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Age at start of endurance training is associated with patterns of left ventricular hypertrophy in middle-aged runners

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ABSTRACT

Background: Left ventricular hypertrophy (LVH) is a physiological adaptation to long-term endurance training. We investigated the impact of age at start of endurance training on LV geometry in a cohort of male, middle-aged, non-elite endurance athletes.

Methods: A total of 121 healthy, normotensive, Caucasian participants of a 10-mile race were recruited and assessed with an echocardiogram and a comprehensive interview. Athletes were classified based on patterns of LVH.

Results: Thirty-five athletes (31%) had LVH. Athletes with eccentric LVH (16%) were significantly younger at start of endurance training compared to athletes with concentric LVH (15%, 14 ± 5 years vs. 31 ± 8 years; $P < 0.001$). Although the yearly volume of endurance training was comparable between athletes with eccentric and concentric LVH, athletes with eccentric LVH had shorter race times. All athletes with an increased LV end diastolic volume index (LVEDVI; ≥74 ml/m^2) started endurance training before or at age 25.

Conclusions: In our cohort of non-elite middle-aged runners, eccentric LVH was found only in athletes with an early start of endurance training. In case of a mature starting age, endurance training may, contrary to what is commonly assumed, also lead to concentric LVH. The consideration of endurance training starting age may lead to a better understanding of morphological adaptations of the heart.

1. Introduction

Regular long-term exercise results in a series of adaptations of cardiac structure. This phenomenon, also called the athlete's heart, has been known for over a century and observed in different athletic populations [1–4]. The 'Morganroth Hypothesis' (MH) formed a milestone for the understanding of these adaptations and was subsequently widely adopted. This hypothesis states that the type of training plays a central role in the differential adaptation to exercise stress: Endurance training is proposed to lead, as a consequence of volume overload, to eccentric left ventricular hypertrophy (LVH), whereas strength training, as a consequence of pressure overload, to concentric LVH [5]. Despite ample evidence, the MH has been challenged by at least 6 recent studies. Utomi et al. and Spence et al. described a lack of concentric LVH in strength-trained athletes [6–8]. Caselli et al. demonstrated a balanced adaptation of LV mass and LV volume regardless of type of training [9]. Arbab-Zadeh et al. showed that the LV responded to endurance training with initial concentric but not eccentric remodeling during the first 6 to 9 months after commencement, with a normalization of mass-to-volume ratio thereafter [10]. Finally, Finocchiaro et al. observed that a significant proportion of endurance-trained elite athletes showed concentric LVH [11].

Concentric LVH is characterized by an overproportional increase in wall thickness compared to the cavity dimensions. Eccentric LVH, on the other hand, is the result of a proportionate increase in LV cavity dimensions and wall thickness [12,13]. A multivariate analysis based on data of a large Italian elite athlete population showed that 72% of variability in LV cavity dimension was attributable to non-genetic factors, such as body surface area (BSA), type of sport, gender and age [1]. The remaining 25% of variability could not be explained and was ascribed to genetic factors [14,15].

While the MH was primarily based on studies in young elite athletes [16], studies on middle-aged amateur athletes are rare. Whether findings from young athletes can be translated to previously sedentary persons starting endurance training at an advanced age is questionable. It is a relatively recent phenomenon that previously sedentary persons take up participation in endurance competitions requiring a large volume of training, which may be why studies including older and previously sedentary athletes are rare. It is plausible that the adaptive responses of the heart and the cardiovascular system may differ between peripubertal

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and mature aspiring athletes, similar to what has been well established in bone [17,18].

The central hypothesis of the present study was that the morphological cardiac adaptation to endurance training is a function of age at start of endurance training, with athletes starting endurance training at a more mature age having a lesser potential for cavity enlargement. Therefore we assessed the effect of starting age on LV geometry in a cohort of male, middle-aged, non-elite endurance athletes.

