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Ethnic Differences in Physiological Cardiac Adaptation to Intense Physical Exercise in Highly Trained Female Athletes

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Background—Ethnicity is an important determinant of cardiovascular adaptation in athletes. Studies in black male athletes reveal a higher prevalence of electric repolarization and left ventricular hypertrophy than observed in white males; these frequently overlap with those observed in cardiomyopathy and have important implications in the preparticipation cardiac screening era. There are no reports on cardiac adaptation in highly trained black females, who comprise an increasing population of elite competitors.

Methods and Results—Between 2004 and 2009, 240 nationally ranked black female athletes (mean age 21 ± 4.6 years old) underwent 12-lead ECG and 2-dimensional echocardiography. The results were compared with 200 white female athletes of similar age and size participating in similar sports. Black athletes demonstrated greater left ventricular wall thickness (9.2 ± 1.2 versus 8.6 ± 1.2 mm, $P < 0.001$) and left ventricular mass (187.2 ± 42 versus 172.3 ± 42 g, $P = 0.008$) than white athletes. Eight black athletes (3%) exhibited a left ventricular wall thickness > 11 mm (12 to 13 mm) compared with none of the white athletes. All athletes revealed normal indices of systolic and diastolic function. Black athletes exhibited a higher prevalence of T-wave inversions (14% versus 2%, $P < 0.001$) and ST-segment elevation (11% versus 1%, $P < 0.001$) than white athletes. Deep T-wave inversions (-0.2 mV) were observed only in black athletes and were confined to the anterior leads (V_1 through V_3).

Conclusions—Systematic physical exercise in black female athletes is associated with greater left ventricular hypertrophy and higher prevalence of repolarization changes than in white female athletes of similar age and size participating in identical sporting disciplines. However, a maximal left ventricular wall thickness > 13 mm or deep T-wave inversions in the inferior and lateral leads are rare and warrant further investigation. (*Circulation*. 2010;121:1078-1085.)

Key Words: ethnicity ■ echocardiography ■ electrocardiography ■ women ■ hypertrophy ■ exercise

Regular participation in intense sporting activity is associated with physiological electric, structural, and functional cardiac modifications¹ that frequently manifest on the ECG,^{2,3} 2-dimensional echocardiogram,⁴⁻⁶ and exercise stress test.⁷ The magnitude of such adaptations is largely determined by demographic factors and sporting discipline.²⁻⁶ Generally, extreme manifestations of the athlete's heart are confined to adult males participating in endurance sporting disciplines; in rare instances, these overlap with manifestations observed in individuals with hypertrophic cardiomyopathy (HCM).⁴ In contrast, white female athletes do not exhibit ECG or echocardiographic changes that may be regarded as representing HCM.^{8,9}

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Clinical Perspective on p 1085

There is increasing evidence that an athlete's ethnic origin may have a significant impact on the cardiovascular response

to exercise. Recent studies examining cardiac adaptation in African/Afro-Caribbean (black) male athletes demonstrated that black male athletes develop more striking repolarization changes on the ECG and exhibit a greater magnitude of left ventricular hypertrophy (LVH) than white male athletes of similar age and size participating in identical sports.^{10,11} Indeed, up to 25% of black athletes exhibit either repolarization changes or LVH that overlaps with morphologically mild HCM.¹¹ These observations are relevant to recent recommendations attempting to mandate cardiovascular screening among elite sportsmen, particularly in countries such as the United States and the United Kingdom, where black athletes represent a substantial fraction of athletes competing at the national level.

Current standardized ECG guidelines that are used to differentiate between a normal ECG and one that is potentially indicative of cardiac pathology are derived from the white athletic population and raise the potential for false

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diagnoses and unnecessary disqualification in black athletes.^{12,13} There are no data relating to cardiovascular adaptation in black female athletes, who comprise an increasing proportion of athletes representing Western countries at international sporting events. However, this unstudied group may potentially be subject to similar issues as black male athletes. The aim of the present study was to examine the ECG and echocardiographic appearances in highly trained national-level black female athletes to facilitate clinical decisions relating to future preparticipation cardiovascular screening.

Methods

Setting

The study was part of a collaborative research program between the United Kingdom and France since 2006 to characterize cardiovascular adaptation in black athletes. Neither country has a nationally sponsored cardiovascular screening program for athletes; however, in the United Kingdom, certain sporting bodies, including the International Olympic Committee,¹³ football associations (Union of European Football Associations, Fédération Internationale de Football),¹⁴ Lawn Tennis Association, and the International Rugby Board, have privately funded mandatory screening for all athletes competing at the national level.

