Ultra Endurance Athletes – Can It Ever Be Too Much Of A Good Thing?

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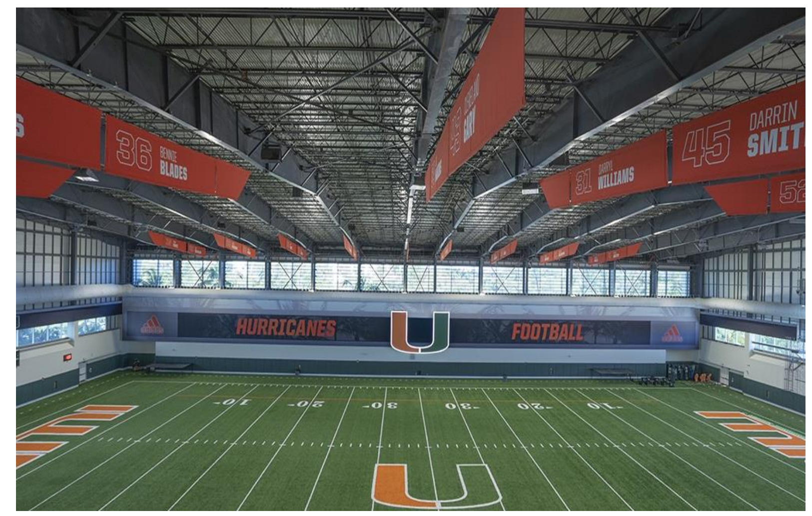
Outline

- **Exercise is good medicine!**
- **Dose-response of exercise and overall health**
- **Acute effects of exercise on the cardiovascular system**
- **Cardiovascular (mal)adaptation to chronic exercise**



Running – When Can It Be Too Much Of A Good Thing?

- Concern regarding effects of repetitive joint loading on development and progression of OA remain in question
- History of recreational running **does not appear** to increase risk of incident knee or hip OA (Timmins KA, Batt MA, et al. *Am J Sports Med* 2017, Miglorini F et al. *Sports Med Arthrosc Rev* 2022) or accelerate OA progression (Lo GH et al. *Arthritis Care & Res* 2017)
- A dose-response with sedentary individuals and competitive runners potentially having an increased risk of knee OA (Driban JF, Hootman JM et al. *J Ath Training* 2017)
- 24 studies using MRI measured change in hip or knee articular cartilage within 48 hours pre- and post-running
- 446 knees evaluated (all subjects less than 40 years of age)
- Risk of bias judged to be low
- Knee cartilage thickness and volume decreased immediately after running (3.3 to 4.9%), with recovery by 90 mins post-run
- Changes in patellofemoral cartilage generally larger than changes in tibiofemoral cartilage
- Current thinking – there is an optimal loading pattern (exercise dose), too little is harmful, too much may be problematic (U shaped curve)

Is running good or bad for your knees? A systematic review and meta-analysis of cartilage morphology .. And patellofemoral joints. Coburn et al *O&C* 2022.

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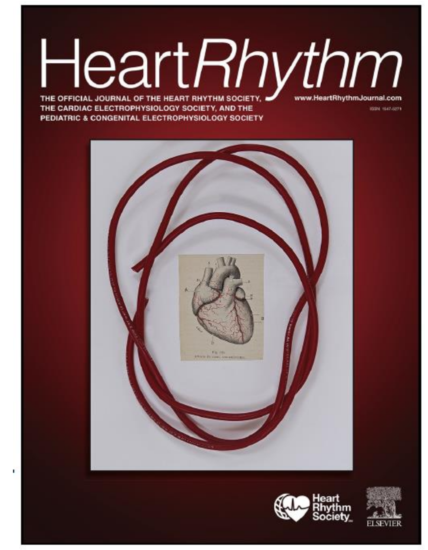
2024 HRS expert consensus statement on arrhythmias in the athlete: Evaluation, treatment, and return to play

Rachel Lampert, MD, FHRS (Chair),[1,*] Eugene H. Chung, MD, MPH, MSc, FHRS (Vice-Chair),[2,*] Michael J. Ackerman, MD, PhD,[3,*] Alonso Rafael Arroyo, MD,[15,†] Douglas Darden, MD,[4,*] Rajat Deo, MD,[5,*] Joe Dolan,[‡] Susan P. Etheridge, MD, FAHA, FHRS, FACC, CEP-S,[6,§] Belinda R. Gray, MBBS, PhD, FHRS, CCDS,[7,*] Kimberly G. Harmon, MD,[8,¶] Cynthia A. James, PhD, CGC,[9,*] Jonathan H. Kim, MD, MSc, FACC,[10,#] Andrew D. Krahn, MD, FHRS,[11,*] Andre La Gerche, MBBS, PhD,[12,**] Mark S. Link, MD, FHRS,[13,*] Ciorsti MacIntyre, MD,[3,*] Lluis Mont, MD, PhD, FEHRA,[14,††] Jack C. Salerno, MD, FHRS,[16,‡‡] Maully J. Shah, MBBS, FHRS, CCDS, CEPS-P[17,‡‡]



Top 10 Take-Home Messages

1. For many arrhythmogenic disease entities, current data in athletes, while often not large enough to be definitive, have not confirmed increased arrhythmic risk of continuing sports participation for athletes who are appropriately risk-assessed and treated, and thus the approach to return to play is one of individualized shared decision-making.
2. The overarching goal in caring for athletes should be facilitating the athlete's return to sport if this is the desired outcome, through appropriate risk assessment and athlete-focused management of their arrhythmic condition. Restriction from sport is not benign.
3. Both venue-based and individualized emergency action plans including plans for early defibrillation are critical to survival of athletes with sudden cardiac arrest.
4. Disease-specific and guideline-based risk assessment and treatment of arrhythmogenic conditions prior to return to play is critical.
5. For patients with underlying complex arrhythmias, appropriate strategies for sudden death prevention and arrhythmia suppression are needed prior to return to play, including confirmation of suppression of arrhythmia during exercise.