2. Methods

2.1. Participants and protocol

The Grand Prix of Bern is a popular 10 mile race in Switzerland with over 30,000 participants annually. Male non-elite runners were recruited for two studies on endurance exercise and atrial remodeling as previously described [19,20]. Runners aged 30 years and older, with and without a history of former long-distance runs, were included. Exclusion criteria were a history of cardiovascular disease, medication intake, or cardiovascular risk factors, in particular arterial hypertension, defined as an office blood pressure (BP) ≥140/90 mm Hg at the initial visit [21].

Athletes included in the above cited studies were contacted by e-mail and/or postal mail to arrange a comprehensive phone interview on their sports history. The interview included questions regarding their sports disciplines based on the Mitchell classification [22,23], starting age of the concerned disciplines and average volume of training per week of concerned sports disciplines on a year by year basis. The calculation of average training hours was determined by the athletes' estimation and/or exercise diary. Age at start of endurance sports career and, if applicable, average volume of competitions per year (in hours), as well as longer training interruptions were also recorded and accounted for in the calculations. Endurance training starting age was defined as the age when athletes performed at least 2 h of endurance training per week. Lifetime cumulative training hours according to Mitchell sports categories were calculated using the following formula: average training hours per sports category and per week × 52 × training years [19,20], calculated on a year by year basis if volume varied. Mitchell classes CI-CIII were further subdivided in cumulative lifetime ball sports including soccer, tennis, handball, field hockey, badminton, basketball, ice hockey, and cumulative lifetime endurance training including running, orienteering, cross-country skiing, swimming, rowing, cycling and triathlon. All athletes provided written informed consent and the protocol was approved by the local ethics committee.

2.2. Transthoracic echocardiography

Standard two-dimensional TTE was performed on a Phillips iE33 System (X5-1 transducer, Phillips Medical Systems, Zurich, Switzerland). LV internal diameter (LVID), interventricular septum (IVS) and posterior wall thickness (PWT) were measured in M-mode from the parasternal long-axis view at end-diastole. LV mass was calculated based on the cube formula: LV mass $= 0.8 \times 1.04 \times [(IVS + LVID + PWT)^3 - LVID^3] + 0.6$ g and indexed for BSA [12]. LVH was defined as LV mass/BSA ≥ 116 g/m^2 [12,24].

LV end-diastolic (LVEDV), and LV end-systolic volumes (LVESV) were calculated using the biplane method of disks summation technique. Volume measurements were based on tracings of the blood-tissue interface in the apical four- and two-chamber views. At the mitral valve level, the contour was closed by connecting the two opposite sections of the mitral ring with a straight line. LV length was measured from this line to the apical point of the LV contour. All volumes were indexed for BSA [12,13].

Phenotypic characterization of the LV geometry was based on the 4-tiered classification for LVH as recently proposed by Khouri and co-workers [25]. Echocardiographic thresholds for increased concentricity were ≥ 9.1 g/ml$^{2/3}$ and for increased LVEDV/BSA ≥76 ml/m^2 [24].

LV systolic function was expressed as ejection fraction (EF), derived from the LVEDV and LVESV. LV diastolic function was assessed by pulse-wave and tissue Doppler in the apical four-chamber view. Peak early and late diastolic velocities at the septal and lateral side of the mitral annulus were recorded and the mean value was calculated and defined as E′ mean and A' mean [12].

2.3. Data analysis

The data was analysed with SPSS Software for Windows (Version 17.0, SPSS Inc., Chicago, USA). The normality of quantitative variables was inspected visually and homogeneity of variances tested by Levene test. Normally distributed data were presented as mean ± standard deviation (SD), and non-normally distributed variables as median and interquartile range (IQR).

All athletes were classified by patterns of LVH [26] and resulting groups were compared with regard to anthropometric and echocardiographic data, as well as detailed sports history. Normally distributed variables with homogenous variances were compared by univariate ANOVA with Tukey post-hoc testing or Dunnet T3 post-hoc testing if variances were heterogeneous. Between group comparison of data with non-parametric distribution was performed by Kruskal-Wallis tests with Bonferroni-adjusted Mann-Whitney-U post-hoc testing.