Athletes not affiliated with these organizations but participating in the Commonwealth Games also undergo mandatory preparticipation screening. Most UK screenings are supervised by the senior author (SS) at national sporting training camps, the Olympic Medical Institute, King's College Hospital, and University Hospital Lewisham. In France, all athletes participating at the national level undergo mandatory preparticipation cardiovascular screening; the majority of screenings are supervised by the second author (FC) at the University of Rennes.

Subjects

Between 2006 and 2009, 440 consecutive nationally ranked female athletes (240 [55%] black) underwent assessment with a health questionnaire, physical examination, ECG, and 2-dimensional echocardiography as part of a standard preparticipation cardiac evaluation. All athletes provided written consent for the evaluation. Ethics approval was obtained from the University Hospital Lewisham Research Ethics Committee. Black ethnicity was determined through self-reported questionnaires that included terms such as black African, black Afro-Caribbean, black British, and black French.

Twelve-Lead ECG

A standard ECG was performed with the subject in a supine position with a Philips Pagewriter Trim III (Philips, Bothell, Wash) recorder as described previously.¹⁵ Heart rate and QRS axis were calculated. P-, Q-, R-, S-, and T-wave voltages; ST segments; QRS duration; PR interval; and QT interval were measured in each lead with calipers. The QT interval was corrected for the heart rate by use of the Bazett formula.¹⁶ Electrocardiographic LVH was defined with the Sokolow-Lyon voltage criterion.¹⁷ T-wave inversions in 2 or more contiguous leads were considered significant, other than in leads V₁ and III.

Transthoracic Echocardiography

A 2-dimensional echocardiogram was conducted by 1 of 3 experienced cardiologists (including 2 authors: J.R. and G.K.) using GE Vivid I (General Electric, Tirat Carmel, Israel), Philips Sonos 7500, or Philips CPX50 cardiac ultrasound equipment. Standard views of the heart were obtained and analyzed according to the protocol specified by the European Society of Echocardiography.¹⁸ Left ventricular (LV) wall thickness (LVWT) was measured in the 2-dimensional parasternal short axis, at the levels of the mitral valve and papillary muscles, the greatest measurement being defined as the

maximal LVWT. LV mass (LVM) was calculated with the formula of Devereux.¹⁹ LV ejection fraction was calculated from LV volumes by Simpson's rule.²⁰ Assessment of diastolic function included traditional pulsed-wave Doppler across the mitral valve²¹ and tissue Doppler velocity imaging²² of the septal and lateral mitral valve annulus. Echocardiographic studies were saved to compact discs as numeric files to generate anonymity, and cardiac measurements were repeated independently by an experienced cardiologist (S.S.) blinded as to the identity of the athlete.

Further Evaluation

Athletes with LVH (LVWT >11 mm) or deep (more than -0.2 mV) T-wave inversions in 2 contiguous leads were investigated further with an exercise test, 48-hour Holter monitor, and cardiac magnetic resonance scan to investigate the broader phenotypic features of HCM.

Exercise Stress Testing

An upright treadmill stress test was performed with the standard Bruce protocol.²³ ECGs and blood pressure (BP) were recorded at 1-minute intervals. Athletes were exercised to volitional exhaustion and assessed specifically for the development of ischemic changes, BP response,²⁴ and arrhythmias.

Forty-Eight-Hour ECG Monitoring

Forty-eight-hour ambulatory ECG monitoring was performed to check specifically for supraventricular and ventricular tachyarrhythmias.²⁵ Athletes were encouraged to continue daily activities, including exercise, during the investigation.

Cardiac Magnetic Resonance Imaging

Cardiac magnetic resonance imaging was performed with a Siemens Sonata 1.5T system (Erlangen, Germany) with steady-state, free-precession breath-hold cines (time to echo/repetition time 1.6/3.2 ms, flip angle 60°) in long-axis planes and sequential 7-mm short-axis slices (3-mm gap) from the atrioventricular ring to the apex. Late gadolinium enhancement images were acquired 10 minutes after intravenous administration of gadolinium-DTPA (Schering, 0.1 mmol/kg) in identical short-axis planes with an inversion-recovery gradient echo sequence. Inversion times were adjusted to null normal myocardium (typically 320 to 440 ms; pixel size 1.7×1.4 mm). Late gadolinium enhancement images were phase-swapped to exclude artifact. Ventricular volumes and function were measured for both ventricles by standard techniques^{26,27} and analyzed with semiautomated software (CMR tools, Cardiovascular Imaging Solutions, London, United Kingdom). All volumes and masses were indexed for age and body surface area.