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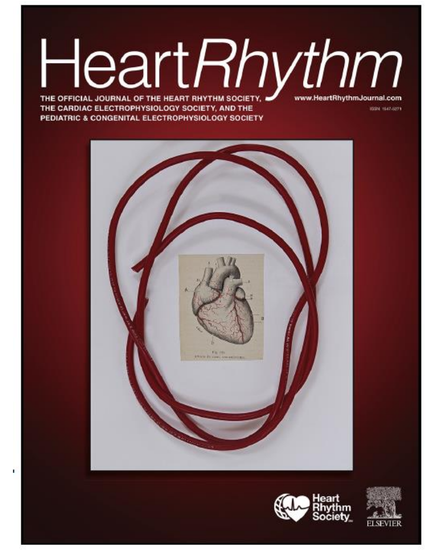

6. Treatment decisions—including those regarding antiarrhythmic medications, ablation, and devices—should take athletic performance and training into consideration.

7. Exercise stress testing in athletes for diagnostic purposes or defining therapeutic efficacy should mimic the athlete's sport where possible and be terminated based on maximal effort, symptoms, and/or documentation of arrhythmia.

8. Endurance exercise in particular may contribute to arrhythmogenic conditions such as atrial fibrillation and genotype-negative arrhythmogenic right ventricular cardiomyopathy; risks and benefits of continued participation in endurance sports should be carefully weighed in athletes with these conditions.

9. The choice of pacemaker or defibrillator form factor and programming parameters should take into consideration the type of sport and training required so as to minimize risk of damage to the system.

10. Athletes with a diagnosis of Wolff-Parkinson-White pattern or syndrome should be allowed to return to play pending timely expert evaluation and treatment, as there is lack of conclusive evidence of increased risk of life-threatening arrhythmias with athletic participation.

Evidence for exercise-based interventions across 45 different long-term conditions: an overview of systematic reviews

Grace O. Dibben,[a,n,*] Lucy Gardiner,[b] Hannah M. L. Young,[c,d] Valerie Wells,[a] Rachael A. Evans,[b] Zahira Ahmed,[b] Shaun Barber,[e] Sarah Dean,[f] Patrick Doherty,[g] Nikki Gardiner,[c] Colin Greaves,[h] Tracy Ibbotson,[i] Bhautesh D. Jani,[i] Kate Jolly,[j] Frances S. Mair,[i] Emma McIntosh,[k] Paula Ormandy,[l] Sharon A. Simpson,[a] Sayem Ahmed,[k] Stefanie J. Krauth,[i] Lewis Steell,[i] Sally J. Singh,[b,n] and Rod S. Taylor,[a,m,n] on behalf of the PERFORM research team

eClinicalMedicine
2024;72: 102599
Published Online 30 April 2024
https://doi.org/10.1016/j.eclinm.2024.102599

Summary

Background Almost half of the global population face significant challenges from long-term conditions (LTCs) resulting in substantive health and socioeconomic burden. Exercise is a potentially key intervention in effective LTC management.

Methods In this overview of systematic reviews (SRs), we searched six electronic databases from January 2000 to October 2023 for SRs assessing health outcomes (mortality, hospitalisation, exercise capacity, disability, frailty, health-related quality of life (HRQoL), and physical activity) related to exercise-based interventions in adults (aged >18 years) diagnosed with one of 45 LTCs. Methodological quality was assessed using AMSTAR-2. International Prospective Resister of Systematic Reviews (PROSPERO) ID: CRD42022319214.

Findings Forty-two SRs plus three supplementary RCTs were included, providing 990 RCTs in 936,825 people across 39 LTCs. No evidence was identified for six LTCs. Predominant outcome domains were HRQoL (82% of SRs/RCTs) and exercise capacity (66%); whereas disability, mortality, physical activity, and hospitalisation were less frequently reported (≤25%). Evidence supporting exercise-based interventions was identified in 25 LTCs, was unclear for 13 LTCs, and for one LTC suggested no effect. No SRs considered multimorbidity in the delivery of exercise. Methodological quality varied: critically-low (33%), low (26%), moderate (26%), and high (12%).

Interpretation Exercise-based interventions improve HRQoL and exercise capacity across numerous LTCs. Key evidence gaps included limited mortality and hospitalisation data and consideration of multimorbidity impact on exercise-based interventions.

Evidence for exercise-based interventions across 45 different long-term conditions: an overview of systematic reviews

Grace O. Dibben,[a,n,*] Lucy Gardiner,[b] Hannah M. L. Young,[c,d] Valerie Wells,[a] Rachael A. Evans,[b] Zahira Ahmed,[b] Shaun Barber,[e] Sarah Dean,[f] Patrick Doherty,[g] Nikki Gardiner,[c] Colin Greaves,[h] Tracy Ibbotson,[i] Bhautesh D. Jani,[i] Kate Jolly,[j] Frances S. Mair,[i] Emma McIntosh,[k] Paula Ormandy,[l] Sharon A. Simpson,[a] Sayem Ahmed,[k] Stefanie J. Krauth,[i] Lewis Steell,[i] Sally J. Singh,[b,n] and Rod S. Taylor,[a,m,n] on behalf of the PERFORM research team

