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Cardiovascular screening in adolescents and young adults: a prospective study comparing the Pre-participation Physical Evaluation Monograph 4th Edition and ECG

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Abstract

Background—This study compares the accuracy of cardiovascular screening in active adolescents and young adults using a standardised history, physical examination and resting 12-lead ECG.

Methods—Participants were prospectively screened using a standardised questionnaire based on the Pre-participation Physical Evaluation Monograph 4th Edition (PPE-4), physical examination and ECG interpreted using modern standards. Participants with abnormal findings had focused echocardiography and further evaluation. Primary outcomes included disorders associated with sudden cardiac arrest (SCA).

Results—From September 2010 to July 2011, 1339 participants underwent screening: age 13–24 (mean 16) years, 49% male, 68% Caucasian, 17% African-American and 1071 (80%) participating in organised sports. Abnormal history responses were reported on 916 (68%) questionnaires. After physician review, 495/ 916 (54%) participants with positive questionnaires were thought to have non-cardiac symptoms and/or a benign family history and did not warrant additional evaluation. Physical examination was abnormal in 124 (9.3%) participants, and 72 (5.4%) had ECG abnormalities. Echocardiograms were performed in 586 (44%) participants for abnormal history (31%), physical examination (8%) or ECG (5%). Five participants (0.4%) were identified with a disorder associated with SCA, all with ECG-detected Wolff-Parkinson-White. The false-positive rates for history, physical examination and ECG were 31.3%, 9.3% and 5%, respectively.

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Conclusions—A standardised history and physical examination using the PPE-4 yields a high false-positive rate in a young active population with limited sensitivity to identify those at risk for SCA. ECG screening has a low false-positive rate using modern interpretation standards and improves detection of primary electrical disease at risk of SCA.

INTRODUCTION

Sudden cardiac arrest (SCA) is the leading cause of non-traumatic sudden death in children and young adults.[1–3] SCA is usually the result of an underlying structural or electrical cardiac abnormality that goes undetected during the preparticipation screening evaluation or annual well child medical assessment.[45] The prevalence of warning signs, symptoms or family history in young athletes that may precede SCA is variable and not fully understood, making the diagnosis of pathological cardiac conditions through screening more difficult.[5–7] For 50–80% of athletes with SCA, sudden death is the sentinel cardiovascular event.[48–10]

The American Heart Association (AHA) screening recommendations and the Pre-participation Physical Evaluation Monograph 4th Edition (PPE-4) provide the current standard for conducting cardiovascular screening in the USA.[1112] However, no studies have been carried out to validate the recommended AHA history elements or the proposed PPE-4 questionnaire.

Some authorities recommend the inclusion of a resting 12-lead ECG in the cardiovascular screening of young athletes.[13–17] However, widespread debate regarding the efficacy and concerns for false-positive results, unnecessary disqualifications and higher costs has limited ECG implementation in the USA.[18–20]

The purpose of this study was to evaluate and compare the accuracy of cardiovascular screening in active adolescents and young adults using a stan-dardised history, physical examination and ECG.

METHODS

This study was conducted in collaboration with the Nick of Time Foundation, a non-profit organisation (Seattle, Washington, USA; http://www.nickoftimefoundation.org) whose mission is to prevent SCA in the young through education, emergency planning and cardiovascular screening. The Nick of Time Foundation offers a free heart screening programme for students, athletes and young adults (age 13–24 years) conducted at high schools in the greater Seattle area.

This research involves the use of non-identifiable data provided by the Nick of Time Foundation. Written informed consent, including the use of non-identifiable data for research purposes, is required by the Nick of Time Foundation to participate in the screening programme. Participants under 18 years of age must provide signed parental consent and participant assent forms. Each participant is assigned a unique identification number at the screening and all data collected at the event are de-identified. The Nick of Time Foundation releases de-identified, coded data to the University of Washington investigators for research purposes. The identity of the screening participants is confidential and available only to the

Nick of Time Foundation. De-identified data are maintained in a secure REDCap database maintained by the Biomedical Informatics core of the University of Washington Institute for Translational Health Sciences (ITHS). A Human Subjects Division review determination form for 'Use of Non-identifiable Specimen/Data' was completed and reviewed by regulatory advisors from the ITHS.

