	19 (16–23)	20 (17–26)	18 (17–23)	23 (17–26)	22 (18–26)
15 to 17 (%)	2441 (41.1)	1013 (41.8)	847 (43.5)	581 (36.9)	57 (31.7)	25 (36.8)	18 (32.1)	14 (25.0)
18 to 25 (%)	2452 (41.2)	988 (40.7)	759 (39.0)	705 (44.8)	74 (41.1)	27 (39.7)	24 (39.3)	23 (48.2)
26 to 35 (%)	1052 (17.7)	425 (17.5)	340 (17.5)	287 (18.3)	49 (27.2)	18 (23.5)	16 (28.6)	15 (26.8)
Height (cm)	178.0 ± 8.0	178.6 ± 8.9	177.0 ± 8.0	178.8 ± 7.5	177.0 ± 7.0	176.2 ± 6.4	177.8 ± 7.2	179.9 ± 6.7
Weight (kg)	72.0 ± 9.0	73.2 ± 9.0	71.7 ± 8.6	73.3 ± 8.3	72.0 ± 9	71.6 ± 9.0	72.6 ± 8.3	75.3 ± 9.0
Field position								
Goalkeeper (%)	582 (9.8)	364 (15.0)	132 (6.8)	86 (5.5)	6 (3.3)	3 (4.3)	3 (5.2)	0 (0.0)
Center-back (%)	1105 (18.6)	409 (16.9)	323 (16.6)	373 (23.7)	26 (14.4)	7 (10.0)	8 (13.8)	11 (21.1)
Wing-back (%)	827 (13.9)	321 (13.2)	279 (14.3)	227 (14.4)	25 (13.9)	8 (11.4)	10 (17.2)	7 (13.5)
Midfielder (%)	1926 (32.4)	835 (34.4)	653 (33.6)	438 (27.9)	66 (36.7)	30 (42.9)	23 (39.7)	13 (25.0)
Forward (%)	1505 (25.3)	497 (20.5)	559 (28.7)	449 (28.5)	57 (31.7)	22 (31.4)	14 (24.1)	21 (40.4)

Age: data expressed as median (quartile 1–quartile 3). Height and weight: data expressed as mean ± standard deviation.

Table 3
ECG-12 parameters of male Brazilian soccer players.