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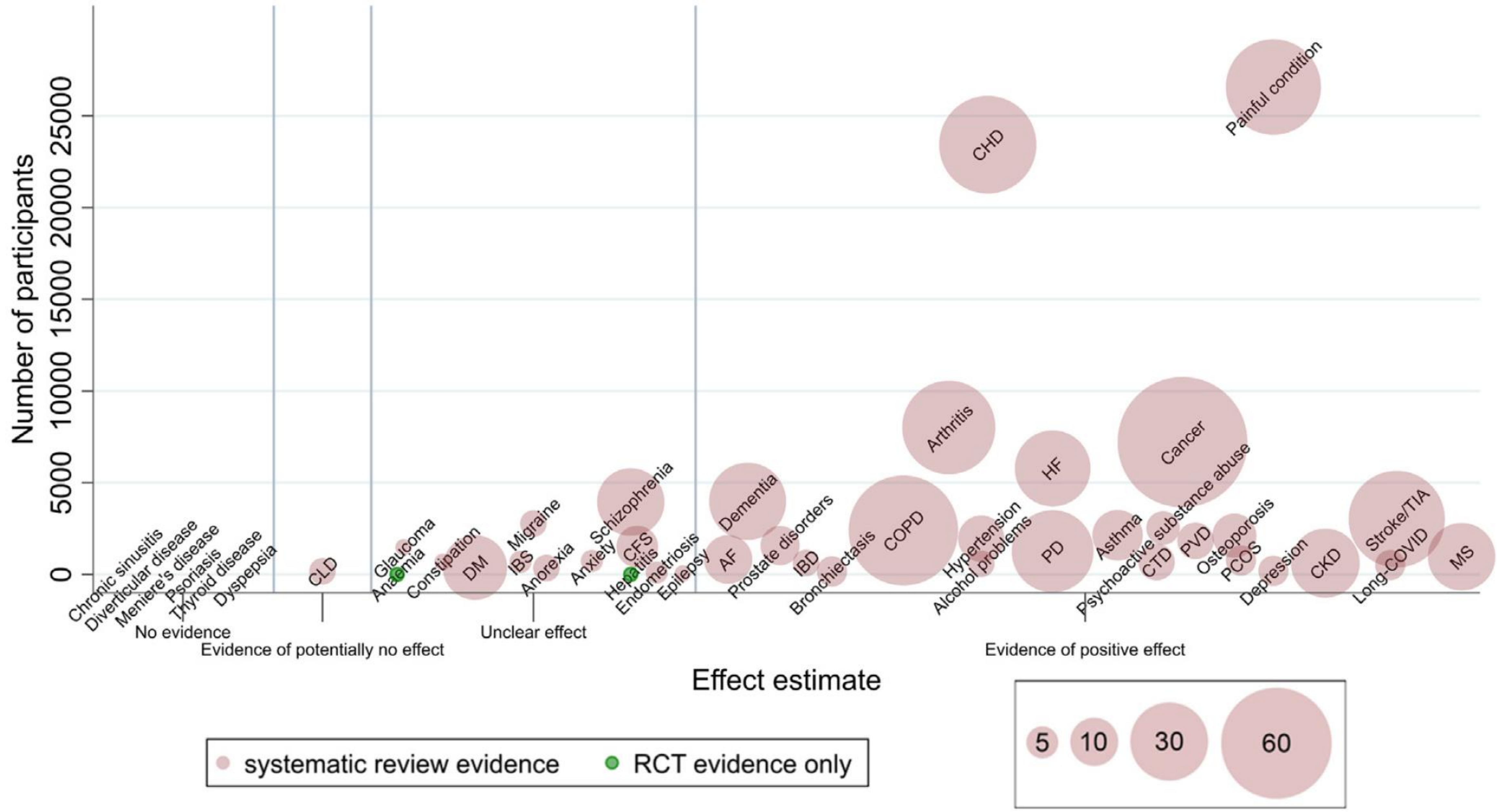
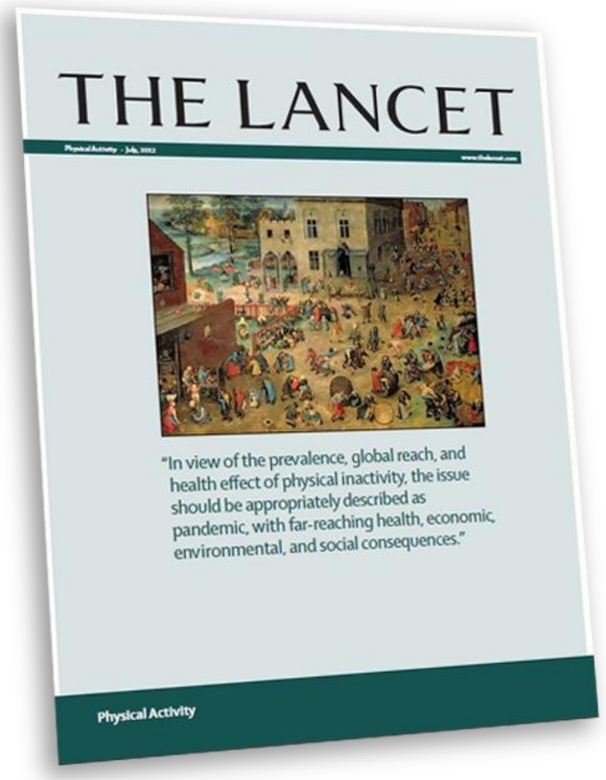
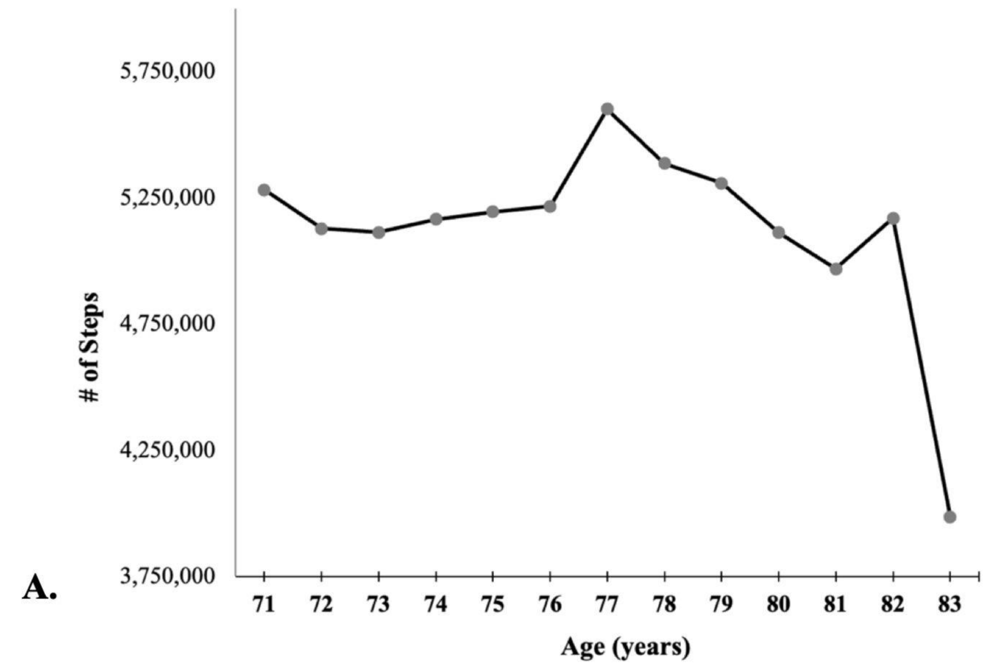
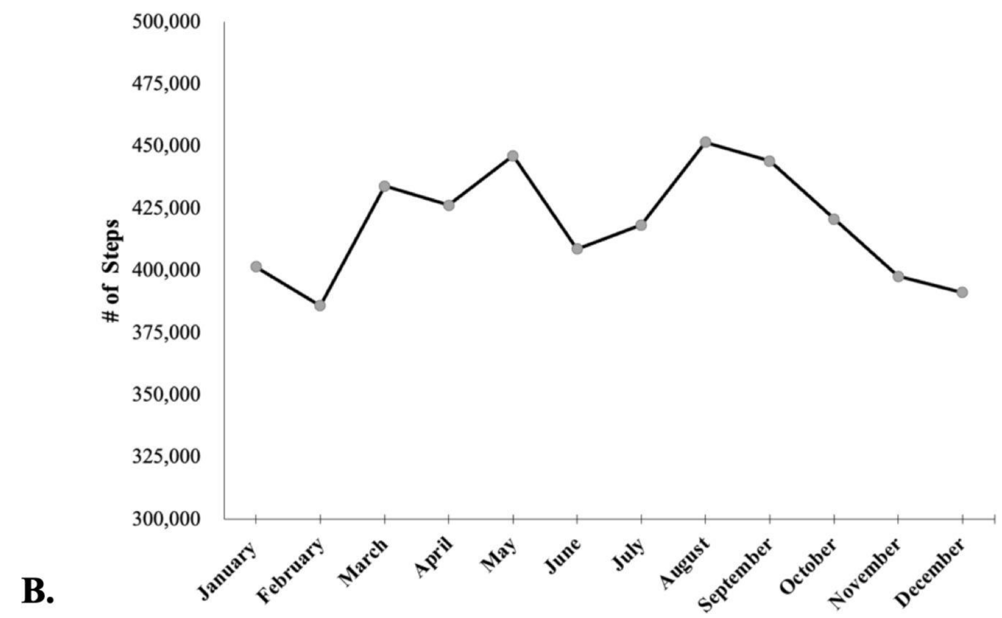


