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# Risk of arrhythmias in 52 755 long-distance cross-country skiers: a cohort study

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**Aims** We aimed to investigate the association of number of completed races and finishing time with risk of arrhythmias among participants of *Vasaloppet*, a 90 km cross-country skiing event.

**Methods and results** All the participants without cardiovascular disease who completed *Vasaloppet* during 1989–98 were followed through national registries until December 2005. Primary outcome was hospitalization for any arrhythmia and secondary outcomes were atrial fibrillation/flutter (AF), bradyarrhythmias, other supraventricular tachycardias (SVT), and ventricular tachycardia/ventricular fibrillation/cardiac arrest (VT/VF/CA). Among 52 755 participants, 919 experienced arrhythmia during follow-up. Adjusting for age, education, and occupational status, those who completed the highest number of races during the period had higher risk of any arrhythmias [hazard ratio (HR)1.30; 95% CI 1.08–1.58; for ≥5 vs. 1 completed race], AF (HR 1.29; 95% CI 1.04–1.61), and bradyarrhythmias (HR 2.10; 95% CI 1.28–3.47). Those who had the fastest relative finishing time also had higher risk of any arrhythmias (HR 1.30; 95% CI 1.04–1.62; for 100–160% vs. >240% of winning time), AF (1.20; 95% CI 0.93–1.55), and bradyarrhythmias (HR 1.85; 95% CI 0.97–3.54). SVT or VT/VF/CA was not associated with finishing time or number of completed races.

**Conclusions** Among male participants of a 90 km cross-country skiing event, a faster finishing time and a high number of completed races were associated with higher risk of arrhythmias. This was mainly driven by a higher incidence of AF and bradyarrhythmias. No association with SVT or VT/VF/CA was found.

**Keywords** Arrhythmia • Atrial fibrillation • Bradycardia • Exercise training • Cross-country skiing

## Introduction

Physical inactivity is a major risk factor for cardiovascular disease, and regular leisure-time exercise reduces cardiovascular risk significantly.[1–4] On the other hand, strenuous physical exercise may induce life-threatening ventricular arrhythmias in patients with pre-existing heart disease; autopsies of 1435 athletes who suffered sudden cardiac death during training have revealed cardiac abnormalities in 97% of the cases.[5–8]

Endurance training can lead to a number of physiological structural cardiac changes, including left atrial dilation and left ventricular dilation and hypertrophy.[9,10] Further, sinus bradycardia, first-degree atrioventricular block, and second-degree atrioventricular block type I (Wenckebach) are considered normal responses to training.[11] These structural changes are at least partly reversible, but an increased incidence of sinus node dysfunction is seen in retired elite cyclists.[12,13] Although some of these structural changes and bradyarrhythmias may be physiological, associations with adverse clinical outcomes are unknown. Several small case–control studies and one cohort study have demonstrated that athletes committed to endurance exercise have increased risk of atrial fibrillation and flutter compared with the normal population,[14–20] but adequately powered cohort studies are lacking.

We hypothesized that a long-term increased workload as a consequence of prolonged endurance training would lead to structural changes in the heart and autonomic disturbances, which could increase arrhythmogenicity. We investigated the association of number of completed races and finishing time in the race, with the

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risk of hospitalization for arrhythmias in a cohort of 47 477 male and 5278 female participants in a long-distance cross-country ski race, ranging from recreational skiers to elite athletes.

# Methods

## Setting and participants

All Swedish participants in the 90 kilometre skiing event *Vasaloppet* (www.vasaloppet.se) who completed the race during the period 1989–98 were included. *Vasaloppet* takes place on the first Sunday in March every year and is a cross-country skiing event from *Sälen* to *Mora* in *Dalarna*, Sweden. Approximately 15 000 participants ranging from recreational to elite skiers complete the 90 kilometres of cross-country skiing every year. The 90 km *Vasaloppet* has two competitions: (i) the main race on the first Sunday of March where participants start in a large group; (ii) for those who prefer avoiding the stress of the group start, there are two additional race days ('*öppet spår*') where participants can start any time within an hour. The track completed is the same. This study includes both participants starting in the main race and in the '*öppet spår*' race. During the inclusion period, one race was cancelled (1990, because of thawing).

The participants in *Vasaloppet* generally have higher leisure time physical activity, lower incidence of physical and mental illness, tobacco consumption, fat intake, and higher fibre consumption than average Swedes.[21] Further, participants in the race have lower mortality in all major diagnostic groups (cancers and diseases of the circulation system), injuries and poisoning.[21]

The *Vasaloppet* office provided information on all Swedish participants who completed any of the races 1989–98 (49 117 men and 5443 women), including year of the race, finishing time, and the unique 10 digit national registration number to *The National Board of Health and Welfare, Sweden. The National Board of Health and Welfare* linked the data to: (i) the *Swedish National In-Patient Register* to obtain a list of diagnoses, (ii) censuses 1960, 1970, 1980, and 1990 to receive information on occupation and educational level, and (iii) the *Swedish Population Register* to obtain information of emigration. Anonymous data were then delivered to the authors. Participants hospitalized with cardiovascular disease (ICD-10 I.00–99 or similar diagnosis in ICD-7/8/9) before the baseline date were excluded ($n = 1803$). The final study sample comprised 47 477 men and 5278 women without any cardiovascular disease. The study protocol was approved by the Regional Ethical Review Board, Karolinska Institutet, Stockholm, Sweden.