Participants were provided with a questionnaire prior to undergoing heart screening and were encouraged to complete this in conjunction with their parents. This questionnaire included self-reported demographic information, information on sports participation and physical activity levels, medical and family history and the PPE-4 heart health questions (shown in table 2). The heart screening programme also included (1) a focused physical examination including a resting blood pressure (BP), cardiac auscultation (standing, supine and with Valsalva) and assessment for the physical stigmata of Marfan syndrome; (2) a resting 12-lead ECG and (3) a physician interview with the participant including a review of the questionnaire, physical examination and ECG. Participants with abnormalities were referred for on-site echocardiography with a limited protocol.

BP measurements were conducted by local firefighters using manual sphygmomanometry, and were repeated after three or more minutes of rest if the systolic BP was >140 mm Hg or diastolic BP >90 mm Hg initially. BP that remained above these levels was considered abnormal. Cardiac auscultation was performed by licensed, volunteer medical physicians and any murmur or physical stigmata of Marfan syndrome noted. ECGs were performed by medically trained volunteers using a standard 12-lead placement and a portable ECG machine (Cardiac Science Burdick Atria 6100, Waukesha, Wisconsin, USA). ECGs were interpreted by experienced sports medicine or cardiology physicians using modern standards for interpretation based on the 2010 European Society for Cardiology (ESC) recommendations (see online supplementary appendix 1; supplementary file).[21–23]

After physical examination and ECG, participants were interviewed by a physician to review history responses. If the physician felt that a positive history response was benign and non-cardiac in nature, no additional evaluation was performed. Any participant with a positive history or family history response thought to be clinically relevant, an abnormal physical examination or an abnormal ECG was referred for an on-site echocardiogram.

Echocardiograms were performed by licensed cardiac sonographers using portable ultrasound systems (Sonosite M-Turbo, Bothell, Washington, USA). Paediatric and adult cardiologists familiar with cardiac athletic remodelling and disorders associated with SCA in young athletes supervised all image acquisition and interpretation. The limited echocardiogram protocol consisted of parasternal long axis and short axis and apical four-chamber views. Quantitative assessments included the enddiastolic left-ventricular chamber and wall thickness dimensions, fractional shortening, aortic diameters at the sinuses of Valsalva and the ascending aorta and tricuspid regurgitant jet velocities (for pulmonary artery pressure assessment) using spectral Doppler. Valve function was assessed qualitatively using two-dimensional imaging and colour Doppler, and attempts were made to identify the location of the right and left coronary artery ostia and left main bifurcation. The right ventricle (RV) was evaluated from parasternal and apical views, with subjective

assessment of size and function. Quantitative assessment of the RV, including basal diameter and tricuspid annular plane systolic excursion, was performed when RV abnormalities were suspected by ECG or initial echocardiographic images. After all testing had been performed, the complete cardiac screen was reviewed by physicians trained in sports medicine, cardiology and/or electrophysiology.

A ‘student athlete’ was defined as any study participant competing in an organised or school-sponsored sport that would traditionally require preparticipation screening for sports eligibility in the USA. A ‘student non-athlete’ was defined as a study participant not involved in organised or school-sponsored sports.

Primary outcome measures include the identification of disorders known to cause sudden cardiac death (SCD). Secondary outcome measures include the identification of a clinically significant cardiac condition requiring medical surveillance, further evaluation or treatment, but not associated with SCD. Descriptive statistics such as proportions, means and cross tabulations were used to analyse collected data. Personal and family history responses were compared between student athletes and student non-athletes using a χ^2 analysis. Statistical significance was defined as a p value of <0.001 to account for multiple testing.

RESULTS

Demographics

In total, 1339 consecutive participants aged 13–24 partook in the cardiac screenings between September 2010 and July 2011. Forty-nine per cent of participants were men, 68% Caucasian, 18% Asian or Pacific Islander and 17% African-American (table 1). Eighty per cent of students were involved in an individual or team organised sport (student athlete) and 70% of students participated in physical activity for more than 5 h/week.