We performed linear regression models for the dependent variable LVEDV. Rather than performing models for LVEDV indexed by BSA, we decided to enter BSA as an independent variable into the models. This allowed a direct comparison with the model presented by Pelliccia and colleagues [14]. To identify the independent parameters for forced inclusion into the models we performed a correlation matrix with Pearson and Spearman correlation coefficients between LVEDV and the following variables: BSA, BMI, HR at rest, systolic BP, age, age at start of endurance training, hours of endurance training per year, 10 mile race time, cumulative lifetime training hours for all, high dynamic, and endurance sports. We only entered independent parameters with significant linear relationship to LVEDV into the models. In case of collinearity between independent parameters, we chose to enter only the parameter with the stronger association with LVEDV. Further, we performed a logistic regression model for athletes with LVH with eccentric and concentric LVH as binary dependent variable and the three training variables age at start of endurance training, cumulative lifetime endurance training, and yearly endurance training as independent variables. We also performed univariate logistic regression models with the same dependent variable and the independent training variables entered individually into the models. Alpha was set at 0.05.

3. Results

3.1. Study subjects

A total of 174 male runners were contacted by mail. An interview lasting approximately 45 min was performed with 121 athletes, of whom 98 completed the interview by phone and 23 chose to complete a questionnaire by postal mail. Mean and SD of age was 42 ± 8 years. A broad spectrum of endurance athletes was included, ranging from leisure-time runners with a first participation in a 10 mile race up to semi-professional long-distance runners with >20,000 cumulative lifetime endurance training hours (median 3692, IQR 1963-8398).

3.2. LV geometry

Baseline characteristics and echocardiographic data are shown in Table 1 stratified according to patterns of LVH. Athletes with eccentric LVH had a lower HR and greater LVEDVI than all other athletes. Furthermore, athletes with eccentric LVH had a significantly lower posterior and relative wall thickness than athletes with concentric LVH.

Characteristics of sports history, stratified according to patterns of LVH, are shown in Table 2. Thirty-five athletes (31%) had LVH. Significant differences between groups were found for age at start of endurance training, 10 mile race time and cumulative lifetime training hours for all, high dynamic, and endurance sports. Athletes with eccentric LVH had significantly more cumulative lifetime endurance training hours compared to athletes with concentric LVH. However, the amount of endurance training hours per year did not differ between athletes with eccentric and those with concentric LVH. Athletes with eccentric LVH were younger at start of endurance training and had shorter race times compared to athletes with normal LV geometry or concentric LVH.

The influence of age at start of endurance training on LV geometry can be seen in Fig. 1. All athletes with eccentric LVH started endurance training at an age ≤ 25 years (mean 14 ± 5 years). On the other hand, age at start of endurance training in athletes with concentric LVH was considerably older (31 ± 8 years), and only three athletes (17%) in this group started endurance training between age 17–25. Similarly all athletes with an increased LVEDVI (≥74 ml/m^2) started endurance training at an age ≤ 25 years (mean 14 ± 5 years).

3.3. Determinants of LV cavity size

There was a significant association between LVEDV and the following parameters: Age (Spearman correlation coefficient − 0.30), BSA (0.19), HR at rest (−0.46), age at start of endurance training (−0.46), endurance training per year (0.25), 10 mile race time (−0.44) and cumulative lifetime training hours for all (0.27), high dynamic (0.29), and endurance sports (0.32, all $P < 0.01$, except BSA $P < 0.05$). The variables most strongly related to LVEDV were age at start of endurance training and HR at rest. Age and age at start of endurance training were correlated (0.35, $P < 0.001$). Age at start of endurance training

Table 1
Baseline characteristics and echocardiography stratified according to patterns of left ventricular hypertrophy.