## Baseline data

Because improvements in $VO_2$max are directly related to the intensity, duration, and frequency of training,[22] we used the number of finished races and finishing time as a measure of the participants' duration and intensity of exposure to physical exercise. We investigated finishing time as a categorical variable, divided into four groups of percentages of the winning time that year [100–160%, 161–200%, 201–240%, and >240% (reference group)]. Only the best relative finishing time for each individual during the 10 year period was considered. Further, we investigated number of races as a categorical variable [1 race (reference group); 2 races; 3–4 races; and ≥5 races]. Number of races and finishing time before 1989 or after 1998 were not considered in the exposure assessment.

The cohort was linked to censuses 1960, 1970, 1980, and 1990 to receive information on occupation and educational level. The latest, most updated information for each person was used in this study. Occupation was grouped into four categories (blue-collar, lower-middle white-collar, high white-collar, and entrepreneur). Highest education level obtained was categorized as low (elementary school only), medium (secondary school), and high (university) levels. There were missing values for education in 3072 participants and for occupational status in 6331 participants.

## Follow-up and outcome parameter

Participants were followed from the last participation in the race during the period from 1989–98 (the baseline date) to the date of first diagnosis of the outcome of interest, death, date of emigration, or the end of the follow-up (31st December 2005). Because the national registries were used for follow-up, loss to follow up was negligible.

The primary outcome was for *any arrhythmia* (all of the diagnoses below, plus ICD-10: I47.9). As secondary endpoint, we used (i) Bradyarrhythmias (ICD-10: I44.1, I44.2, I45.2, I45.3, I45.9, I49.5), (ii) Atrial fibrillation or flutter (AF) (ICD-10: I48.9), (iii) Other supraventricular tachycardias (SVT) (ICD-10: 45.6, I47.1), and (iv) ventricular tachycardia/ventricular fibrillation/cardiac arrest (VT/VF/CA) (ICD-10: I47.0, I47.2, I46.0, I46.1, I46.9, I49.0, R96.0). Corresponding codes for ICD-9 were used; see Supplementary material online, *Table S1* for complete list of codes. Both main diagnosis and secondary diagnoses were taken under consideration. Note that use of ICD codes does not allow differentiation between Mobitz-types of A/V-block grade II.

## Statistical analysis

Missing values for the variables 'occupational status' and 'education' were imputed from all other variables using multiple imputations by a chained equation approach (number of imputation cycles 25).[23] For each endpoint, person-years of risk were calculated and Nelson-Aalen plots were produced to test the hazard proportionality assumption. No deviation was observed. To investigate associations of the exposures 'number of races' and 'finishing time group' with risk of arrhythmia outcomes, a Cox proportional hazards regression model was used. We modelled the risk of the primary endpoint (all arrhythmias) and the secondary endpoints (bradyarrhythmias, AF, other SVT, VT/VF/CA) in separate models. Using directed acyclic graphs, a model adjusting for age, occupational status, and education was deemed sufficient to estimate the total effect (evaluating all causal paths) of training level on arrhythmias, also in the absence of important covariates such as blood pressure, diabetes, hyperthyroidism, use of doping, smoking, and alcohol intake (Supplementary material online, *Figure S1*).[24] Hence, two sets of models were investigated: (i) age-adjusted and (ii) adjusted for age, occupational status, and education. Further, to test for a trend by increasing exposure, a model treating 'numbers of races' and 'finishing time group' as continuous variables were performed. Multiplicative interaction terms between contrasting levels of the variables 'number of races' and 'finishing time group', and each of those two variables with contrasting age and sex groups, were investigated in the primary endpoint models using likelihood-ratio tests, but did not indicate important interactions. Stata 12 (StataCorp LP, USA) was used for all calculations, and two-tailed 95% confidence intervals (CI) were considered.

# Results

Baseline characteristics of the participants are shown in *Table 1*. For the primary outcome *any arrhythmia*, the median follow-up time was 9.7 years (minimum 0.01 years; maximum 16.8 years). Mean age at inclusion was 38.5 (SD 12.2) years, and mean age of first diagnosis was 56.8 (SD 13.5) years. Tables with separate results for men and women are shown in Supplementary material online, *Table S2*.

**Table 1 Baseline characteristics and incidence of any arrhythmias**

| | *n* skiers | *n* cases | PYAR | Incidence rate of any arrhythmias (95% CI)/10 000 PYAR |
|---|---|---|---|---|
| | 52 755 | 919 | 513 496 | 17.9 (16.8–19.1) |
| Age (years) | | | | |
| 15–24 | 6258 | 30 | 64 867 | 4.6 (3.2–6.6) |
| 25–34 | 17 288 | 106 | 169 553 | 6.3 (5.2–7.6) |
| 35–44 | 12 086 | 131 | 119 665 | 10.9 (9.2–13.0) |
| 45–54 | 11 328 | 264 | 108 401 | 24.4 (21.6–27.5) |
| 55–64 | 4546 | 245 | 41 101 | 59.6 (52.6–67.6) |
| 65+ | 1249 | 143 | 10 962 | 130.4 (110.7–153.7) |
| Number of completed races | | | | |
| 1 | 27 515 | 393 | 287 873 | 13.7 (12.4–15.1) |
| 2 | 9838 | 166 | 94 457 | 17.6 (15.1–20.5) |
| 3–4 | 8390 | 172 | 75 326 | 22.8 (19.7–26.5) |
| ≥5 | 7012 | 188 | 56 930 | 33.0 (28.6–38.1) |
| Finishing time (% of winner time) | | | | |
| 100–160 | 9411 | 159 | 87 944 | 18.1 (15.5–21.1) |
| 161–200 | 17 098 | 311 | 164 364 | 19.0 (17.0–21.2) |
| 201–240 | 15 673 | 292 | 154 437 | 20.5 (16.9–21.3) |
| >240 | 10 573 | 157 | 107 804 | 14.9 (12.5–17.0) |
| Education level | | | | |
| Low | 11 215 | 250 | 108 798 | 23.0 (20.3–26.0) |
| Medium | 22 539 | 324 | 222 317 | 14.6 (13.1–16.3) |
| High | 15 929 | 299 | 155 832 | 19.2 (17.1–21.5) |
| Occupation | | | | |
| Blue-collar | 18 071 | 302 | 178 801 | 16.9 (15.1–18.9) |
| Lower-middle White-collar | 18 293 | 341 | 179 680 | 18.9 (17.0–21.1) |
| High White-collar | 7292 | 176 | 70 361 | 24.9 (21.5–28.9) |
| Entrepreneur | 2768 | 61 | 27 249 | 22.3 (17.4–28.7) |