Statistical Analysis

Data are expressed as mean±SD. Statistical analyses were performed with unpaired Student *t* test and Fisher exact test, calculated from a 2×2 contingency table.

For continuous variables, a stepwise multivariable linear regression model was constructed to assess the relationship between LVWT and LVM as dependent variables, with age, height, weight, body surface area, ethnicity, and hours trained as predictors. For binary variables, a binary logistic regression model was constructed to assess any relationship between T-wave inversions or ST-segment elevation as dependent variables and age, height, weight, body surface area, number of hours trained, ethnicity, maximal LVWT, and LV end-diastolic cavity diameter as independent variables. SPSS version 12 was used for all statistical analyses. *P*<0.05 was considered significant and was essential for predictors to enter and remain in multivariable regression models.

Results

Subjects

All athletes were asymptomatic and normotensive (BP ≤120/80 mm Hg), and none volunteered a family history of

Table 1. Demographics of Black and White Athletes

	Black Athletes (n=240)	White Athletes (n=200)	P
Age, y	21±4.6 (14, 35)	20±4.0 (14, 35)	0.18
Weight, kg	66.1±11.6 (39, 106)	64.1±8.8 (45, 92)	0.06
Height, m	1.71±8.4 (1.50, 1.92)	1.70±7.7 (1.50, 1.91)	0.07
BSA, m ²	1.78±0.17 (1.31, 2.21)	1.73±0.18 (1.33, 1.96)	0.10
Resting BP, mm Hg	110±19 (120, 80)	111±13 (120, 80)	0.80
Training h/wk	13.7±3.4 (8, 24)	14.4±6.1 (8, 36)	0.41
Sporting discipline, %			
Athletics*	25	23	0.58
Basketball	20	18	0.63
Football (soccer)	16	20	0.26
Netball	18	18	1.00
Martial arts	13	11	0.56
Other	8†	10‡	0.50
LDR	n=8	n=10	
Fencing	n=3	n=2	
Handball	n=3	n=2	
Weightlifting	n=3	n=2	
Hockey	n=2	n=4	

BSA indicates body surface area; LDR, long-distance running. Data are expressed as mean±SD (limits).

*Track and field events.

†n=19.

‡n=20.

cardiomyopathy or premature sudden cardiac death. Athletes were of similar age and size and competed in a similar range of sporting disciplines. The majority of black athletes (n=169; 70%) and white athletes (n=140; 70%) were from the United Kingdom (Table 1).

LV Dimensions

Black athletes demonstrated a greater maximal LVWT than white athletes (9.2±1.2 versus 8.6±1.2 mm, $P<0.001$), which amounted to a 7% difference between the 2 groups (Table 2). Calculated LVM was also greater in black athletes than in white athletes (187.2±42 versus 172.3±42 g, $P=0.008$).

Black athletes also exhibited a greater left atrial diameter than white athletes (35.3±4.7 versus 32.5±4.8 mm, $P<0.001$). There were no differences between the ethnic groups with respect to LV cavity size and aortic root diameter. Twenty black athletes (8%) and 12 white athletes (6%) revealed an enlarged (>54 mm) LV end-diastolic cavity. All athletes had normal indices of systolic and diastolic function.

LVH in Female Athletes

The distribution of maximal LVWT is shown in Figure 1. None of the white athletes demonstrated a maximal LVWT of >11 mm. In contrast, 8 black athletes (3.3%) exhibited a maximal LVWT >11 mm (12 to 13 mm) and were considered to exhibit LVH. The demographic, echocardiographic,

Table 2. Comparison of Echocardiographic Cardiac Dimensions Between Black and White Female Athletes