Variable	Normal LV geometry (n = 68)	Concentric LV remodeling (n = 18)	Eccentric LVH (n = 18)	Concentric LVH (n = 17)	P-value
Athlete characteristics					
Age (years)	40 ± 7	46 ± 8	40 ± 7	45 ± 9	0.017
Body mass index (kg/m^2)	22.7 ± 1.9	23.9 ± 1.9	22.4 ± 1.4	23.0 ± 1.9	0.060
Body surface area (m^2)	1.9 ± 0.1	2.0 ± 0.2	1.9 ± 0.1	1.9 ± 0.1	0.286
Heart rate at rest (bpm)	59.4 ± 10	65.8 ± 10	50.3 ± 7[†,‡,§]	61.5 ± 10	<0.001
Systolic blood pressure at rest (mm Hg)	121 ± 9	127 ± 6	123 ± 10	123 ± 10	0.095
Echocardiography					
LA volume/BSA (ml/m^2)	30.1 ± 5.8	28.8 ± 5.9	34.8 ± 5.3[†,‡]	34.1 ± 7.1	0.002
LV mass/BSA (g/m^2)	93.6 ± 12.1	103.8 ± 7.8	126.0 ± 8.6	129.1 ± 7.4	<0.001[*]
LV EDV/BSA (ml/m^2)	61.1 ± 9.6	48.7 ± 5.7[†]	78.5 ± 8.6[†,‡,§]	57.0 ± 8.7	<0.001
Posterior wall thickness (mm)	9.4 ± 1.1	10.2 ± 0.9[†]	10.0 ± 1.0§	10.9 ± 0.8[†]	<0.001
LV internal diameter (mm)	50.7 ± 4.1	50.0 ± 4.8	55.9 ± 3.1[†,‡]	53.2 ± 3.4	<0.001
Relative wall thickness	0.37 ± 0.06	0.41 ± 0.07[†]	0.36 ± 0.05[‡,§]	0.41 ± 0.05	0.004
LV ejection fraction (%)	63.6 ± 4.9	64.1 ± 4.6	64.3 ± 4.9	65.8 ± 6.2	0.453
E′ mean(cm/s)	13.0 ± 2.1	12.2 ± 1.8	12.1 ± 1.7	11.9 ± 1.9	0.114
A′ mean(cm/s)	8.9 ± 1.9	9.5 ± 1.3	8.8 ± 2.0	9.4 ± 1.7	0.452
EA ratio	1.7 ± 0.4	1.4 ± 0.2	1.8 ± 0.4[‡]	1.5 ± 0.4	0.010

Please note: As no athlete was classified as concentric dilated LVH and due to the small numbers in non-dilated and dilated LVH, only four groups are presented. Eccentric LVH includes non-dilated and dilated patterns of the four tiered classification of LVH, resulting in four remaining groups. Normal LV geometry (LV mass/BSA < 116 g/m^2 and concentricity < 9.1 g/ml$^{2/3}$), concentric LV remodeling (LV mass/BSA < 116 g/m^2 and concentricity ≥ 9.1 g/ml$^{2/3}$), eccentric LVH (LV mass/BSA ≥ 116 g/m^2 and concentricity < 9.1 g/ml$^{2/3}$) and concentric LVH (LV mass/BSA ≥ 116 g/m^2 and concentricity ≥ 9.1 g/ml$^{2/3}$).
LA, left atrium; BSA, body surface area; LV, left ventricle; EDV, end-diastolic volume; E′ mean, early diastolic septal and lateral tissue Doppler mitral annular velocity; A′ mean, late diastolic septal and lateral tissue Doppler mitral annular velocity.
[*] By definition.
[†] P < 0.05 vs normal LV geometry.
[‡] P < 0.05 vs concentric remodeling.
[§] P < 0.05 vs concentric LVH.

was more strongly correlated with LVEDV than age, therefore we omitted age from the model. Likewise, variables of sports characteristics were highly correlated with each other (all Spearman correlation coefficients between 0.50 and 0.94, all P < 0.001), except for the correlation between age at start of endurance training and endurance training per year (Spearman inverse correlation coefficient of 0.20, P = 0.03). Therefore we included the variable least correlated with age at start of endurance training, namely endurance training per year. Model 1 was performed with independent parameters BSA, age at start of endurance training and endurance training per year. Model 2 was performed with the additional independent parameter HR at rest. Model 1 explained 27.7% of the total variance (Table 3, model 1), and model 2, with the additional parameter HR at rest, explained 38.2% of the total variance (Table 3, model 2). Standardized beta coefficients of significant parameters were similar (within and between models).