CI, confidence interval; PYAR, person-years at risk.

## Any arrhythmias

During a total of 513 496 person-years at risk, 919 cases of arrhythmia were reported (17.9; 95% CI 16.8–19.1/10 000 person-years at risk). Cumulative incidence of arrhythmias by number of completed races and finishing time is shown in *Figure 1*. Adjusting for age, education, and occupational status, we observed higher incidence of arrhythmias with increasing number of races (HR 1.30; 95% CI 1.08–1.58; for ≥5 vs. 1 completed races) and by faster finishing time (HR 1.30; 95% CI 1.04–1.62; for 100–160% vs. >240% of winning time) (*Figure 2*). Treating exposure as a continuous variable resulted in a HR of 1.06; 95% CI 0.99–1.13 by each step of 'finishing time group' and a HR of 1.10; 95% CI 1.03–1.16 by each step of 'number of races' group. A model only adjusting for age was also tested showing similar results (data not shown). Noteworthy, because of the natural loss of performance with increasing age, the number of elderly athletes in the fastest finishing time groups was limited.

## Bradyarrhythmias

During follow-up, 119 participants were diagnosed with a bradyarrhythmia (2.3; 95% CI 1.9–2.8/10 000 person-years at risk), mainly grade II and III atrioventricular blocks and sick sinus syndromes (*Table 2*). When adjusting for age, education, and occupational status, higher risk of bradyarrhythmias was observed with increasing number of races (HR 2.10; 95% CI 1.28–3.47; for ≥5 vs. 1 completed races) and with faster finishing times (HR 1.85; 95% CI 0.97–3.54; for 100–160% vs. 240% of winning time) (*Tables 3* and *4*). Treating exposure as a continuous variable resulted in a HR of 1.29; 95% CI 1.10–1.52 by each step of 'number of races' group and a HR of 1.16; 95% CI 0.95–1.40 by each step of 'finishing time group'. As a sensitivity analysis, we excluded potentially non-pathological bradyarrhythmias (atrioventricular blocks II and bi- and tri-fascicular blocks) from the outcome, with comparable results (Supplementary material online, *Table S2*).

## Atrial fibrillation and flutter

The most frequent arrhythmia was atrial fibrillation, which occurred in 681 skiers (13.2; 95% CI 12.3–14.3/10 000 person-years at risk). In a model adjusted for age, educational, and occupational status, we observed higher incidence of atrial fibrillation with higher number of races (HR 1.29; 95% CI 1.04–1.61 for ≥5 vs. 1 completed races) and a tendency to higher incidence of atrial fibrillation with faster finishing times (HR 1.20; CI 0.93–1.55; for 100–160% vs. 240% of winning time) (*Tables 3* and *4*). Treating exposure as a continuous variable resulted in a HR of 1.09; 95% CI 1.02–1.17 by each step of 'number of races' group and a HR of 1.04; 95% CI 0.96–1.13 by each step of 'finishing time group'.

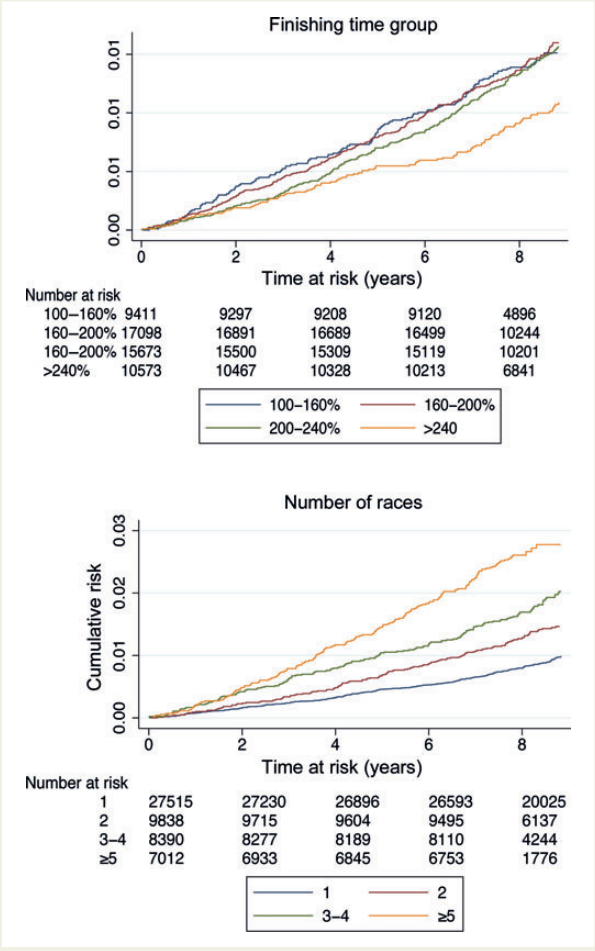


**Figure 1** Cumulative incidence of any arrhythmia by finishing time group in per cent of winning time and number of completed races during the period 1989–98.