An Enduring Legacy – Stephen Blair, PhD



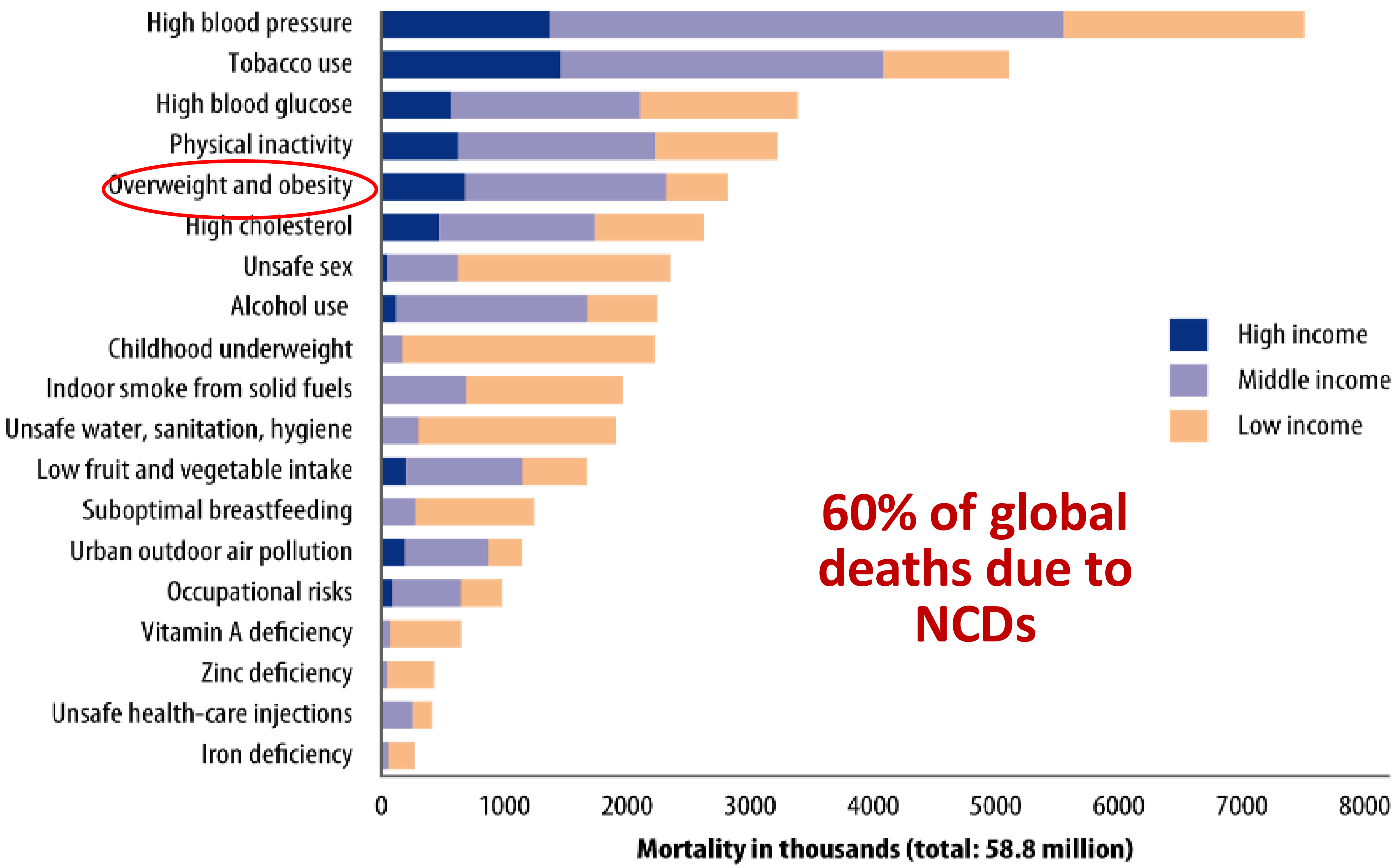
"In view of the prevalence, global reach and health effect of physical inactivity, the issue should be appropriately described as pandemic, with far-reaching health, economic, environmental and social consequences."