	Black Athletes (n=240)	White Athletes (n=200)	P
Ao, mm	27.2±2.9 (23, 38)	26.4±3.5 (17, 33)	0.21
LA, mm	35.3±4.7 (21, 41)	32.5±4.8 (25, 47)	<0.0001
LVED, mm	48.6±3.9 (39, 60)	48.2±3.5 (40, 62)	0.93
LVES, mm	27.3±4.0 (21, 44)	30.5±4.7 (20, 44)	0.47
IVSd, mm	9.0±1.3 (6, 13)	8.4±1.2 (6, 11)	<0.001
PTWD, mm	8.7±1.3 (6, 12)	8.4±1.2 (6, 11)	0.14
Max LVWT, mm	9.2±1.2 (6, 13)	8.6±1.2 (6, 11)	<0.001
LVM, g	187.2±42 (95, 322)	172.3±42 (86, 293)	0.008
E wave, m/s	0.89±0.2 (1.36, 0.6)	0.90±0.2 (1.33, 0.53)	0.49
A wave, m/s	0.41±0.1 (1.1, 0.2)	0.44±0.1 (0.9, 0.2)	0.076
E/A ratio	2.3±0.8 (5.5, 1.1)	2.2±0.8 (5.5, 1.1)	0.15
E', m/s	0.22±0.03 (0.25, 0.13)	0.23±0.03 (0.28, 0.17)	0.40
A', m/s	0.07±0.03 (0.16, 0.02)	0.06±0.03 (0.13, 0.03)	0.43
E:E'	4.41±0.71 (5.61, 2.30)	4.46±0.74 (5.55, 1.96)	0.39
EF, %	67±6.7 (41, 78)	66±6.9 (44, 76)	0.48

Ao indicates aortic annulus diameter; LA, left atrial diameter; LVED, LV end-diastolic diameter; LVES, LV end-systolic diameter; IVSd, maximal LV septal wall thickness in end diastole; PTWD, LV posterior wall thickness in end diastole; Max LVWT, maximal LVWT in end diastole; E wave, early diastolic mitral valve peak inflow velocity; A wave, late diastolic mitral valve inflow peak velocity; E', early diastolic annular peak velocity (lateral mitral annulus); A', late annular diastolic peak velocity (lateral mitral annulus); E:E', ratio of peak early diastolic mitral inflow velocity to peak early diastolic mitral annular velocity; and EF, ejection fraction.

Data are expressed as mean±SD (limits).

and ECG features of the 8 black athletes with LVH are shown in Table 3.

The pattern of LVH in all of the black female athletes was homogeneous, with a difference of <2 mm between adjacent segments. All athletes with LVH exhibited a normal LV diastolic cavity size (Table 3). None of the athletes with LVH exhibited dynamic LV outflow obstruction.²⁸ There were no differences in age (21.5±1.9 versus 21.3±4.6 years, $P=0.92$), height (1.69±0.11 versus 1.72±0.09 m, $P=0.496$), weight (75±11 versus 67±10.9 kg, $P=0.12$), or body surface area (1.85±0.19 versus 1.79±0.17 m², $P=0.45$) between black athletes with LVH and those without.

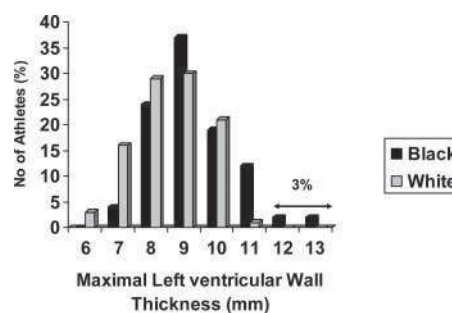


Figure 1. Histogram showing the distribution of maximal LVWT in black (black bars) and white (gray bars) female athletes. Three percent of black athletes demonstrated a maximal LVWT >11 mm compared with none of the white athletes.

Table 3. Demographic, Echocardiographic, and ECG Features of Black Athletes With LVH

Age, y	BSA, m ²	Sport	LVED, mm	LVES, mm	LAD, mm	MLVWT, mm	LVM, g	EF, %	E, m/s	A, m/s	E:A	E', m/s	E:E'	T-Wave Inversion (Leads)	LAE	LVH
20	1.62	Judo	53	35	30	12	236	64	1.00	0.47	2.1	0.17	5.9	None	No	No
20	2.01	Netball	48	34	32	12	276	65	0.8	0.4	2	0.15	5.3	None	Yes	No
20	1.82	Sprinting	50	37	36	13	329	66	0.8	0.42	1.90	0.22	3.6	None	No	Yes
21	1.98	Basketball	51	37	36	13	260	68	0.8	0.39	2.1	0.16	5.0	None	No	No
22	1.71	Football	45	26	32	13	279	70	0.9	0.38	2.3	0.19	4.7	V ₁ , V ₂	No	No
22	2.02	Netball	51	40	37	13	322	65	0.6	0.42	1.4	0.16	3.7	V ₁ , V ₂	No	No
23	1.87	Football	48	33	31	12	276	67	0.72	0.41	1.8	0.21	3.4	None	No	Yes
24	1.77	Weightlifting	42	24	37	13	211	72	0.91	0.42	2.2	0.21	4.3	None	No	No

BSA indicates body surface area; LVED, LV end-diastolic diameter; LVES, LV end-systolic diameter; LAD, left atrial diameter; MLVWT= maximal LVWT; EF, ejection fraction; LAE, voltage criterion for left atrial enlargement; and LVH, voltage criterion for LVH.