Parameter	Total (N = 6125)	White (N = 2496)	Mixed-race (N = 2004)	Black (N = 1625)	aPR or MD, 95 % CI, and *P*-value[a]
Sinus bradycardia (%)	3.069 (50.1)	1.242 (49.8)	1.005 (50.1)	822 (50.6)	Black vs. White: aPR = 1.0 (0.9 to 1.1); $P = 0.82$ Black vs. Mixed-race: aPR = 1.0 (0.9 to 1.1); $P = 0.96$ Mixed-race vs. White: aPR = 1.0 (0.9 to 1.1); $P = 0.85$
PR interval (ms)[b]	153.0 ± 28.0	150.6 ± 27.1	152.8 ± 27.8	156.8 ± 29.1	Black vs. White: MD = 5.9 ms (3.9 to 8.0); **$P < 0.0001$** Black vs. Mixed-race: MD = 3.6 ms (1.5 to 5.8); **$P = 0.0002$** Mixed-race vs. White: MD = 2.3 ms (0.4 to 4.2); **$P = 0.01$**
QRS duration (ms)[b]	93.4 ± 12.6	94.3 ± 12.9	93.2 ± 12.4	92.4 ± 12.3	White vs. Black: MD = 1.9 ms (0.9 to 2.8); **$P < 0.0001$** Mixed-race vs. Black: MD = 0.8 ms (−0.1 to 1.8); $P = 0.11$ White vs. Mixed-race: MD = 1.0 ms (0.1 to 1.9); **$P = 0.02$**
QTc interval (ms)[b]	401.8 ± 25.0	402.0 ± 26.5	401.8 ± 24.3	401.2 ± 24.1	White vs. Black: MD = 1.1 ms (−0.7 to 2.9); $P = 0.31$ White vs. Mixed-race: MD = 0.5 ms (−1.2 to 2.2); $P = 0.75$ Mixed-race vs. Black: MD = 0.6 ms (−1.3 to 2.5); $P = 0.74$
LV hypertrophy (%)[c]	2.150 (35.1)	790 (31.7)	683 (34.1)	677 (41.7)	Black vs. White: aPR = 1.3 (1.2 to 1.5); **$P < 0.0001$** Black vs. Mixed-race: aPR = 1.2 (1.1 to 1.4); **$P = 0.0001$** Mixed-race vs. White: aPR: 1.1 (1.0 to 1.2); $P = 0.17$
Early repolarization (%)	2.451 (40.0)	857 (34.3)	811 (40.5)	783 (48.2)	Black vs. White: aPR = 1.4 (1.2 to 1.5); **$P < 0.0001$** Black vs. Mixed-race: aPR = 1.2 (1.1 to 1.3); **$P = 0.003$** Mixed-race vs. White: aPR = 1.2 (1.1 to 1.3); **$P = 0.005$**
Incomplete RBBB (%)	773 (12.6)	384 (15.4)	229 (11.4)	160 (9.8)	White vs. Black: aPR = 1.6 (1.3 to 1.9); **$P < 0.0001$** White vs. Mixed-race: aPR = 1.3 (1.1 to 1.6); **$P = 0.0004$** Mixed-race vs. Black: aPR = 1.2 (0.9 to 1.4); $P = 0.13$
First-degree AV block (%)	192 (3.1)	72 (2.9)	54 (2.7)	66 (4.1)	Black vs. White: aPR = 1.4 (1.0 to 1.9); $P = 0.06$ Black vs. Mixed-race: aPR = 1.5 (1.0 to 2.2); **$P = 0.03$** Mixed-race vs. White: aPR = 0.9 (0.7 to 1.3); $P = 0.70$
Mobitz type I second-degree AV block (%)	4 (0.07)	0	2 (0.01)	2 (0.1)	–
T-wave inversion V1 to V4 (%)	29 (0.5)	0	0	29 (1.8)	–
Left axis deviation[d]	54 (0.9)	15 (0.6)	21 (1.0)	18 (1.1)	Black vs. White: aPR = 2.2 (1.0 to 4.9); $P = 0.06$ Black vs. Mixed-race: aPR = 1.1 (0.5 to 2.1); $P = 0.86$ Mixed-race vs. White: aPR = 2.1 (0.9 to 4.5); $P = 0.07$
Right axis deviation[d]	42 (0.7)	17 (0.7)	14 (0.7)	11 (0.7)	White vs. Black: aPR = 1.1 (0.5 to 2.6); $P = 0.76$ White vs. Mixed-race: aPR = 1.2 (0.6 to 2.7); $P = 0.61$ Black vs. Mixed-race: aPR = 1.1 (0.4 to 2.7); $P = 0.87$
Complete RBBB (%)[d]	44 (0.7)	26 (1.0)	11 (0.5)	7 (0.4)	White vs. Black: aPR = 2.4 (1.1 to 5.6); $P = 0.05$ White vs. Mixed-race: aPR = 1.9 (0.9 to 3.8); $P = 0.07$ Mixed-race vs. Black: aPR = 1.3 (0.5 to 3.3); $P = 0.60$
RA enlargement (%)[d]	140 (2.3)	55 (2.2)	43 (2.1)	42 (2.6)	Black vs. White: aPR = 1.2 (0.8 to 1.8); $P = 0.41$ Black vs. Mixed-race: aPR = 1.2 (0.8 to 1.9); $P = 0.37$ Mixed-race vs. White: aPR = 1.0 (0.7 to 1.4); $P = 0.89$
LA enlargement (%)[d]	215 (3.5)	72 (2.9)	70 (3.5)	73 (4.5)	Black vs. White: aPR = 1.5 (1.1 to 2.1); **$P = 0.02$** Black vs. Mixed-race: aPR = 1.3 (0.9 to 1.8); $P = 0.15$ Mixed-race vs. White: aPR = 1.2 (0.9 to 1.7); $P = 0.25$

AV: atrioventricular; LA: left atrial; LV: left ventricular; QTc: corrected QT interval; RA: right atrial; RBBB: right bundle branch block; MD: mean difference; aPR: adjusted prevalence ratio; Values shown in bold are statistically significant.
[a] Adjusted for age, body mass index, and field position.
[b] Mean ± standard deviation.
[c] Sokolow-Lyon criteria.
[d] In isolation, without other borderline criteria.

29 (1.8 %) showed a convex ST-segment elevation followed by T-wave inversion in leads V1 to V4.

The prevalence of isolated left and right axis deviation was 0.9 % and 0.7 %, respectively, with no difference between the three groups. Isolated complete RBBB was found in 0.7 % of athletes, also without significant group differences. Isolated right atrial enlargement occurred in 2.3 % (2.2 %, 2.1 %, and 2.6 % for white, mixed-race, and black athletes, respectively), with no significant ethnic variation. Meanwhile, left atrial enlargement had an overall prevalence of 3.5 % and was more common in black athletes than in white athletes (4.5 % vs. 2.9 %, aPR: 1.5; 95 % CI, 1.1 to 2.1; $P = 0.02$). The prevalence of left atrial enlargement in mixed-race athletes was 3.5 %. Table 3 summarizes the ECG findings for each group, while Table 4 provides an overview of the abnormal ECG findings.