## Other arrhythmias

The secondary endpoints of other SVT ($n = 105$) and VT/VF/CA ($n = 90$) were analysed in the same way. No associations of number of completed races or finishing time group with risk of SVT or VT/VF/CA were found (*Tables 3* and *4*).

# Discussion

This study confirms findings from earlier studies of higher incidence of arrhythmias with higher training level in athletes.[14–20] We observed a higher rate of AF and bradyarrhythmias among skiers with higher number of completed races and with faster relative finishing times, over a 10 year follow-up period. We did not observe associations between the number of completed races or finishing time group and the risk of other SVT or the more dangerous VT/VF/CA. This study extends current knowledge by providing cohort study data on persons in the higher end of the distribution of physical activity.

## Bradyarrhythmias

Abnormal ECG patterns are very common among elite athletes. Distinctly or mildly abnormal ECGs have been observed in as much as 50–60% of athletes committed to endurance sports.[11] Sinus bradycardia, grade I atrioventricular block, and grade II Mobitz type I block should be considered as normal findings[11,12,25–27] but even the incidence of AV-block grade III is reported more frequently among athletes than that in the general population.[26] Further, one earlier study reports higher rate of subclinical sinus node dysfunction among retired elite cyclists.[13] The present study observed an approximately two-fold higher risk of hospitalization for

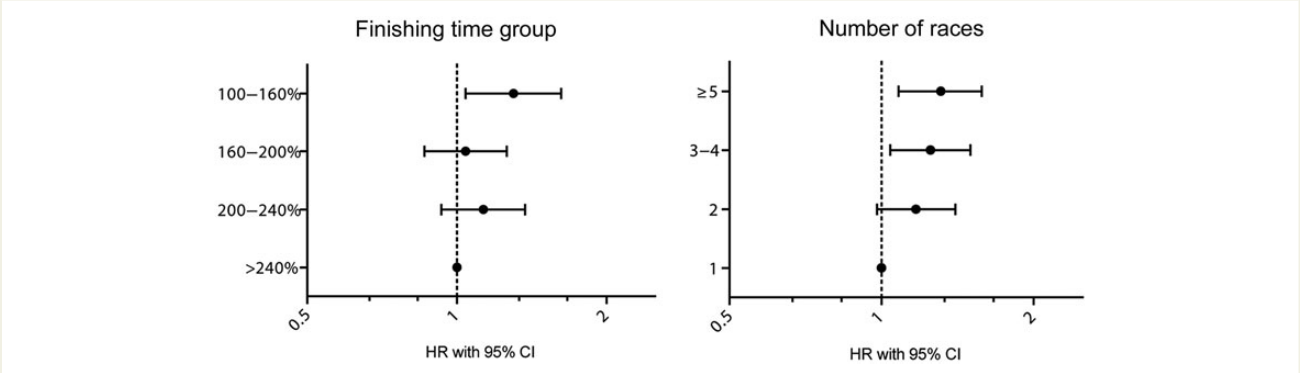


**Figure 2** Hazard ratios of any arrhythmia with 95% confidence intervals (log scale) by finishing time group in per cent of winning time and number of previous races. Model adjusted for age, occupation, and education level.

**Table 2** List of bradyarrhythmia diagnoses

| Diagnosis | Diagnosis position | | | | Total |
|---|---|---|---|---|---|
| | Primary | Secondary 1 | Secondary 2 | Secondary 3 | |
| I44.1 Atrioventricular block, second degree | 16 | 8 | 6 | 1 | 31 |
| I44.2 Atrioventricular block, complete | 23 | 7 | 2 | 2 | 34 |
| I45.2 Bifascicular block | — | — | 2 | — | 2 |
| I45.3 Tri-fascicular block | — | — | 1 | — | 1 |
| I45.9 Conduction disorder, unspecified | 3 | 2 | — | — | 5 |
| I49.5 Sick sinus syndrome | 33 | 15 | — | 1 | 49 |
| Total | 75 | 32 | 11 | 4 | 122 |

Three patients were diagnosed with both atrioventricular blocks grade II and III.

**Table 3** Risk of secondary outcomes by finishing time group

| | Atrial fibrillation ($n$ = 681, PYAR = 514 550) | Bradyarrhythmias ($n$ = 119, PYAR = 516 905) | Other SVT ($n$ = 105, PYAR 516 9908) | VT/VF/CA ($n$ = 90; PYAR = 517 057) |
|---|---|---|---|---|
| >240% | 1.00 (ref.) | 1.00 | 1.00 (ref.) | 1.00 (ref.) |
| 200–240% | 1.02 (0.82–1.28) | 1.44 (0.81–2.59) | 1.65 (0.94–2.91) | 1.46 (0.78–2.72) |
| 160–200% | 0.98 (0.79–1.22) | 1.29 (0.72–2.31) | 1.09 (0.60–1.99) | 1.03 (0.54–1.96) |
| 100–160% | 1.20 (0.93–1.55) | 1.85 (0.97–3.54) | 1.38 (0.71–2.69) | 1.19 (0.57–2.52) |
| Per category | 1.04 (0.96–1.13) | 1.16 (0.95–1.40) | 0.98 (0.81–1.19) | 0.99 (0.79–1.22) |

PYAR, person-years at risk.
Data are hazard ratios with 95% confidence intervals, by groups of finishing time in per cent of winning time. Results adjusted for age, occupation, and education level.