Determinants of LVH

The results of a multivariable linear regression model that assessed the relationship between maximal LVWT and age, body surface area, ethnicity, and number of hours trained demonstrated that ethnicity was the strongest independent predictor of maximal LVWT ($\beta=0.263$, CI 0.29 to 0.855, $P<0.001$), with age being the only other significant factor ($\beta=-0.155$, CI -0.07 to 0.01 , $P=0.006$). There was no relationship between sporting discipline and LVH.

Reliability of LVWT Measurements in Athletes

The averaged coefficients of variation between intraobserver and interobserver reliability for maximal LVWT measurements were 4% and 6.2%, respectively.

ECG Findings

Black athletes demonstrated a greater PR interval than white athletes, whereas white athletes revealed a slightly greater QRS duration than black athletes. There were no significant differences between black athletes and white athletes with respect to QRS axis, QT interval, voltage criteria for LVH, right or left atrial hypertrophy, or incomplete right bundle branch (Table 4). None of the athletes exhibited pathological Q waves (>40 ms wide or exceeding in depth 25% of the height of the preceding R wave), ST-segment depression, left bundle-branch block, or epsilon waves.

Repolarization Anomalies

Black athletes demonstrated a higher prevalence of ST-segment elevation than white athletes ($n=26$ [11%] versus $n=2$ [1%]; $P<0.001$). Black athletes also exhibited a higher prevalence of contiguous T-wave inversions than white athletes ($n=34$ [14%] versus $n=4$ [2%]; $P<0.001$; Figure 2). In black athletes, T-wave inversions were confined to leads V₁ through V₃ and exceeded -0.2 mV (deep T-wave inversions) in 6 individuals (2%; Figure 3D). In contrast, white athletes only showed T-wave inversions in leads III and aVF, and none exhibited deep T-wave inversions.

Determinants of Repolarization Anomalies

The results of a binary logistic regression model, with the dependent variable being the presence of T-wave inversions, demonstrated that black ethnicity was the only significant

independent predictive factor ($\beta=1.94$, $SE=0.417$, $P=0.003$). Black ethnicity was also the strongest independent predictive factor ($\beta=1.29$, $SE=349$, $P<0.001$) when ST-segment elevation was used as a dependent variable in the model, with athlete height having a weak additional effect ($\beta=0.042$, $SE=0.021$, $P=0.043$).

Correlation Between ECG and Echocardiogram

There was a weak correlation between the presence of T-wave inversions and magnitude of LVWT and LVM in both groups (maximal LVWT: $P=0.039$; LVM: $P=0.041$). However, there were no significant differences in absolute values of maximal LVWT between athletes with T-wave inversions and those without in either group (black athletes: $P=0.12$; white athletes: $P=0.07$). The identification of T-wave inversions did not predict the presence of LVH or increased LV cavity size. There was no relationship between the presence of Sokolow-Lyon voltage criteria for LVH on the ECG and maximal LVWT or LVM (maximal LVWT: $P=0.278$; LVM: $P=0.408$).

Table 4. Comparison of ECG Parameters Between Black and White Female Athletes

	Black Athletes (n=240)	White Athletes (n=200)	P
Heart rate, bpm	61 ± 8.3 (44, 85)	60 ± 9.5 (35, 85)	0.26
PR interval, ms	162 ± 25 (112, 246)	149 ± 23 (88, 228)	<0.001
QRS duration, ms	84 ± 10 (43, 105)	87 ± 10 (66, 120)	0.0072
QT interval, ms	400 ± 32 (330, 475)	415 ± 33 (290, 447)	0.17
QTc (Bazett's), ms	404 ± 42 (358, 465)	407 ± 41 (285, 474)	0.28
Axis, degrees	67 ± 14 (32, 89)	65 ± 32 (-26 , 129)	0.66
LAE, %	12.5	10	0.45
RAE, %	5	4	0.65
LVH voltage, %	8	12	0.16
Partial RBBB, %	14	14	0.89

QTc indicates corrected QT interval; LAE, voltage criterion for left atrial enlargement; RAE, voltage criterion for right atrial enlargement; and RBBB, right bundle-branch block.