Steve Blair pedometer step data by age (A) and months of the year (B).

Physical Inactivity: 4th Leading Risk Factor for Global Mortality



https://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf

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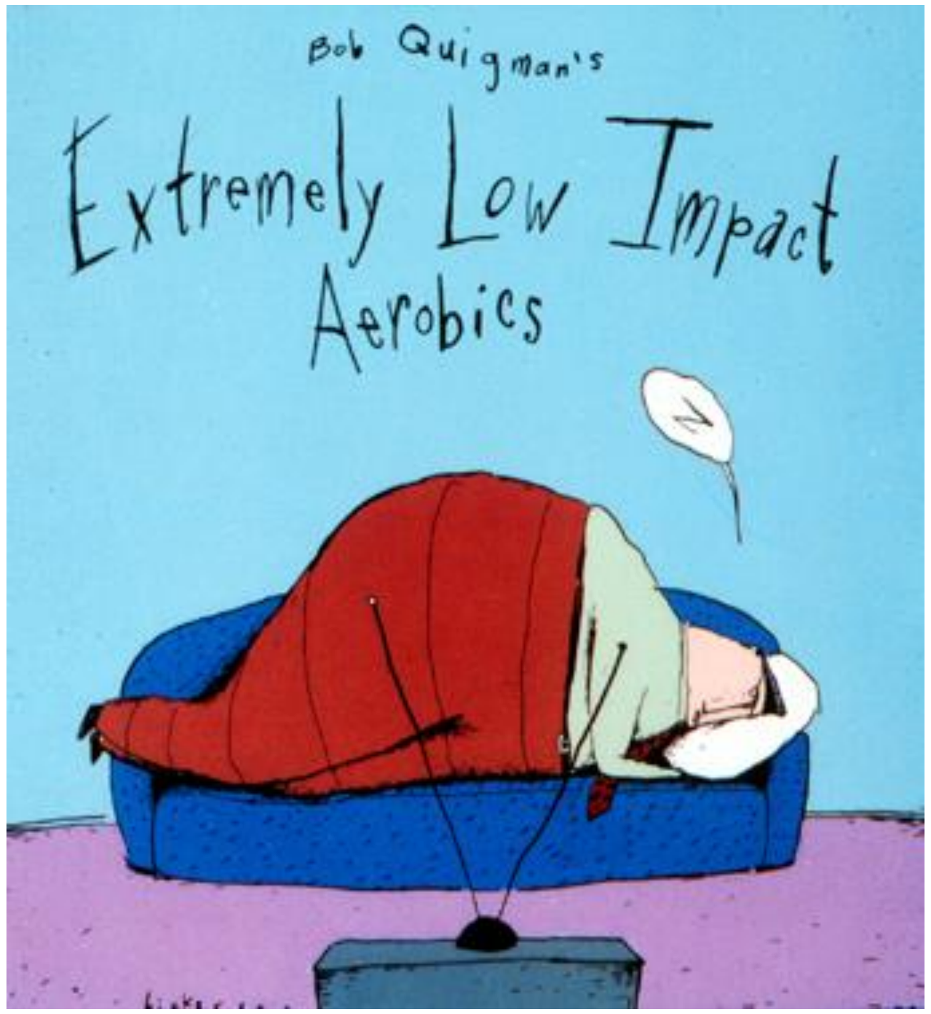
US 2021: Leading Causes of Death



1. Heart Disease
2. Cancer (Malignant neoplasms)
3. COVID-19
4. Accidents (unintentional injuries)
5. Stroke (Cerebrovascular diseases)
6. Chronic lower respiratory diseases
7. Alzheimer's disease
8. Diabetes
9. Chronic liver disease and cirrhosis
10. Nephritis, nephrotic syndrome and nephrosis (kidney disease)

Physical INACTIVITY-related diseases !!!

https://www.cdc.gov/nchs/products/databriefs/db395.htm

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Topic 2 – Dose-Response Of Exercise And Overall Health

Optimal Dose of Running for Longevity – Is More Better?