History

Nine hundred and sixteen (68%) of the study population reported at least one positive response on the PPE-4 questionnaire (table 2). Common positive symptom responses included chest discomfort, pain, tightness or pressure (28%), light-headedness or shortness of breath more than expected with exercise (25.5%), feeling more tired or short of breath more quickly than friends during exercise (22%), syncope or near-syncope during or after exercise (12.5%) and feeling the heart race or skip beats during exercise (12%). In reviewing the family history, 16% of participants reported a family member who died of a heart condition or had any unexpected or unexplained sudden death before the age of 50, and 3.4% reported a family history of cardiac conditions as listed on the PPE-4 including hypertrophic cardiomyopathy, Marfan syndrome, arrhythmogenic right ventricular cardiomyopathy, long QT syndrome, short QT syndrome, Brugada syndrome or catecholaminergic polymorphic ventricular tachycardia.

Positive responses on the screening form were discussed in detail with a physician. All 495 of the 916 (54%) participants with a positive response on the screening questionnaire were thought to have a non-cardiac symptom and/or benign family history and thus did not warrant further cardiac evaluation. After review by a physician, 421/1339 (31.4%) of the

study population had at least one relevant response on the PPE-4 questionnaire that required additional cardiac evaluation (table 2).

Positive personal and family history responses were compared among student athletes versus student non-athletes (table 3). After physician evaluation, student non-athletes overall were more likely than student athletes to report one or more positive personal and family history responses ($p<0.001$). Specifically, student non-athletes were more likely to report chest pain, light-headedness and shortness of breath ($p<0.001$) that was of sufficient quality and severity to be judged by physicians as potentially cardiac in aetiology and warranted further evaluation.

Physical examination

One hundred and twenty-four (9.3%) participants had an abnormal physical examination. One hundred and fourteen (8.5%) had a cardiac murmur, 22 (1.6%) elevated BP and 10 (0.7%) physical stigmata of Marfan syndrome (table 4).

ECG

Seventy-two (5.4%) participants had an abnormal ECG. The most common abnormalities included T wave inversions (1.5%), Q waves (0.8%), left axis deviation (0.8%), right ventricular hypertrophy (0.6%) and ventricular pre-excitation (0.4%; table 4). There were no findings of complete left bundle branch block, ST segment depression, Mobitz Type II 2nd degree AV block, 3rd degree AV block, long QT interval, short QT interval, Brugada ECG pattern, epsilon wave or profound sinus bradycardia.

Echocardiogram

Five hundred and eighty-six (44%) participants had a limited echocardiogram to further evaluate an abnormality found on history, physical examination or ECG. The indications for an echocardiogram among the total study population were a medical history causing concern (24%), a positive family history (12%), an abnormal physical examination (8%) or an abnormal ECG (5%; table 5).

Clinical outcomes

After the physician interview, 60% of participants had a normal screen with no clinically relevant abnormalities on the history questionnaire, physical examination or ECG. An additional 35.6% of the study population was thought to have a normal evaluation after echocardiography. In total, 4.4% of participants had an abnormal screen that required further investigation or medical follow-up for a confirmed or suspected cardiac condition (table 6). Five (0.4%) participants were identified with a disorder associated with SCD, all with Wolff-Parkinson-White (WPW) and all detected by ECG. Two-fifth (40%) of these participants reported symptoms, although their association with the diagnosis was uncertain. One athlete with WPW reported a history of near-syncope or syncope with exercise, and another athlete with WPW reported near-syncope or syncope with exercise, chest pain and palpitations. Three-fifth (60%) of participants with WPW were detected by ECG alone, and 4/5 (80%) were student athletes. The false-positive rate for history, physical examination and ECG for conditions associated with SCD was 31.3%, 9.3% and 5%, respectively. A

minor cardiovascular condition requiring medical follow-up or further evaluation was identified in 52 (3.9%) participants (table 6).

DISCUSSION

A standardised history and physical examination is recommended for the cardiovascular screening of athletes.[1112] However, the questionnaires developed remain largely unstudied. The Pre-participation Physical Evaluation Monograph is a collaboration of six national organisations including primary care and sports medicine societies and incorporates the AHA cardiovascular screening guidelines into a comprehensive questionnaire used when conducting sports physicals.[12] Currently in its fourth edition, the PPE-4 has emerged as the standard of care within the USA sports medicine community.