**Table 4** Risk of secondary outcomes by number of completed races

| | Atrial fibrillation ($n$ = 681, PYAR = 514 550) | Bradyarrhythmias ($n$ = 119, PYAR = 516 905) | Other SVT ($n$ = 105, PYAR 516 9908) | VT/VF/CA ($n$ = 90; PYAR = 517 057) |
|---|---|---|---|---|
| 1 | 1.00 (ref.) | 1.00 (ref.) | 1.00 (ref.) | 1.00 (ref.) |
| 2 | 1.22 (0.99–1.51) | 1.23 (0.70–2.16) | 0.96 (0.56–1.65) | 1.32 (0.75–2.34) |
| 3–4 | 1.27 (1.02–1.57) | 1.76 (1.05–2.94) | 1.31 (0.78–2.21) | 0.98 (0.51–1.86) |
| ≥5 | 1.29 (1.04–1.61) | 2.10 (1.28–3.47) | 0.56 (0.26–1.21) | 1.53 (0.85–2.76) |
| Per category | 1.09 (1.02–1.17) | 1.29 (1.10–1.52) | 0.94 (0.77–1.14) | 1.12 (0.92–1.35) |

PYAR, person-years at risk.
Data are hazard ratios with 95% confidence intervals, by number of completed races. Results adjusted for age, occupation, and education level.

bradyarrhythmias in athletes who completed five or more races compared with those who only completed one race. Of note, in order to capture clinically relevant bradyarrhythmias (i.e. potentially requiring a pacemaker), sinus bradycardia and grade I atrioventricular block were not included in this outcome. The use of ICD codes did not give opportunity to differ between atrioventricular blocks II Mobitz type I and II. For this reason, it is possible that some normal variants are included as pathological findings. However, grade II atrioventricular block only represents 23% of the bradyarrhythmia cases, and the results were consistent after excluding potentially non-pathological bradyarrhythmias (atrioventricular blocks II and bi- and tri-fascicular blocks) from the outcome. Interestingly, there may exist a link between bradycardia and increased risk of atrial fibrillation since atrial size, long PQ time, and bradycardia seem to be risk factors for atrial fibrillation among endurance trained athletes.[19]

## Atrial fibrillation

Earlier case–control studies report higher incidence of atrial fibrillation in endurance sports-trained athletes and present odds ratios between 1.9 and 8.8 compared with non-athletes.[15–18] The effects of physical training in the present study may seem modest compared with earlier findings, but there are several methodological differences

between the present study and the earlier studies, and the risks of bias in case–control studies are higher than in cohort studies. It is important to stress that this study only compares the risk of arrhythmias in an active population, and there may be a threshold training amount, below the level of most *Vasaloppet* participants. The Physicians Health study among 1572 healthy physicians showed increased risk of atrial fibrillation by increasing days per week of exercise vigorous enough to break a sweat.[14] Although neither that study nor the present study had direct measurements of fitness level, the present study likely investigates individuals at a higher fitness level and hence extends the dose–response curve. It is possible that associations of physical training level with atrial fibrillation would have been even greater had the cohort included also less physically active people.

Incidence rates of atrial fibrillation have been sparsely reported for young people. The Rotterdam and Framingham studies report incidence rates of atrial fibrillation among men aged 55–64 representing the general population at 22 and 31 per 10 000 person-years at risk, respectively.[28,29] In the present cohort, we find an incidence rate of atrial fibrillation and flutter of 49 (95% CI 43–51) per 10 000 person-years at risk among men aged 55–64. Although there are several methodological differences between the studies, this could indicate a higher rate in the skiers of this study than in the general population.

## Other arrhythmias and death

It is well established that young athletes with pre-existing heart disease are at higher risk of sudden cardiac death.[5] The heart disease is often unknown to the athlete, and this may also pertain to *Vasaloppet* participants. We did not observe higher incidence of sudden cardiac death with higher number of completed races or finishing time, but again it must be stressed that this study does not compare with the normal population. We have previously shown that participants in *Vasaloppet* have lower mortality than the general population and that mortality decreases with increasing number of races.[21] Similar associations were observed in a Dutch long-distance skating event.[30] We hence believe that it is generally safe to prepare for and participate in the race.

The Swedish National Board of Health and Welfare recommends, in accordance with the recommendations of the European Society of Cardiology,[31] that all athletes competing at elite level have a physical evaluation including personal and family medical history, physical examination, and resting ECG. Only if these investigations reveal abnormal findings, further examinations (like echocardiography or stress testing) are performed. Which athletes are regarded as elite is defined by the specific sports associations (for skiers, the Swedish Ski Association). The elite group in *Vasaloppet* consists of a few hundred skiers of different nationality (this study only includes Swedish participants). We hence believe that the potential bias of screening is low, and for all practical purposes, this cohort should be regarded as non-screened.

Earlier cross-sectional studies report similar prevalence of SVT among athletes and the normal population, and this study supports independence of training level and SVT, at least in the setting of recreational skiers to elite athletes.[26] This is not surprising since these arrhythmias (e.g. AV nodal reentrant tachycardia and Wolff-Parkinson-White) often rely on congenital or developmental changes in the heart's conduction system.

## Strength and limitations

Strengths of the present study include the very large sample size of more than 52 000 athletes without known pre-existing heart disease, the cohort design, and the use of official registries for determination of socioeconomic measures and identification of the outcomes, which also minimizes loss-to-follow-up.