- The Copenhagen City Heart Study Schnohr et al 2015
  - 1,098 health joggers and 3,950 healthy nonjoggers followed since 2001
  - Compared with sedentary nonjoggers, 1 to 2.4h of jogging per week associated with lowest mortality
  - Optimal frequency of jogging was 2 to 3 times/week
  - Joggers – divided into light, moderate, and strenuous (self-reported pace, quantity, frequency)
  - Lowest hazard ratio was found in the light joggers…

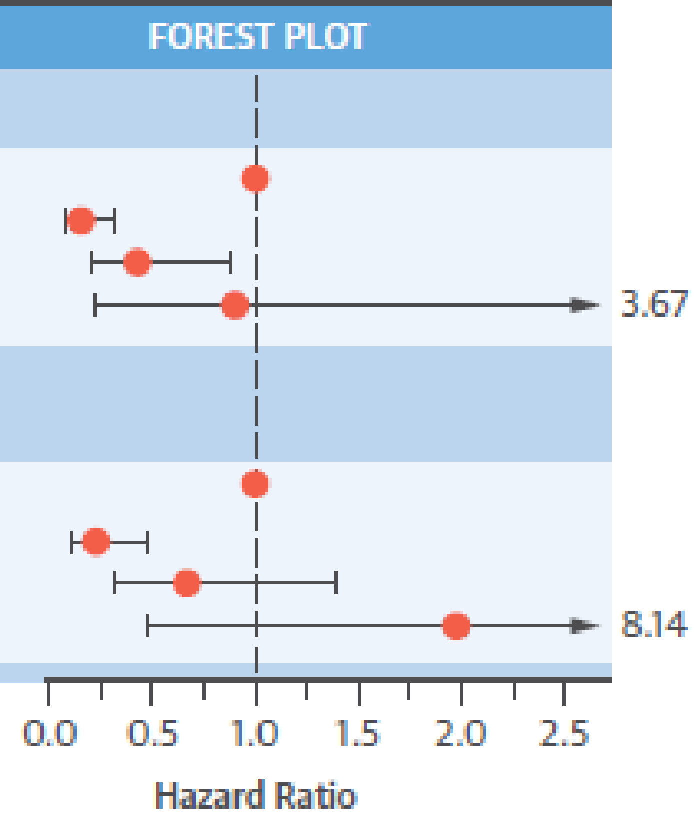
An athlete cannot run with money in his pockets. He must run with hope in his heart and dreams in his head.

Emil Zatopek

Optimal Dose of Running for Longevity – Is More Better?

CENTRAL ILLUSTRATION Dose of Jogging and Long-Term Mortality

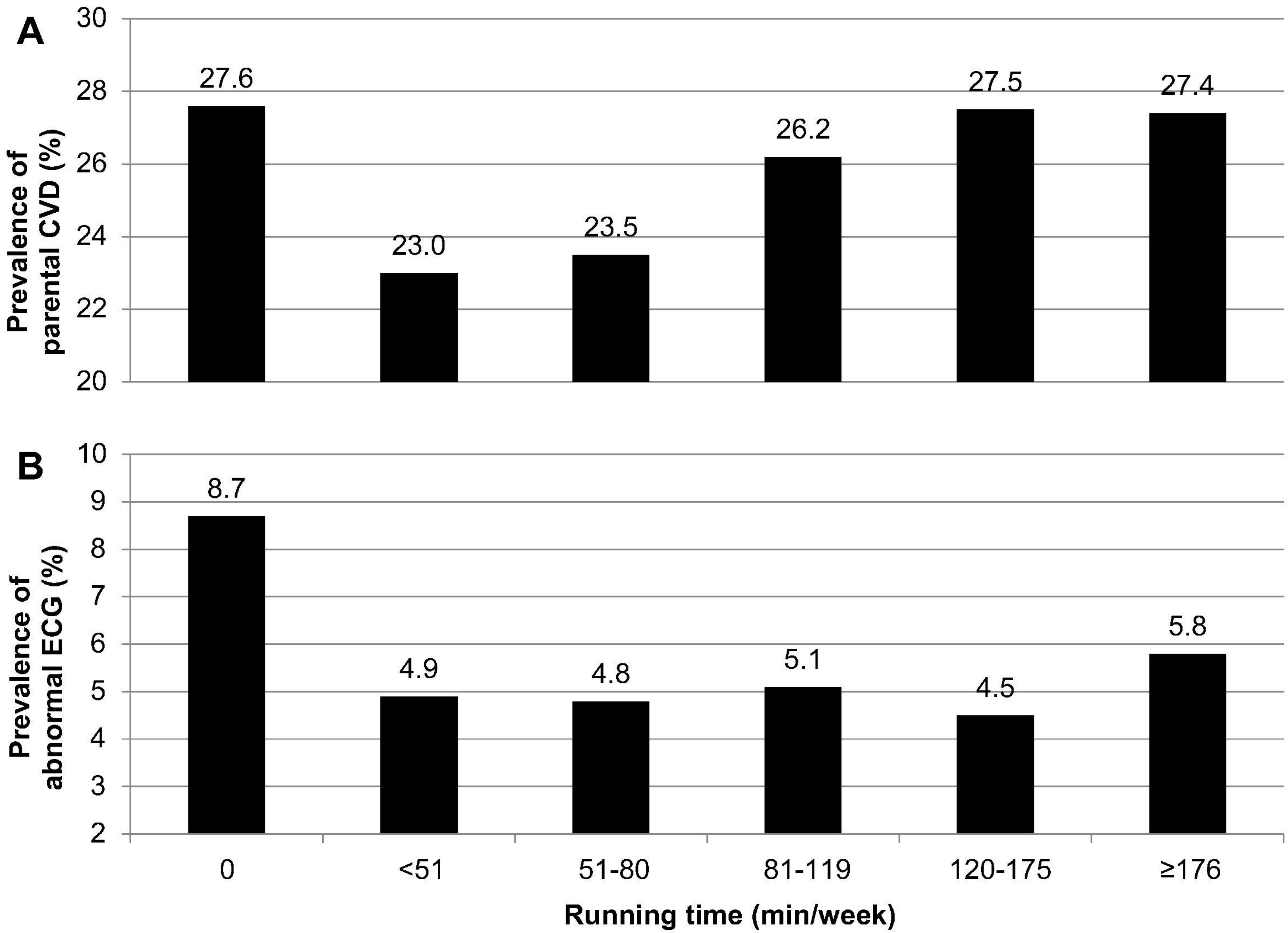
DOSE OF JOGGING	NO. OF PARTICIPANTS	ALL-CAUSE MORTALITY DEATHS
Adjusted for age and sex		
Sedentary nonjogger (reference)	413	128
Light jogger	576	7
Moderate jogger	262	8
Strenuous jogger	40	2
Adjusted for age, sex, smoking, alcohol intake, education, and diabetes		
Sedentary nonjogger (reference)	394	120
Light jogger	570	7
Moderate jogger	252	8
Strenuous jogger	36	2