Little is known about the prevalence of cardiovascular symptoms in young athletes, and no study until now has reported findings by using the PPE-4 questionnaire. This study found a remarkably high rate of reported symptoms in adolescent students and student athletes. Sixty-eight per cent of participants checked ‘yes’ to one of the personal or family history questions on the PPE-4. While a physician review of these responses revealed that approximately half were not clinically relevant, one-third of the entire study population still required further cardiac evaluation based on abnormal history alone. In a prior study, Fuller *et al*[24] screened 5617 high school athletes by history, physical examination and ECG and reported that 8% of athletes had cardiovascular symptoms, although the questionnaire used was not presented. Price *et al*[25] studied preparticipation screening in 2017 high school athletes and found that 12.1% of athletes reported at least one positive finding on the history questionnaire. In college athletes, Baggish *et al*[26] screened 510 athletes and reported that 6% had positive history findings using the AHA history guidelines.

The reasons for the high rate of reported cardiovascular symptoms in this population are unclear. The PPE-4 questions were developed by expert consensus but not tested before release, and thus may be too broad in scope. The rate of positive responses may also be influenced by participant participation in a ‘heart screening’ event rather than a ‘sports physical’, and thus history response rates may be lower in other settings. This was a voluntary and free heart screen and selection bias may have influenced adolescents and families with greater cardiovascular concerns to participate. Approximately 15% of participants reported a family history of heart problems, unexpected sudden death or a genetic cardiac condition that could not be judged as benign after physician interview. In addition, positive responses to questions pertaining to the presence of chest pain, light-headedness or shortness of breath with exercise were higher in student non-athletes compared to student athletes, which were most likely related to lower conditioning in non-athletes and unfamiliarity to common cardiopulmonary symptoms related to exertion. Thus, the PPE-4 or similar models for heart screening in the young should be applied cautiously in non-athletic populations. Still, 30% of student athletes in this study reported one or more positive history responses on the PPE-4 that warranted further investigation.

Our experience also suggests that the positive history response rate declines in more competitive athletes, such as college and professional athletes. The inclusion of high school

athletes participating at various levels of school-sponsored teams may contribute to the high rate of reported symptoms in this study.

Further research is needed to improve the history questions used during cardiovascular screening to minimise false-positive responses, and future versions of the PPE should be guided by scientific investigations rather than consensus.

This study evaluated the PPE-4 questions in comparison to a resting ECG for the detection of pathological cardiac conditions known to cause SCD. Prior studies have also found a low sensitivity of history and physical examination to detect potentially lethal cardiovascular disorders. In a study of 2720 competitive athletes and physically active schoolchildren in the UK, Wilson *et al*[27] reported that nine (0.3%) athletes had a cardiovascular condition known to cause SCD in the young, and all of these athletes were detected by ECG and not by history or physical examination. Hevia *et al*[28] investigated cardiovascular screening in 1220 amateur athletes from Spain and reported that two athletes were diagnosed with hypertrophic cardiomyopathy identified by ECG alone, with none of the cases with a positive finding on history or physical examination demonstrating a structural cardiac disease on the echocardiogram. In a US college population, only one of three athletes diagnosed with a potentially lethal cardiovascular disorder was detected due to an abnormal history and physical examination.[26]

This study found an ECG false-positive rate of 5% using criteria adapted from the 2010 ESC guidelines.[2223] ECG inter-pretation by less experienced clinicians or in more competitive athlete populations may yield a higher false-positive rate. Past studies in elite athletes as well as older general populations have found higher false-positive rates using the 2010 ESC guidelines.[29–31] This study was conducted before publication of revised international consensus standards for ECG interpretation in athletes which have been shown to improve specificity during athlete screening.[3233]

Concern for a high false-positive rate is commonly cited as a reason against the use of ECG screening in athletes.[18–20] However, the false-positive rate (30% in athletes) for the PPE-4 history questions in this study was actually six times higher than the false-positive rate for ECG alone. A low sensitivity and high false-positive rate of the PPE-4 is not in itself a justification for more intensive screening of athletes. While physician training and experience are needed to ensure proper ECG interpretation, the low false-positive rate and improved detection of pathological cardiac conditions suggest that ECG can be a valuable and feasible tool in the cardiovascular screening of athletes.

In this study, the number of echocardiograms obtained may not represent what would occur in clinical practice. The referral rate for an echocardiogram was most likely higher because of the convenience of free, on-site evaluations. The study methods also required echocardiography for any participant with a positive history response or abnormal physical examination to assess the sensitivity of the screening procedures, a protocol that may not parallel clinical practice.