Some limitations of the study are worth noting. The incidence of atrial fibrillation increases dramatically with age, and because this cohort is quite young, possibly important associations at older age remain unknown. The exposure may be imprecisely measured, as the exposure is not limited to the participation in the race but may also include training before the race. Furthermore, many participants are likely committed to other sports activities during the summer. Indeed, in an earlier study of this population, 79.1% participants, compared with 29.5% in the normal population, reported strenuous exercise over the last year.[21] Hence, our exposure measure may reflect all-year activity, which on the other hand may be viewed as a strength. Since we do not have any information on participation in races before the index date, it is possible that some of the participants have completed other races before the index date and only one afterwards. Likewise, follow-up was longer than the inclusion time, and participants could continue to race. Thus, it is likely that we may underestimate this exposure. This misclassification is not suspected to affect exposure groups differentially and should hence not bias the associations, but may affect the interpretation of the absolute numbers of races. It is possible that some participants did not complete the race because they developed arrhythmia during the race, and such participants are not included in the cohort. We do not have any information on non-fatal arrhythmias during the race, but we know that only one participant died in the track during the inclusion period.[8]

It is possible that some of the athletes have suffered from ischaemia-induced arrhythmias or arrhythmias of other specific aetiology, but we excluded persons with previous cardiovascular disease, and the incidence of subsequent cardiovascular disease is low in this population of physically active persons.[21] Residual protopathic bias by pre-existing cardiovascular disease is possible (which would tend to bias results towards the null) but is unlikely a major explanation, as *Vasaloppet* is a strenuous race.

The study design limits the possibility of adjusting for several potentially important confounders, including smoking, alcohol use, blood pressures, and diabetes, but these were not identified as crucial covariates in order to minimize bias using the directed acyclic graphs approach, although residual confounding by these and other unmeasured factors is possible. This study is also limited by the lack of comparison of the sport active persons with inactive persons. The use of data from the Swedish National In-patient Register likely identifies outcomes with some random misclassification, which would tend to bias us towards the null and also precludes separation of atrial flutter and fibrillation or grade II atrioventricular blocks type I or II. On the other hand, this study uses diagnoses that can be read from standard ECG also by non-experienced doctors. Furthermore, it is possible that physically active persons have a lower threshold for seeking hospital service for arrhythmia symptoms than less physically active persons. We believe this potential confounding to be limited because the present cohort consists of persons with a training level needed for 90 km strenuous cross-

country skiing; hence, most of the participants will likely experience symptoms and seek hospital services for arrhythmias regardless of race result or number of completed races. The generalizability to other ethnic groups is unknown. We did not find any interactions between sexes, but the limited number of women did not allow us to draw any firm conclusions regarding any sex-specific effect of exercise and risk of arrhythmias in women. This study cannot assess causality, but other studies suggest that longstanding endurance training could lead to vagal predominance[32] and increased risk of extrasystoles and increases left atrial size[33] and the amount of myocardial fibrosis,[34,35] which may act as arrhythmia triggers and substrates.

# Conclusions

In this study of 52 755 participants of a 90 km cross-country skiing event, a fast finishing time and a high number of completed races were associated with higher risk of arrhythmias. This was mainly driven by associations with risk of atrial fibrillation and bradyarrhythmias. No associations of number of completed races or finishing time with other SVT or dangerous arrhythmias such as VT/VF/CA were observed, which parallels previous observations in this cohort of lower standardized mortality with higher number of completed races.[21]

# Supplementary material

Supplementary material is available at *European Heart Journal* online.

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**Conflict of interest:** J.S. is on the scientific advisory board for Itrim, a weight-loss company. The other authors did not report any conflicts of interest.