4. Discussion

To the best of our knowledge, this study quantified the prevalence of training-related ECG changes among male Brazilian soccer players of different ethnic backgrounds with the largest multi-ethnic sample to date. The main findings can be summarized as follows: (1) normal ECG patterns were present in 97 % of cases; and (2) black players had a higher prevalence of ECG findings indicative of 'athlete's heart' compared to white and mixed-race players. The diversity of Brazil's population, which has a particularly significant proportion of mixed-race individuals – an ethnic group that is not included in the international guidelines for interpreting athletes' ECGs[5] – emphasizes the importance of understanding the unique ECG characteristics of Brazilian athletes. Furthermore, Brazil emerged as the world's leading exporter of soccer players in the 2022–23 season.[17] This highlights the significance of understanding the distinctive features in the ECGs of Brazilian players, suggesting that this knowledge could be highly valuable to the global sports cardiology community.

Numerous studies worldwide have investigated normal training-induced ECG changes among athletes.[6–13] Riding et al.[9] observed a higher prevalence of first-degree AV block in black African athletes compared to white athletes, and a higher prevalence of incomplete RBBB in white athletes compared to black African athletes. In line with these findings, we identified a higher prevalence of incomplete RBBB in white athletes compared to black athletes. On the other hand, although we also observed a higher prevalence of first-degree AV block in black athletes compared to white athletes, there was no statistical significance ($P = 0.06$). It is important to note that the prevalence of first-degree AV block in black athletes in our sample was lower (4.1 %) than that

Table 4
Abnormal ECG parameters in male Brazilian soccer players.

Parameter	Total (N = 6125)	White (N = 2496)	Mixed-race (N = 2004)	Black (N = 1625)	*P*-value
Overall (%)	180 (3.0)	70 (2.8)	58 (2.9)	52 (3.2)	NS
Prolonged QTc interval (%)	0	0	0	0	–
QRS ≥140 ms (%)	1 (0.02)	1 (0.04)	0	0	–
PR interval ≥400 ms (%)	1 (0.02)	0	0	1 (0.06)	–
Complete LBBB (%)	0	0	0	0	–
≥2 PVCs (%)	3 (0.05)	1 (0.04)	1 (0.05)	1 (0.06)	NS
Mobitz type 2 AV block (%)	0	0	0	0	–
Third-degree AV block (%)	0	0	0	0	–
WPW pattern (%)	2 (0.03)	2 (0.08)	0	0	–
Brugada type 1 pattern (%)	0	0	0	0	–
Pathological Q waves (%)	0	0	0	0	–
ST-segment depression (%)	7 (0.1)	2 (0.08)	3 (0.1)	2 (0.1)	NS
Epsilon wave (%)	0	0	0	0	–
Abnormal TWI (%)	170 (2.8)	63 (2.5)	58 (2.9)	49 (3.0)	NS
Two borderline criteria					
RAD + complete RBBB (%)	1 (0.02)	1 (0.04)	0	0	–

AV: atrioventricular; LBBB: left bundle branch block; PVCs: premature ventricular contractions; RAD: right axis deviation; RBBB: right bundle branch block; QTc: corrected QT interval; TWI: T-wave inversion; WPW: Wolff-Parkinson-White; NS: not significant.

reported in studies by Riding et al.,[9] which involved black African athletes (24 %; mean age: 25 years), and by Papadakis et al.,[7] which included black athletes from the United Kingdom and France (11.2 %; mean age: 23 years). In addition to the potential influence of place of birth on these results, the inclusion of athletes with a higher mean age by these authors may contribute to explaining these differences.

Our results are in line with those by Basavarajaiah et al.,[10] who reported a higher prevalence of voltage criteria for LVH in black athletes compared to white athletes. Similarly, our findings are consistent with those by Malhotra et al.,[16] who found a higher prevalence of LVH in black athletes compared to white and mixed-race athletes. However, in contrast to the latter study,[16] we found no difference in LVH between white and mixed-race athletes.

In our study, we observed a more pronounced pattern of early repolarization in black players compared to white players, which is consistent with previous research.[16,18] Our study revealed a significantly higher prevalence of early repolarization in black players (48.2 %) compared to mixed-race players (40.5 %). Papadakis et al.[7] reported a higher prevalence of complete RBBB in white athletes compared to black athletes (1.2 % vs. 0.3 %; $P = 0.03$). In contrast, our study found no significant differences between the three ethnic groups. To our knowledge, our study is the first to document the prevalence of early repolarization and complete RBBB in mixed-race athletes and to conduct a comparative analysis with athletes from other ethnic backgrounds.