The logistic regression model for eccentric and concentric LVH showed that only age at start of endurance training was significantly related to allocation to eccentric and concentric LVH (P = 0.016). The model with all three training variables accurately allocated 91.4% of athletes with LVH to eccentric and concentric LVH, the same percentage as was correctly allocated with age at start of endurance training alone. Cumulative lifetime endurance training and yearly endurance training were insignificant predictors in the model with all three training variables (P = 0.205 and P = 0.520, respectively). In the univariate models they were significant but the percentage of accurately allocated athletes was considerably smaller (74% and 57%, respectively).

Table 2
Sports history parameters of endurance athletes, stratified according to patterns of left ventricular hypertrophy.

Variable	Normal LV geometry (n = 68)	Concentric LV remodeling (n = 18)	Eccentric LVH (n = 18)	Concentric LVH (n = 17)	P-value
Sports history parameters					
Age at start of endurance training	24 ± 10	27 ± 8	14 ± 5[†,‡,§]	31 ± 8	<0.001[*]
Cumulative lifetime training (h)	6669 (4063, 11,505)	5122 (3094, 7839)	10,608 (9120, 14,196)[†,‡]	6656 (3913, 10,205)	0.007
Cumulative lifetime high dynamic training (h)	5122 (3120, 9393)	3926 (3094, 6351)	8957 (8392, 13,715)[†,‡]	6188 (3185, 9516)	0.005
Cumulative lifetime ball sports training (h)	988 (0, 2860)	1014 (156, 1924)	78 (0, 2444)	1768 (390, 3588)	0.198
Cumulative lifetime endurance training (h)	3146 (1560, 6942)	3458 (1931, 5265)	8957 (3744, 13,299)[†,‡,§]	2808 (1742, 6903)	0.002
Endurance training per year (h)	259 (156, 393)	189 (134, 299)	337 (206, 527)	243 (208, 356)	0.059
Cumulative lifetime resistance training (h)	0 (0, 280)	0 (0, 780)	0 (0, 0)	0 (0, 0)	0.177
Resistance training per year (h)	0 (0, 26)	0 (0, 85)	0 (0, 0)	0 (0, 0)	0.169
10 mile race time (hours:min)	1:11 ± 0:10	1:17 ± 0:14	1:01 ± 0:04[†,‡,§]	1:08 ± 0:08	<0.001[*]

Please note: As no athlete was classified as concentric dilated LVH and due to the small numbers in non-dilated and dilated LVH, only four groups are presented. Eccentric LVH includes non-dilated and dilated patterns of the four tiered classification of LVH, resulting in four remaining groups. Normal LV geometry (LV mass/BSA < 116 g/m^2 and concentricity < 9.1 g/ml$^{2/3}$), concentric LV remodeling (LV mass/BSA < 116 g/m^2 and concentricity ≥ 9.1 g/ml$^{2/3}$), eccentric LVH (LV mass/BSA ≥ 116 g/m^2 and concentricity < 9.1 g/ml$^{2/3}$) and concentric LVH (LV mass/BSA ≥ 116 g/m^2 and concentricity ≥ 9.1 g/ml$^{2/3}$).
LVH, left ventricular hypertrophy; LV, left ventricular.
[*] P-value of Dunnett-Test because of heterogeneity of variances.
[†] P < 0.05 vs normal LV geometry.
[‡] P < 0.05 vs concentric remodeling.
[§] P < 0.05 vs concentric LVH.