ECG detected five participants with WPW with a prevalence of 1 in 268 (0.4%). Given the high prevalence of cardiovascular symptoms reported by athletes in this study, the

significance of the reported symptoms such as chest pain or near-syncope/syncope in two participants with WPW remains uncertain. Other studies have found a similar prevalence of WPW, ranging 1–4.5/1000 individuals.[34–37] WPW accounts for at least 1% of deaths in a long-term registry of SCD in athletes, though it may account for a larger proportion of cases with autopsy-negative sudden unexplained death due to challenges in postmortem diagnosis.[238] Prior reports have suggested that the risk of life-threatening arrhythmias is higher in asymptomatic children than in adults, with as many as 10–48% of paediatric cases of WPW presenting with SCD as the initial event.[39–41] More research is needed to understand the risk associated with WPW in the young athletic population.

An integrated screening protocol consisting of history, physical examination and ECG also increased detection of many minor cardiac abnormalities of clinical significance warranting further evaluation and/or monitoring. Given that 80% of the student population in this study were student athletes and had previously received medical clearance for sports (a requirement to participate on a high school athletic team), the reasons some of these conditions were not previously detected by history or physical examination is unclear. The inclusion of ECG as part of an integrated screening protocol may raise awareness of abnormal history and physical examination findings that otherwise go unreported, unrecognised or unevaluated.

CONCLUSION

A standardised history and physical examination using the PPE-4 heart questions yields a high false-positive rate in a young active population with limited sensitivity to identify those at risk for SCD. ECG screening has a low false-positive rate using modern standards for interpretation and improves detection of pathological cardiac disease. Additional research is needed to understand potential improvements to the PPE questionnaire.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What are the new findings?

- ▶ A standardised history questionnaire based on the Pre-participation Physical Evaluation Monograph, 4th Edition yields a high false-positive rate (31%) during cardiovascular screening of adolescent athletes.
- ▶ ECG screening has a low false-positive rate (5%) using modern standards for interpretation and improves detection of primary electrical disease at risk of sudden cardiac arrest.
- ▶ Student non-athletes are more likely than student athletes ($p<0.001$) to report chest pain, light-headedness and shortness of breath on heart screening questionnaires.

How might it impact on clinical practice in the near future?

- ▶ Positive history responses on the PPE-4 questionnaire are common in young athletes, with over half of the responses thought to be non-cardiac or benign and not warranting further evaluation.
- ▶ The inclusion of ECG as part of an integrated screening protocol improves sensitivity for conditions at risk for SCA and may raise awareness of abnormal history and physical examination findings that otherwise go unreported, unrecognised or unevaluated.
- ▶ Additional research is needed to refine and improve the sensitivity and specificity of the personal and family history questions asked during cardiovascular screening of athletes.

Table 1

Study demographics

Study demographics	Total number (%)
Age (years)	
13-15	483 (36)
16-20	838 (63)
21-24	15 (<1)
Not documented	3 (<1)
Total	1339
Race	
Caucasian	911 (68)
Asian/Pacific Islander	243 (18)
African-American	230 (17)
Hispanic/Latino	113 (8)
Native American	36 (3)
Other	8 (0.6)
Gender	
Male	661 (49)
Female	678 (51)
Physical activity/week	
>10h	454 (35)
5-10h	444 (34)
2-5 h	284 (22)
<2 h	120 (9)
Organised sports team	
High school	860 (64)
Club/select level	308 (23)
Recreational level	250 (19)
Professional	6 (0.5)
College	4 (0.3)
Total	1071 (80)

Table 2

Personal and family history responses to the PPE-4 Monograph before and after review with a physician