Over a decade ago, Papadakis et al.[7] established that T-wave inversions limited to leads V1 to V4 in black athletes of African/Afro-Caribbean origin should be considered a normal variant of the 'black athlete's heart'. Subsequently, another study involving black soccer players from Ghana identified this variant in 18.7 % of the 159 athletes examined.[12] In a study assessing 154 adolescent African soccer players in eight countries (Algeria, Burkina Faso, Cameroon, Gambia, Guinea, Malawi, Nigeria, and Zimbabwe), di Paolo et al.[19] observed that the prevalence of T-wave inversion in leads V1 to V4 was 6 %. In another study involving 77 elite Nigerian athletes (42 men and 35 women),[20] the prevalence of the dome-shaped ST-segment elevation with T-wave inversion in leads V1 to V4 surpassed that reported in previous studies, reaching 29.3 %. In contrast, our study revealed that the prevalence of this pattern is significantly lower in black male Brazilian soccer players, as only 1.8 % of these athletes were found to have this characteristic. Due to the high level of miscegenation in Brazil, Brazilian athletes may have distinctive genetic traits and a unique combination of ethnicity and training load, which is a possible explanation for this observed difference. Finally, due to the significantly lower prevalence of this pattern in black players, we cannot infer that it is benign. However, in a previous publication,[21] we reported that all echocardiographic results for these athletes were within normal limits, suggesting that this finding is a variant of normality. On the other hand, it is necessary to carry out further longitudinal studies evaluating these athletes.

Our study identified a 97 % prevalence of normal ECG findings in male Brazilian soccer players, indicating a low (3 %) occurrence of abnormal results. Details of these players' abnormal ECG findings and their further evaluations have been published previously.[22] For example, this abnormal ECG rate is lower than the 23 % rate observed in male Ghanaian soccer players.[12] It is worth noting that black African ancestry has been previously established as an independent predictor of uncommon ECG changes when compared to West Asian and white athletes.[23] These results emphasize the significance of an athlete's continent of origin and ethnic characteristics as influential factors in determining their ECG parameters.

4.1. Strengths and limitations

The large sample size and the inclusion of athletes from professional clubs all over Brazil strengthen the validity of our research, allowing us to generalize our findings to the entire population of male Brazilian soccer players with greater confidence. The inclusion of mixed-race individuals contributes to a more comprehensive understanding of ECG variations among this population, which has been very little studied to date. However, we recognize that this study has some important limitations. Our study focused exclusively on soccer players, which limits the generalizability of the results to athletes from other sports. We did not gather data on weekly training hours, which hindered our ability to determine whether the differences observed in the ECGs were associated with training load. Additionally, as we only included male participants, our findings cannot be extrapolated to female athletes in Brazil.

5. Conclusion

Our study reveals a high (97 %) prevalence of normal ECG patterns in male Brazilian soccer players. Furthermore, black athletes showed a higher prevalence of training-related ECG changes compared to white and mixed-race athletes. Lastly, the presence of the 'African/Afro Caribbean pattern' in black athletes was significantly lower than that observed in other international cohorts.

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CRediT authorship contribution statement

Study conception and design: F.F., A.D.S., R.S.; data acquisition: F.F., A.D.S., H.C.A., G.D.D., L.G.M.E., F.C.O.M., F.B.C., H.C.S., F.E.F.G, L.G.S.,

A.H.H., R.S.; data interpretation: F.F., A.D.S., V.F.F., R.S.; statistical analysis: F.F., P.K.Z.; manuscript writing: F.F., A.D.S., M.A.L.S., P.K.Z., H.C.A., G.D.D., L.G.M.E., F.C.O.M., F.B.C., M.M.A., F.B., F.B., H.C.S., F.E.F.G, L.G.S., M.D., I.Z.A., L.F.R.M., J.N.J., C.T.F.V., V.T., D.T.M., G.F.I.L., P.B.C.M., F.P.L.C., F.C.D.B., M.F.T., R.O.B.A., A.H.H., V.F.F., R.S.; critical revision of the manuscript for intellectual content: F.F., A.D.S., A.H.H., V.F.F., R.S.

Patient and public involvement

There was no patient or public involvement in the planning, conceptualization, research design, analysis, interpretation, or composition of the findings.

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Confirmation of ethical approval

This study was approved by the Research Ethics Committee of the Research and Postgraduate Group at Hospital de Clínicas de Porto Alegre, Brazil (GPPG-HCPA; number: 2019-0050) and follows with Resolution no. 466/12 of the National Health Council.

Declaration of competing interest

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this study. Filipe Ferrari receives financial support from the Coordination for the Improvement of Higher Education (CAPES). Ricardo Stein is an Established Investigator of the National Council for Scientific and Technological Development (CNPq), Brasília, Brazil.

Data availability

The data are available upon reasonable request.

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