## References

1. World Health O. Global health risks: mortality and burden of disease attributable to selected major risks: , 2009.
2. Held C, Iqbal R, Lear SA, Rosengren A, Islam S, Mathew J, Yusuf S. Physical activity levels, ownership of goods promoting sedentary behaviour and risk of myocardial infarction: results of the INTERHEART study. *Eur Heart J* 2012;**33**:452–466.
3. Kokkinos P, Myers J. Exercise and physical activity: clinical outcomes and applications. *Circulation* 2010;**122**:1637–1648.
4. Nocon M, Hiemann T, Muller-Riemenschneider F, Thalau F, Roll S, Willich SN. Association of physical activity with all-cause and cardiovascular mortality: a systematic review and meta-analysis. *Eur J Cardiovasc Prev Rehabil* 2008;**15**:239–246.
5. Corrado D, Basso C, Rizzoli G, Schiavon M, Thiene G. Does sports activity enhance the risk of sudden death in adolescents and young adults? *J Am Coll Cardiol* 2003;**42**:1959–1963.
6. Link MS, Mark Estes NA 3rd. Sudden cardiac death in athletes. *Prog Cardiovasc Dis* 2008;**51**:44–57.
7. Maron BJ, Thompson PD, Ackerman MJ, Balady G, Berger S, Cohen D, Dimeff R, Douglas PS, Glover DW, Hutter AM Jr, Krauss MD, Maron MS, Mitten MJ, Roberts WO, Puffer JC. Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation. *Circulation* 2007;**115**:1643–1655.
8. Farahmand B, Hallmarker U, Brobert GP, Ahlbom A. Acute mortality during long-distance ski races (Vasaloppet). *Scand J Med Sci Sports* 2007;**17**:356–361.
9. Pelliccia A, Maron BJ, Di Paolo FM, Biffi A, Quattrini FM, Pisicchio C, Roselli A, Caselli S, Culasso F. Prevalence and clinical significance of left atrial remodeling in competitive athletes. *J Am Coll Cardiol* 2005;**46**:690–696.
10. Pelliccia A, Culasso F, Di Paolo FM, Maron BJ. Physiologic left ventricular cavity dilatation in elite athletes. *Ann Intern Med* 1999;**130**:23–31.
11. Pelliccia A, Maron BJ, Culasso F, Di Paolo FM, Spataro A, Biffi A, Caselli G, Piovano P. Clinical significance of abnormal electrocardiographic patterns in trained athletes. *Circulation* 2000;**102**:278–284.
12. Bjornstad HH, Bjornstad TH, Urheim S, Hoff PI, Smith G, Maron BJ. Long-term assessment of electrocardiographic and echocardiographic findings in Norwegian elite endurance athletes. *Cardiology* 2009;**112**:234–241.
13. Baldesberger S, Bauersfeld U, Candinas R, Seifert B, Zuber M, Ritter M, Jenni R, Oechslin E, Luthi P, Scharf C, Marti B, Attenhofer Jost CH. Sinus node disease and arrhythmias in the long-term follow-up of former professional cyclists. *Eur Heart J* 2008;**29**:71–78.
14. Aizer A, Gaziano JM, Cook NR, Manson JE, Buring JE, Albert CM. Relation of vigorous exercise to risk of atrial fibrillation. *Am J Cardiol* 2009;**103**:1572–1577.
15. Karjalainen J, Kujala UM, Kaprio J, Sarna S, Viitasalo M. Lone atrial fibrillation in vigorously exercising middle aged men: case-control study. *BMJ* 1998;**316**:1784–1785.
16. Molina L, Mont L, Marrugat J, Berruezo A, Brugada J, Bruguera J, Rebato C, Elosua R. Long-term endurance sport practice increases the incidence of lone atrial fibrillation in men: a follow-up study. *Europace* 2008;**10**:618–623.
17. Elosua R, Arquer A, Mont L, Sambola A, Molina L, Garcia-Moran E, Brugada J, Marrugat J. Sport practice and the risk of lone atrial fibrillation: a case-control study. *Int J Cardiol* 2006;**108**:332–337.
18. Heidbuchel H, Anne W, Willems R, Adriaenssens B, Van de Werf F, Ector H. Endurance sports is a risk factor for atrial fibrillation after ablation for atrial flutter. *Int J Cardiol* 2006;**107**:67–72.
19. Grimsmo J, Grundvold I, Maehlum S, Arnesen H. High prevalence of atrial fibrillation in long-term endurance cross-country skiers: echocardiographic findings and possible predictors—a 28-30 years follow-up study. *Eur J Cardiovasc Prev Rehabil* 2010;**17**:100–105.
20. Claessen G, Colyn E, La Gerche A, Koopman P, Alzand B, Garweg C, Willems R, Nuyens D, Heidbuchel H. Long-term endurance sport is a risk factor for development of lone atrial flutter. *Heart* 2011;**97**:918–922.
21. Farahmand BY, Ahlbom A, Ekblom O, Ekblom B, Hallmarker U, Aronson D, Brobert GP. Mortality amongst participants in Vasaloppet: a classical long-distance ski race in Sweden. *J Intern Med* 2003;**253**:276–283.
22. Pollock ML, Ward A, Ayres JJ. Cardiorespiratory fitness: response to differing intensities and durations of training. *Arch Phys Med Rehabil* 1977;**58**:467–473.
23. White IR, Royston P, Wood AM. Multiple imputation using chained equations: issues and guidance for practice. *Stat Med* 2011;**30**:377–399.
24. Shrier I, Platt RW. Reducing bias through directed acyclic graphs. *BMC Med Res Methodol* 2008;**8**:70.
25. Jensen-Urstad K, Bouvier F, Saltin B, Jensen-Urstad M. High prevalence of arrhythmias in elderly male athletes with a lifelong history of regular strenuous exercise. *Heart* 1998;**79**:161–164.
26. Zehender M, Meinertz T, Keul J, Just H. ECG variants and cardiac arrhythmias in athletes: clinical relevance and prognostic importance. *Am Heart J* 1990;**119**:1378–1391.
27. Kobza R, Cuculi F, Abacherli R, Toggweiler S, Suter Y, Frey F, Schmid JJ, Erne P. Twelve-lead electrocardiography in the young: physiologic and pathologic abnormalities. *Heart Rhythm* 2012;**9**:2018–2022.
28. Heeringa J, van der Kuip DA, Hofman A, Kors JA, van Herpen G, Stricker BH, Stijnen T, Lip GY, Witteman JC. Prevalence, incidence and lifetime risk of atrial fibrillation: the Rotterdam study. *Eur Heart J* 2006;**27**:949–953.
29. Benjamin EJ, Wolf PA, D'Agostino RB, Silbershatz H, Kannel WB, Levy D. Impact of atrial fibrillation on the risk of death: the Framingham Heart Study. *Circulation* 1998;**98**:946–952.
30. van Saase JL, Noteboom WM, Vandenbroucke JP. Longevity of men capable of prolonged vigorous physical exercise: a 32 year follow up of 2259 participants in the Dutch eleven cities ice skating tour. *BMJ* 1990;**301**:1409–1411.
31. Corrado D, Pelliccia A, Bjornstad HH, Vanhees L, Biffi A, Borjesson M, Panhuyzen-Goedkoop N, Deligiannis A, Solberg E, Dugmore D, Mellwig KP, Assanelli D, Delise P, van-Buuren F, Anastasakis A, Heidbuchel H, Hoffmann E, Fagard R, Priori SG, Basso C, Arbustini E, Blomstrom-Lundqvist C, McKenna WJ, Thiene G, . Cardiovascular pre-participation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol. Consensus statement of the study group of sport cardiology of the working group of cardiac rehabilitation and exercise physiology and the working group of myocardial and pericardial diseases of the European society of cardiology. *Eur Heart J* 2005;**26**:516–524.
32. Wilhelm M, Roten L, Tanner H, Wilhelm I, Schmid JP, Saner H. Atrial remodeling, autonomic tone, and lifetime training hours in nonelite athletes. *Am J Cardiol* 2011;**108**:580–585.