PPE-4 personal and family history	All students (1339)	
	Total positive (%) before physician evaluation	Total positive (%) after physician evaluation
≥1 Positive personal or family history response	916 (68)	421 (31)
Personal history questions		
Have you ever had discomfort, pain, tightness or pressure in your chest during exercise?	377 (28)	217 (16)
Do you get light-headed or feel more short of breath than expected during exercise?	341 (25)	210 (16)
Do you get more tired or short of breath more quickly than your friends during exercise?	295 (22)	165 (12)
Have you ever passed out or nearly passed out DURING or AFTER exercise?	167 (12.5)	126 (9)
Does your heart ever race or skip beats (irregular beats) during exercise?	149 (11)	100 (7.5)
Has a doctor ever ordered a test for your heart? (For example, an ECG/EKG, echocardiogram)	116 (9)	79 (6)
Has a doctor ever told you that you have any heart problems? If so, check all that apply:	99 (7)	70 (5)
Heart murmur	54 (4)	38 (2.8)
High blood pressure	22 (1.6)	16 (1)
High cholesterol	7 (0.5)	2 (<0.5)
Kawasaki disease	2 (<0.5)	2 (<0.5)
Unknown	1 (<0.5)	1 (<0.5)
Heart infection	0	0
Marfan syndrome	0	0
Have you ever had an unexplained seizure?	19 (1.4)	13 (1)
Family history questions		
Does anyone in your family have a heart problem, pacemaker or implanted defibrillator?	339 (25)	165 (12)
Has any family member or relative died of a heart problem or had any unexpected or unexplained sudden death before age 50 (including drowning, unexplained car accident or sudden infant death syndrome)?	211 (16)	118 (9)
Has anyone in your family had unexplained fainting, unexplained seizures or near drowning?	129 (10)	77 (6)
Does anyone in your family have a known cause of SCD:	46 (3.4)	36 (2.7)
Hypertrophic cardiomyopathy	11 (0.8)	10 (0.75)
Marfan syndrome	4 (0.3)	4 (0.3)
CPVT	3 (0.2)	2 (0.2)
Short QT syndrome	1 (<0.1)	1 (<0.1)
Long QT syndrome	1 (<0.1)	1 (<0.1)
ARVC	0	0
Brugada syndrome	0	0
Unknown	13 (1)	11 (1)
Other	11 (0.8)	6 (0.5)

ARVC, arrhythmogenic right ventricular cardiomyopathy; CPVT, catecholaminergic polymorphic ventricular tachycardia; PPE-4, Pre-participation Physical Evaluation 4th Edition; SCD, sudden cardiac death.

Table 3

Comparison of personal and family history responses in student athletes versus student non-athletes before and after review with a physician

PPE-4 personal and family history	Total positive (%) before physician evaluation			Total positive (%) after physician evaluation		
	Student athletes (1071)	Student non-athletes (268)	p Value	Student athletes (1071)	Student non-athletes (268)	p Value
≥1 Positive personal or family history response	714 (67)	202 (75)	<0.01	324 (30)	114 (42)	<0.001
Personal history questions						
Have you ever had discomfort, pain, tightness or pressure in your chest during exercise?	283 (26)	94 (35)	<0.01	155 (14)	61 (23)	<0.001
Do you get light-headed or feel more short of breath than expected during exercise?	245 (23)	96 (36)	<0.0001	140 (13)	68 (25)	<0.0001
Do you get more tired or short of breath more quickly than your friends during exercise?	185 (17)	110 (41)	<0.0001	96 (9)	69 (26)	<0.0001
Have you ever passed out or nearly passed out DURING or AFTER exercise?	131 (12)	36 (13)	0.59	100 (9)	26 (10)	0.85
Does your heart ever race or skip beats (irregular beats) during exercise?	106 (10)	43 (16)	<0.01	68 (6)	32 (12)	<0.01
Has a doctor ever ordered a test for your heart? (For example, an ECG/EKG, echocardiogram)	89 (8)	27 (10)	0.36	56 (5)	23 (8.5)	0.04
Has a doctor ever told you that you have any heart problems?	74 (7)	25 (9)	0.18	50 (5)	20 (7.5)	0.07
Have you ever had an unexplained seizure?	12 (1)	7 (3)	0.06	8 (0.75)	5 (2)	0.09
Family history questions						
Does anyone in your family have a heart problem, pacemaker or implanted defibrillator?	261 (24)	78 (29)	0.11	118 (11)	47 (17)	<0.01
Has any family member or relative died of a heart problem or had any unexpected or unexplained sudden death before age 50 (including drowning, unexplained car accident or sudden infant death syndrome)?	162 (15)	49 (18)	0.20	86 (8)	32 (12)	0.04
Has anyone in your family had unexplained fainting, unexplained seizures or near drowning?	95 (9)	34 (13)	0.06	53 (5)	23 (8.5)	0.02

PPE-4 personal and family history						
	Total positive (%) before physician evaluation			Total positive (%) after physician evaluation		
	Student athletes (1071)	Student non-athletes (268)	p Value	Student athletes (1071)	Student non-athletes (268)	p Value
Does anyone in your family have a known cause of SCD?	36 (3)	10 (4)	0.77	28 (3)	8 (3)	0.74

PPE-4, Pre-participation Physical Evaluation 4th Edition; SCD, sudden cardiac death.