Schnohr, P. et al. J Am Coll Cardiol. 2015; 65(5):411-9.

Forest plot indicating all-cause mortality in light, moderate, and strenuous joggers compared with sedentary nonjoggers.

Optimal Dose of Running for Longevity – Is More Better or Worse?

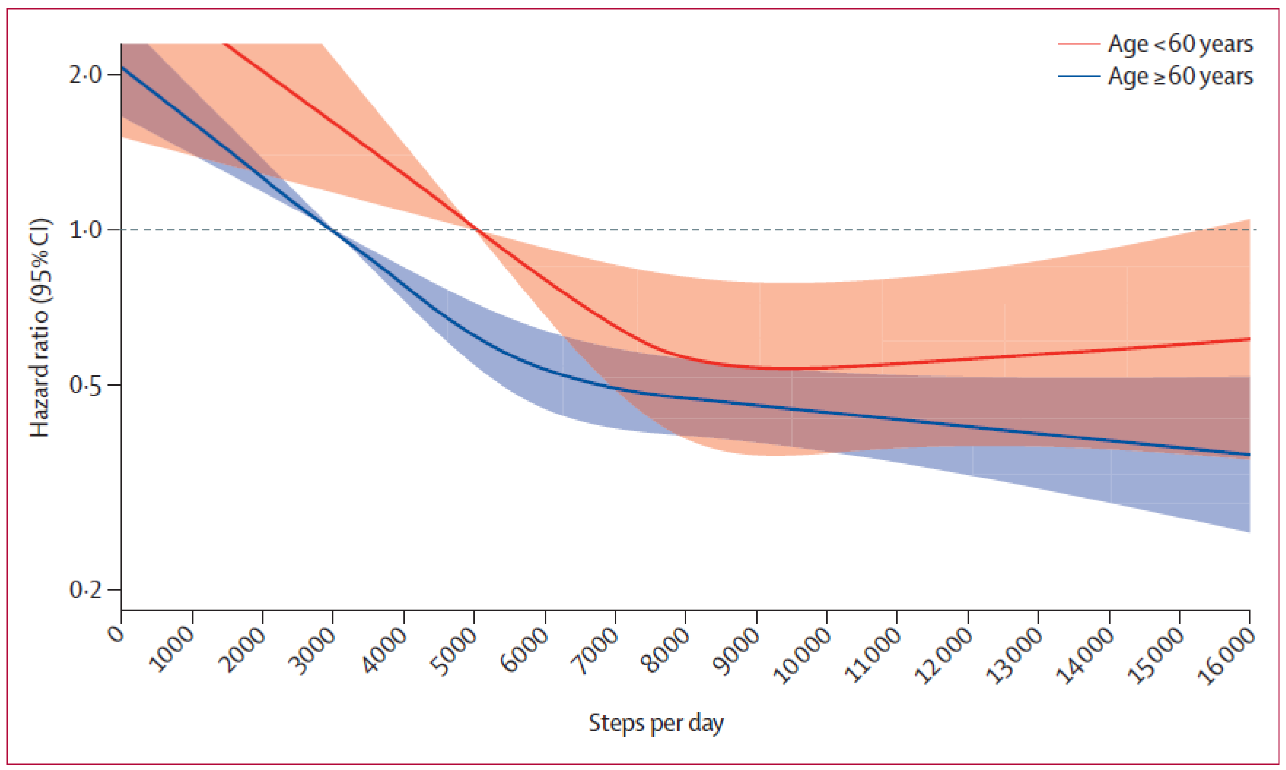


Lee et al *Prog Cardiovas Dis* 2017

Terms and Conditions

Is There A Recommended Dose Of Exercise For Optimal Health?

- Goal of 10,000 steps per day commonly cited to promote optimal health
- Monitoring daily steps more feasible than ever
- Meta-analysis of 15 studies including 47,471 adults to determine association between number of steps per day and stepping rate with all-cause mortality
- 3013 deaths over a median follow-up of 7.1 years



- 4 quartiles; Q1 – 3553, Q2 – 5801, Q3 – 7842, Q4 – 10,901
- Adjusted hazard ratio for all cause mortality was 0.6 for Q2, 0.55 for Q3, and 0.47 for Q4
- Women < 60 years plateau around 7500 steps per day
- Women > 60 years effects seemed to persist

Paluch AE et al. Daily steps and all-cause mortality: a meta-analysis of 15 international cohorts. Lancet 2022.