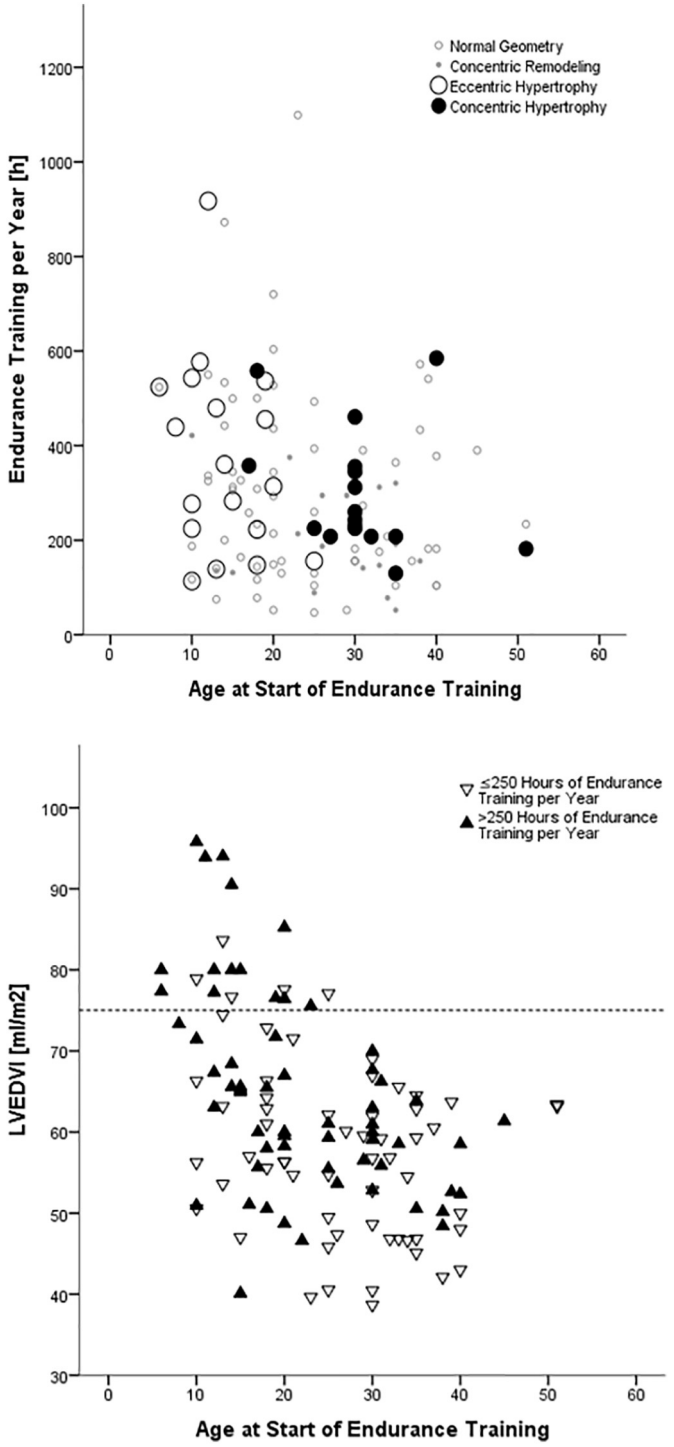

Fig. 1. Relationship of endurance training hours per year and age at start of endurance training with left ventricular geometry (top panel), as well as left ventricular end-diastolic volume (bottom panel).

4. Discussion

In this study assessing LV geometry of a diverse athletic population ranging from recreational to semi-professional runners we found a close association of LV volume with age at start of endurance training. Age at start of endurance training was more closely related to LVEDV than any other measured training variable. Of note, all athletes with an increased LVEDVI (≥74 ml/m^2) started endurance training at an age ≤ 25 years. In particular, athletes with eccentric LVH were younger at start of endurance training compared to athletes with concentric LVH. To the best of our knowledge this is the first study demonstrating an association between the age at start of endurance training and patterns of LVH in athletes.

Table 3
Linear regression models for left ventricular end-diastolic volume.