Data are expressed as mean ± SD (limits) or percentages, as appropriate.

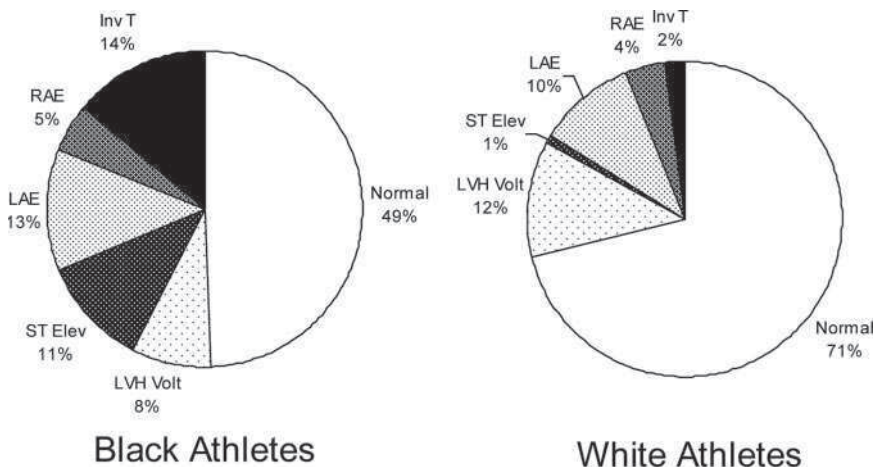


Figure 2. Pie charts comparing ECG anomalies between black athletes and white athletes. Black athletes exhibited a higher prevalence of ST-segment elevation and T-wave inversions than white athletes. LAE indicates voltage criterion for left atrial enlargement; RAE, voltage criterion for right atrial enlargement; LVH volt, voltage criterion for LVH; ST Elev, ST-segment elevation; and Inv T, T-wave inversion.

Subsequent Investigations

Twelve black athletes (exhibiting LVH and/or deep T-wave inversions) underwent an exercise stress test, 48-hour Holter monitoring, and a cardiac magnetic resonance scan. None of the 12 athletes demonstrated any phenotypic features of HCM or any other form of cardiomyopathy. Specifically, none of the 12 athletes exhibited flat BP responses to exercise,²⁴ >1000 ventricular extrasystoles/nonsustained ventricular tachycardia,²⁵ or late gadolinium enhancement (to indicate myocardial fibrosis),²⁹ apical hypertrophy,²⁹ and right ventricular wall-motion abnormalities,³⁰ on exercise testing, the 48-hour Holter monitor, and the cardiac magnetic resonance scan, respectively. There was 100% concurrence between echocardiography and cardiac magnetic resonance for maximal LVWT measurements in all black athletes with LVH.

Discussion

Recent studies indicate that black male athletes exhibit a higher prevalence of LVH and repolarization changes than white male athletes.^{10,11,31,32} The present study is the first to specifically examine the adaptive changes in response to exercise in female international African/Afro-Caribbean athletes and is of particular clinical relevance because black female athletes form an increasing population of high-profile international competitors in the Western world. Compared with the largest published study in white female athletes (n=600),⁸ only 240 black females were studied; however, when one considers that black female athletes currently constitute fewer than 10% of all athletes participating at the national level in the United Kingdom and France, the study cohort represents a sizeable proportion of athletes available for comparisons and inferences.