33. Mont Ls, Tamborero D, Elosua R, Molina I, Coll-Vinent B, Sitges M, Vidal B, Scalise A, Tejeira A, Berruezo A, Brugada J. Physical activity, height, and left atrial size are independent risk factors for lone atrial fibrillation in middle-aged healthy individuals. *Europace* 2008;**10**:15–20.
34. Benito B, Gay-Jordi G, Serrano-Mollar A, Guasch E, Shi Y, Tardif JC, Brugada J, Nattel S, Mont L. Cardiac arrhythmogenic remodeling in a rat model of long-term intensive exercise training. *Circulation* 2011;**123**:13–22.
35. Lindsay MM, Dunn FG. Biochemical evidence of myocardial fibrosis in veteran endurance athletes. *Br J Sports Med* 2007;**41**:447–452.

## CARDIOVASCULAR FLASHLIGHT

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# Ventricular tachycardia in hypertrophic cardiomyopathy with apical aneurysm successfully treated with left ventricular aneurysmectomy and cryoablation

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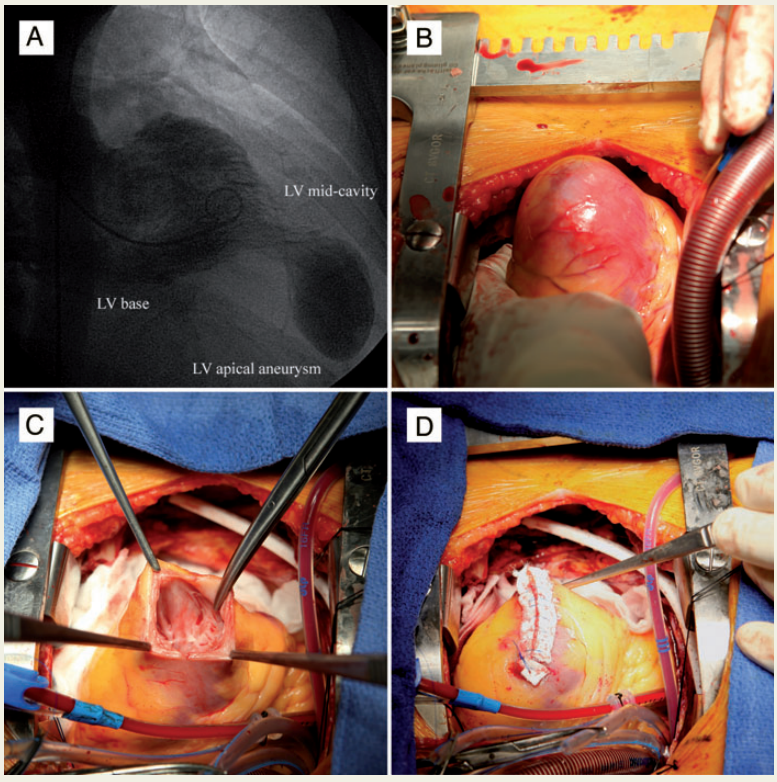
A 64-year-old woman with type II diabetes mellitus was admitted to our institution with incessant ventricular tachycardia. She reverted to sinus rhythm after treatment with intravenous amiodarone, but the tachyarrhythmia recurred days later. Coronary angiography showed unobstructed coronary arteries. Left ventriculography (*Panel A*, Supplementary material online, *Video S1*) revealed apical ballooning with mid-ventricular obstruction, suggestive of either large left ventricular (LV) apical aneurysm or stress (Takotsubo) cardiomyopathy. Transthoracic echocardiography and cardiac magnetic resonance imaging (Supplementary material online, *Video S2*) subsequently demonstrated mid-ventricular hypertrophic cardiomyopathy (HCM) with apical wall thinning, confirming LV apical aneurysm. She underwent LV aneurysmectomy together with patch LV reconstruction and ventricular cryoablation (*Panels B–D*). A cardioverter-defibrillator was implanted 3 weeks post presentation. At follow-up 12 months later, she is well without evidence of arrhythmia recurrence and is not taking antiarrhythmic medication.




HCM is complicated by apical aneurysm in 2% of cases. Apical aneurysm is thought to develop due to apical wall stress caused by dynamic mid-ventricular obstruction. Pathologically, the aneurysm consists of fibrous tissue, an arrhythmogenic substrate for the generation of ventricular tachyarrhythmias. Genetic predisposition and familial transmission of the LV apical aneurysm phenotype have been documented. The presence of apical aneurysm in HCM portends a poor prognosis. Clinical manifestations include tachyarrhythmias, heart failure, myocardial infarction, LV thrombus formation, embolic stroke, and sudden death. Management options in addition to standard cardiac failure therapy may include antiarrhythmic agents, systemic anticoagulation, cardioverter-defibrillator implantation, radiofrequency ablation of malignant ventricular dysrhythmias, and surgical resection of the aneurysm. Surgery with complete excision of the scar tissue and obliteration of the aneurysmal pouch has been reported to decrease the burden of ventricular tachyarrhythmias.

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*Panel A*. Left ventriculogram image in the right anterior oblique view demonstrating a large apical aneurysm.

*Panels B–D*. At surgery, the apical aneurysm is exposed via median sternotomy (*Panel B*), and resected (*Panel C*). Following ventricular cryoablation, a patch reconstruction is performed (*Panel D*).

Supplementary material is available at *European Heart Journal* online.