Variable	Standardized beta coefficient	P-value	Adjusted R^2
Model 1			0.28
Body surface area	0.258	0.001	
Age at start of endurance training	−0.385	<0.001	
Endurance training per year	0.236	0.004	
Model 2			0.38
Body surface area	0.312	<0.001	
Age at start of endurance training	−0.314	<0.001	
Endurance training per year	0.202	0.008	
Heart rate at rest	−0.344	<0.001	

4.1. LVH in endurance athletes

In our cohort of male, middle-aged, non-elite endurance athletes we found some evidence that endurance training led to eccentric LVH, however, only in athletes who started their endurance training early. Furthermore, we found also concentric LVH in endurance athletes, namely in those who started their endurance training at an age of at least 30 years (76%, except for two athletes who started endurance training between 17 and 19 Fig. 1). This confirms our hypothesis that age at start of endurance training may play an important role in LV morphologic adaptations. Concentric remodeling in athletes performing highly dynamic sports has been found also in another cross-sectional study on athletes [11].

In our study, athletes with concentric LVH had a significantly lower LVEDVI (and correspondingly a slower race time) compared to athletes with eccentric LVH (57 ± 9 vs. 78 ± 9 ml/m^2, P < 0.001). Although athletes with concentric LVH had significantly fewer cumulative lifetime endurance training hours compared to athletes with eccentric LVH, the yearly volume of endurance training was comparable. In a longitudinal study in young, previously sedentary people, the development of LV mass was closely related to the quarterly training impulse [10]. The same study showed that the LV responded to endurance training with initial concentric but not eccentric remodeling during the first 6 to 9 months after commencement, with a normalization of the mass-to-volume ratio thereafter. This transient concentric remodeling would not explain our findings, as all of our athletes with concentric LVH had been performing endurance training for at least 3 years (median 12, IQR 6–21). Athletes with concentric LVH did not differ from all other athletes with regard to age, BSA, BMI, BP, EF, E' mean and/or cumulative lifetime resistance training hours. Therefore, age at start of endurance training was the only remaining explaining factor measured in our study. The potentially important role of age at start of endurance training may have been overlooked in older studies, who based their findings on young elite athletes [5,16,27].

4.2. Left ventricular volume

By using Spearman correlation and regression models, we determined factors associated with LV cavity volume in our cohort of male, middle-aged athletes (Table 3). An early start of endurance training, greater BSA, and more yearly endurance training hours were significantly associated with LV cavity enlargement. There was also a significant association between LVEDV and age, mainly driven by the collinearity between age and age at start of endurance training. We chose to enter age at start of endurance training into the models rather than age because the univariate correlation coefficient with LVEDV was higher for this variable. The collinearity between age and age at start of

endurance training was based on a per definition relationship in that the starting age in young athletes could not be older than their age. Consequently, there were no young athletes with an old starting age, and the absence of these data points led to a spurious correlation. Further, when age was also entered into the linear regression model 1 for LVEDV, it had no (further) significant contribution ($P = 0.07$). Of note, age correlated negatively with LVEDV, indicating that the LV cavity becomes smaller with age. We suggest that this interpretation is unlikely to reflect the truth in our generally fit population, but the negative correlation was rather due to the confounding effect of age at start of endurance training (which was positively correlated to age).

For a better comparison with the analyses presented by Pelliccia and colleagues [14], we performed an additional model including HR (Table 3, model 2). While Pelliccia and colleagues' model that included HR explained 63% of the variability in LV cavity dimensions, our corresponding model 2 explained only 38% of the total variance of LVEDV. We suggest that this dissimilarity is primarily based on the difference in study populations. Pelliccia and colleagues had included pubertal, adolescent and adult athletes, which resulted in a broad spectrum of BSA and consequently a strong contribution of age. Therefore the contribution of BSA for explaining LV cavity dimensions was four-times higher compared to BSA in our cohort (univariate correlation coefficients 0.76 vs. 0.19).