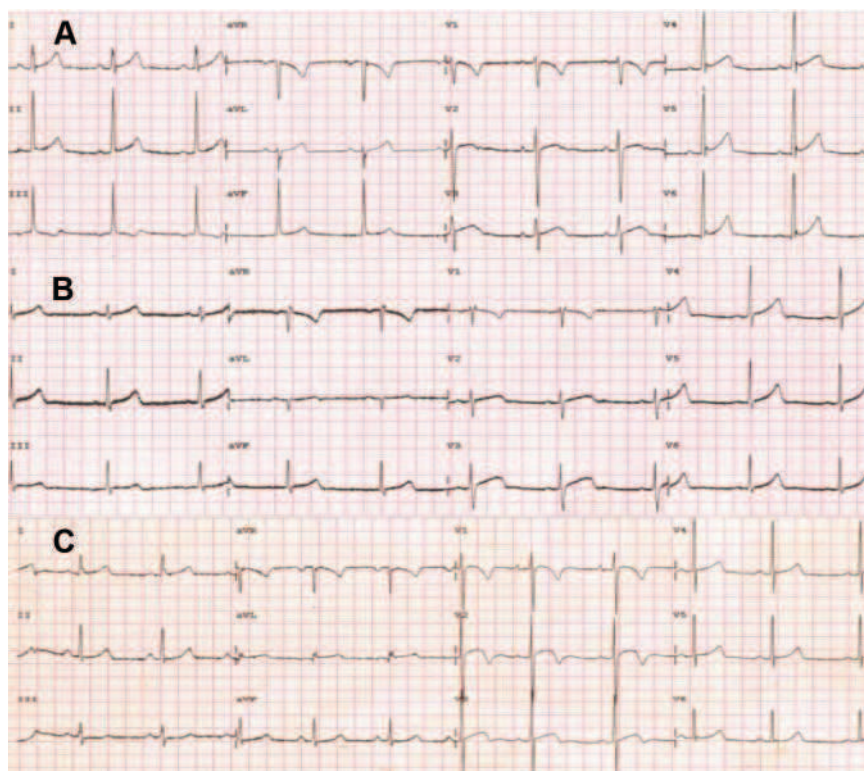


Figure 3. Spectra of ECG observations in black athletes revealing Sokolow-Lyon voltage criteria for LVH and elevated J point in the lateral leads (A), partial right bundle-branch block with accompanying convex ST-segment elevation in leads V₁ through V₃ (B), and convex ST-segment elevation and deep T-wave inversions in leads V₁ through V₃ (C).

Black Athletes With LVH

As with black male athletes,¹⁰ highly trained female athletes of African/Afro-Caribbean descent demonstrated a greater maximal LVWT and LVM than white athletes of similar age, size, and sporting discipline. Consistent with previous reports, none of the white athletes exhibited an LVWT >11 mm.^{4,5,6,9} In contrast, 8 black athletes (3%) demonstrated a maximal LVWT >11 mm (12 to 13 mm) that could have been consistent with morphologically mild HCM. None of the 8 black athletes revealed any further phenotypic features of HCM on further clinical evaluation (Table 3).³³ Importantly, because none of the black athletes exhibited an LVWT >13 mm, it would be reasonable to infer that an absolute maximal LVWT of 13 mm probably represents the physiological upper limit of LVH in an asymptomatic black athlete outside the context of a family history of HCM, and an LVWT >13 mm may be considered to represent pathological LVH.

Black athletes with LVH participated in basketball, football, judo, netball, sprinting, and wrestling, sports that are not traditionally associated with physiological LVH in white athletes, which indicates that the isotonic and isometric stresses of sport induce more cardiac hypertrophy in black athletes than in white athletes. Direct comparisons could not be made in sporting disciplines characteristically associated with a greater LVWT in whites, such as rowing, canoeing, and cycling,⁴⁻⁶ because black female athletes in the United Kingdom and France do not usually excel in such sporting disciplines. Nevertheless, none of the studies in white women participating in these sporting disciplines have reported an LVWT >11 mm.^{4-6,8,9}

Differences in Repolarization Changes Between Black Athletes and White Athletes

Black female athletes exhibited a greater prevalence of T-wave inversions than white athletes. T-wave inversions were confined to V₁ through V₃ and did not appear to be determined by age, body size, sporting discipline, or cardiac dimensions. In particular, athletes with T-wave inversions did not reveal any phenotypic features of HCM³³ or arrhythmogenic right ventricular cardiomyopathy³⁴ on subsequent evaluation.

The prevalence and magnitude of these electric changes remain significantly lower than those observed among black male athletes¹⁰ but higher than those reported in white male athletes.^{2,3} Although the relative risk of sudden cardiac death during sport in women is considerably lower than in men, female athletes are not exempt from cardiac fatalities during sport³⁵⁻³⁷; therefore, the observation that normal healthy black female athletes may demonstrate physiological LVH >11 mm and T-wave inversions that mimic morphologically mild HCM is a major finding and has potential implications in relation to preparticipation cardiovascular screening programs.³⁸ However, unlike HCM, none of the black athletes in the present study exhibited deep T-wave inversions in the inferior or lateral leads; therefore, the identification of deep T-wave inversions in these leads in a black female with LVH may be representative of pathology rather than physiology.