Table 4

Abnormal physical examination and ECG findings

	Total (%)
Abnormal physical examination	
Elevated blood pressure (>140/90)	22 (1.6)
Murmur	114 (8.5)
Marfan stigmata	10 (<1)
Total	124 (9.3)
Abnormal ECG	
T-wave inversion	20 (1.5)
Q waves	10 (0.8)
Left axis deviation	10 (0.8)
Right ventricular hypertrophy	8 (0.6)
Complete right bundle branch block	7 (0.5)
WPW	5 (<0.5)
Other	5 (<0.5)
Intraventricular conduction delay	4 (<0.5)
Left atrial enlargement	2 (<0.5)
Right atrial enlargement	2 (<0.5)
Atrial tachyarrhythmia	1 (<0.5)
PVCs	1 (<0.5)
Total	72 (5.4)

PVC, preventricular contractions; WPW, Wolff-Parkinson-White.

Table 5

Indication for further evaluation with echocardiogram in students with a positive cardiac screen

Indication for echocardiogram	
Echocardiogram for any indication	586 (44%)
Medical history	321 (24%)
Family history	155 (11.5%)
Medical and family history	419 (31%)
Physical examination	105[*] (8%)
Abnormal ECG	70[*] (5%)

[*]Nineteen participants with an abnormal physical examination and 2 participants with an abnormal ECG declined to have an echocardiogram.

Table 6

Cardiac conditions identified

	Total
Primary outcomes (associated with sudden cardiac death)	
Diagnosis	
Wolff-Parkinson-White	5 (0.4%)
Secondary outcomes (requiring further evaluation and/or medical follow-up)	
Diagnosis	
Blood pressure	
Elevated blood pressure	22
Elevated blood pressure+mild concentric LVH	3
Elevated blood pressure+mild subaortic septal thickening	1
Valvular abnormality	
Bicuspid aortic valve with mild aortic valve insufficiency	2
Bicuspid aortic valve	3
Mitral valve prolapse with mitral regurgitation	1
Myxomatous mitral valve	1
Mild pulmonic stenosis	1
Left ventricular abnormality	
Dilated left ventricular chamber; LVEDD (6.5 cm)*	1
Mild concentric LVH (1.2 cm)	1
Asymmetric septal hypertrophy (1.2 cm)†	1
Abnormal septal wall motion	1
Small ventricular septal defect	1
Coronary arteries	
Possible dilated left main coronary artery+chest pain‡	1
History of Kawasaki's disease; possible enlarged right coronary artery	1
Great vessels	
Prominent ascending aorta	1
Dilated main pulmonary artery	1
Personal history or symptoms	
History of Kawasaki's disease and atrial septal defect	1
Palpitations	
Decrease in exercise tolerance, chest pain and racing heart	1
Family history	
Family history of LQTS (sister)	1
Family history of CPVT (father)	1
Family history of early sudden death	1
Other	
Low atrial tachycardia	1
Inappropriate sinus tachycardia	1

	Total
Total	52 (3.9%)

CPVT, catecholaminergic polymorphic ventricular tachycardia; IVS, intraventricular septal; LQTS, long QT syndrome; LVEDD, left ventricular end diastolic diameter; LVH, left ventricular hypertrophy; LVPW, left ventricular posterior wall.

*Sixteen-year-old male wrestler with chest pain and elevated blood pressure; normal ECG; LVEDD 6.5 cm with low normal systolic function on echocardiography.

†Fifteen-year-old male baseball player with an abnormal ECG (Q waves); IVS thickness 1.2 cm, LVPW thickness 1.0; LVEDD 5.2; follow-up echocardiogram was normal showing a prominent moderator band which may have accounted for the septal hypertrophy.

‡Seventeen-year-old male football player; normal ECG; an otherwise normal echocardiogram.