4.3. Adaptation mechanisms to exercise stress

The cellular response mechanisms of cardiomyocytes to growth stimuli that result in morphological changes are hypertrophy (increased cell size) and/or hyperplasia (increased cell number) [28]. For example, endurance exercise in mice induced cardiomyocyte hypertrophy and/or hyperplasia [29], possibly depending on the age of the animals [30,31]. Recent data from a study in humans showed that cardiomyocyte proliferation contributed to heart growth up to the age of 20 [32]. The number of cardiomyocytes in the LV increased 3.4-fold between birth and the age of 20. The percentages of cardiomyocytes in cytokinesis were the highest in infants, with a successive decrease to low levels by the age of 20. After age 20 there was no evidence of cardiomyocyte cytokinesis [32]. Another study reported on cardiomyocyte renewal in adult human hearts, which gradually decreased from 1.9% annual turnover at the age of 19 to 0.45% at the age of 75 [33]. As the ability of cardiomyocytes to proliferate decreases throughout lifetime, hypertrophy may become the main contributor to exercise-induced heart growth in mature athletes.

Cardiomyocyte hypertrophy is characterized by an increase in cell length from 5% to 20% [34–36] as well as in cell width by a similar extent [34,37]. The exercise induced hypertrophy in cardiomyocyte cell length may lead to some LV cavity enlargement, which would explained the LVEDV enlargement of 17% from 10 months of training in previously sedentary middle-aged people [38]. Such an exercise induced cavity enlargement by hypertrophy of cardiomyocyte is accompanied by an increase in cell width, which in turn leads to an increased LV wall thickness, resulting in a concentric remodeling pattern. On the other hand, if hyperplasia contributes highly to exercise-induced heart growth (as suggested up to the age of 20 to 30) [32], a sizeable LV cavity enlargement with proportional wall thickening (i.e. eccentric remodeling) would result.

Confirmatory evidence for this hypothesis is found in morphological changes with detraining. Increased cardiomyocyte length and width (i.e. hypertrophy) induced by a training intervention in rodents has been found to be reversible within 2–4 weeks of detraining [34]. Likewise, a training/detraining study in previously untrained healthy humans found an increase in wall thickness due to endurance training (possibly resulting mainly from hypertrophy), with a decrease within 6 weeks of detraining [7]. Conversely, a cavity enlargement in young elite athletes (probably resulting from hyperplasia) has been found to persist through the same time period of detraining with a slow and small decrease thereafter (mean 7% in 5.6 years) [39].

While in bone the 'window of opportunity' is clearly closed by the end of puberty when the growth plates are fused [40], for the heart this window seems to close more gradually, up until an age of approximately 20 to 30.

4.4. Future research

Based on the results of our study we hypothesize that previously sedentary people who start intensive high volume endurance exercise at a more mature age (after 25 to 30 years) may develop concentric LVH. On the other hand, eccentric LVH will only develop in athletes who start their endurance training early (before age 25–30). This hypothesis should be tested in future studies.

4.5. Limitations

Training hours were based on estimation and/or exercise diary and were therefore prone to recall and social desirability bias. Also, we had no information on endurance training intensity. However, the main objective of our study was to assess age at start of endurance training, which we expected to be less confounded by recall and social desirability bias than training volume or intensity. Further, there was a strong inverse correlation between the precisely measured 10-mile race time and the calculated endurance training hours per year. Secondly, the cross sectional design of the study allowed the detection of associations only, rather than cause and effect relationships. However, a longitudinal (randomised) design allocating people to a training group starting endurance training during adolescence or a training group starting at an advance age would hardly be feasible. Finally, echocardiography with one–dimensional LV mass measurements and biplane two-dimensional volume assessment has well known limitations [12,13].

5. Conclusions

In our cohort of non-elite middle-aged runners, eccentric LVH was found only in athletes with an early start of endurance training. In case of a mature starting age, endurance training may, contrary to what is commonly assumed, also lead to concentric LVH. The consideration of endurance training starting age may lead to a better understanding of morphological adaptations of the heart.

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None.

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