Potential Mechanisms for Ethnic Differences in Electric and Structural Cardiac Manifestations

The precise mechanisms for the exaggerated myocardial hypertrophy and ECG appearances in black athletes in re-

sponse to exercise are yet to be elucidated. There may be racial and gender differences in response to the modulations in BP that occur during systematic training; however, our own experience of exercising male black and white athletes with LVH has not demonstrated any significant differences in exercise-related BP responses between the ethnic groups.¹⁰

Racial and gender differences in large-artery structure and function,³⁹ endothelial function,⁴⁰ the renin-angiotensin system,⁴¹ and levels of vasoactive cytokines⁴² are recognized and may partially explain the differences in the magnitude of LVH between black athletes and white athletes and the greater predilection to LVH in male athletes in both ethnic groups, respectively. Recent *in vitro* and animal studies indicate that physiological LVH is mediated by the effects of insulin-like growth factor 1⁴³ on the phosphatidylinositol-3-kinase-Akt1⁴⁴ pathway, which appears to regulate downstream transcription factor and gene product production.⁴⁵ It is possible that potential race-related polymorphisms in the function of insulin-like growth factor 1 within the African population may also provide an explanation for the greater magnitude of LVH observed in black athletes.

It is historically recognized that a significant proportion of normal black men and women exhibit T-wave inversions in the right precordial leads extending to V₃ and V₄.^{46,47} Our own experience also suggests that black athletes may acquire such T-wave inversions in the right precordial leads during physical training (Figure 2) that are not related to cardiac structure and that regress after a 6- to 8-week period of deconditioning. Alterations in autonomic cardiac innervation, either reduced sympathetic or increased vagal tone, or recently identified sodium channel polymorphisms among the black population⁴⁸ may provide some explanation for the variation found within black athletes; however, more detailed molecular assessment and longitudinal follow-up of black athletes is necessary to unravel the intriguing manifestations of the black athlete's heart.

The authors recognize that misuse of performance-enhancing substances may be associated with LVH and marked repolarization changes⁴⁹; however, all athletes studied were part of national and international squads and as such underwent regular testing for the presence of such substances. Hence, all subjects were considered free from compounds that could have adversely affected the results of the present study.

Conclusions

Systematic physical exercise in black female athletes is associated with greater LVH and higher prevalence of repolarization changes than in white female athletes of similar age and size participating in identical sporting disciplines. However, a maximal LVWT >13 mm or deep T-wave inversions in the inferior and lateral leads are rare and warrant further investigation.

Study Limitations

The study exhibits some limitations that warrant mention. Although a substantial number of black athletes were studied, a relatively limited number of sporting disciplines were examined compared with previous studies in whites for

reasons outlined above. The study was confined to black athletes competing in the United Kingdom and France, and although we are confident that our observations are an accurate representation of black athletes in Europe, caution must be exercised when our conclusions are extrapolated to apply to black athletes in other parts of the world. Finally, the study was cross-sectional in design; therefore, it is possible that some black athletes exhibiting LVH or marked repolarization abnormalities may have had HCM but were unidentifiable owing to incomplete expression of the disease phenotype, which calls for longitudinal studies in black athletes with LVH and/or marked repolarization changes in the future.

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CLINICAL PERSPECTIVE

The investigators provide novel data on physiological cardiac adaptation in highly trained female black athletes. Existing data relating to ethnic differences in exercise-related cardiovascular adaptation are confined to men and indicate a racial predilection to the development of substantial left ventricular hypertrophy and marked repolarization changes in black athletes that may overlap with hypertrophic cardiomyopathy. This study of 240 normotensive, nationally ranked black female athletes and 200 nationally ranked white athletes participating in 10 different sporting disciplines reveals that black women also exhibit greater magnitude of left ventricular hypertrophy and higher prevalence of repolarization anomalies than their white counterparts. Three percent of black athletes showed a left ventricular wall thickness >11 mm (12 to 13 mm) compared with none of the white athletes, and almost 15% demonstrated repolarization changes, including deep T-wave inversions, compared with only 2% of white athletes. In contrast to most individuals with hypertrophic cardiomyopathy, none of the black athletes exhibited a left ventricular wall thickness >13 mm or deep T-wave inversions in contiguous inferior/lateral leads, which indicates that such observations in black female athletes warrant further investigation. Application of standardized criteria derived from white athletes for differentiation of physiological adaptation from hypertrophic cardiomyopathy has the potential to result in unnecessary investigation and unfair disqualification from sport in black athletes. The study is clinically relevant in facilitating the differentiation of physiological adaptation from morphologically mild hypertrophic cardiomyopathy in black female athletes exhibiting left ventricular hypertrophy, particularly in countries where black individuals represent a high proportion of athletes competing at regional and national levels.