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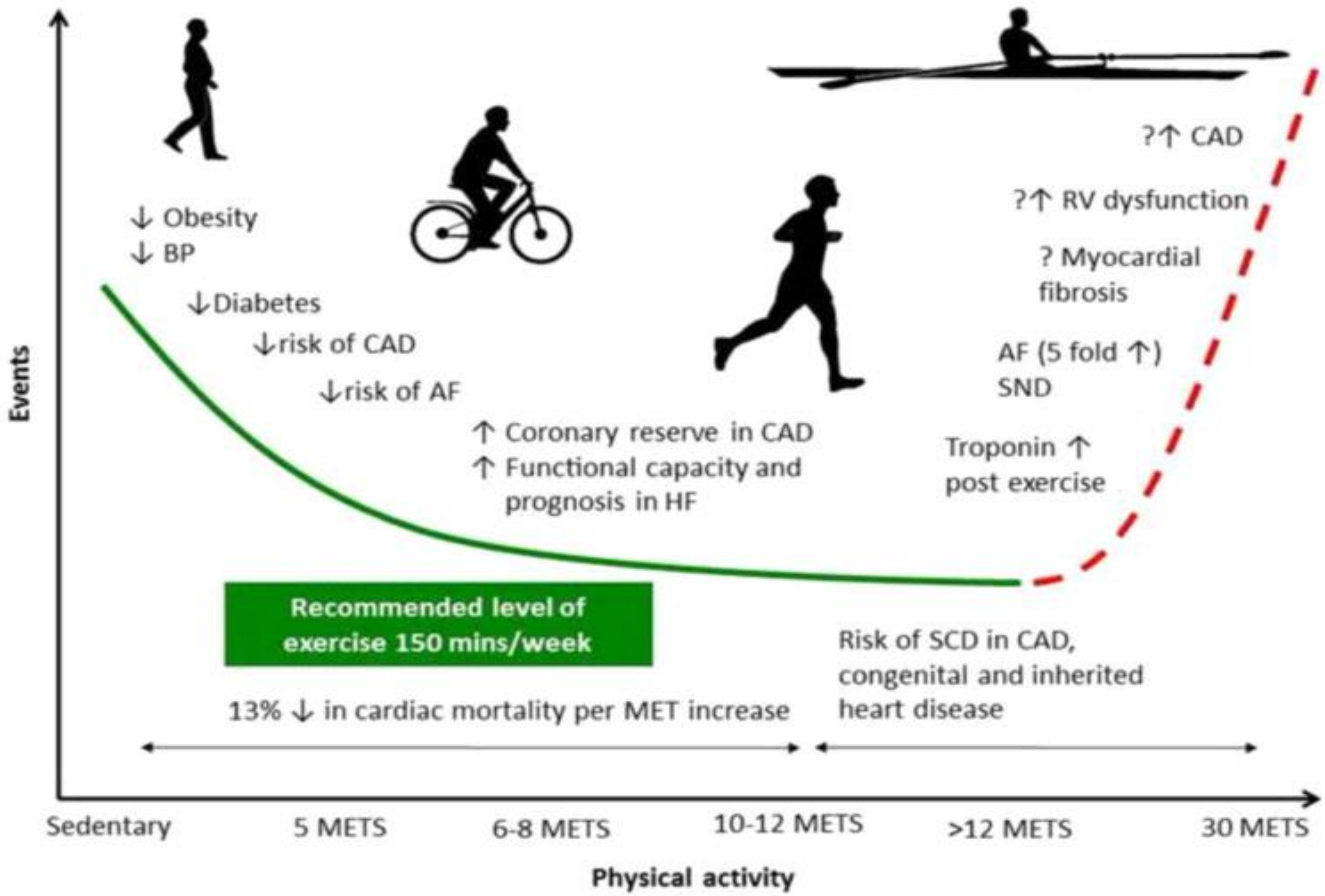
Is There A Recommended Dose Of Exercise?



Merghani A, Malhotra A, Sharma S. *Trends in Cardiovascular Medicine* 2016.

Mental Health in Ultra-Endurance Runners: A Systematic Review

Mabliny Thuany[1] · Carel Viljoen[2] · Thayse Natacha Gomes[3,4,5] · Beat Knechtle[6,7] · Volker Scheer[8]

Sports Medicine (2023) 53:1891–1904
https://doi.org/10.1007/s40279-023-01890-5

Abstract

Background Among ultra-endurance runners (UER), the mental, behavioral, and physical demands of training/competition can result in maladaptive outcomes. Mental health issues are common in athletes and can impact psychology, physical health, and performance.

Objective To synthesize information regarding the incidence/prevalence and factors associated with mental health issues among UER.

Methods Systematic searches were performed in PubMed, SPORTDiscus, Scopus, Cochrane databases, CINAHL, Web of Science, and Medline Ovid using key terms related to UER (e.g., trail running, road running) and psychological issues (e.g., exercise addiction, depression). Inclusion criteria included original articles published in peer-reviewed journals in English, using qualitative or quantitative approaches. We considered papers reporting incidence/prevalence and associated factors with mental health outcomes in UER of both sexes, all ages, and levels of competition (e.g., elite, nonprofessional runners). The Joanna Briggs Institute Analytical Cross-Sectional Studies critical appraisal tool was used for quality assessment.

Results A total of 282 studies were identified, and 11 studies were included in the final selection. A total of 3670 UER were included in the studies. The prevalence of mental health issues among UER ranged between 32.0% and 62.5% for eating disorders, from 11.5% to 18.2% for exercise addiction, 18.6% for depressive symptoms, and 24.5% for sleep disturbance. Exercise addiction was not related to weekly volume, but a strong relationship with exercise in an unstructured space, age, and body mass index was shown.

Conclusion Mental health issues among UER are common, especially eating disorders, exercise addiction, sleep disturbances, and depressive symptoms. Further high-quality studies are needed to examine underlying factors and find preventative strategies to protect UER.

Key Points
The past decade has witnessed an increase in interest in mental health in ultra-endurance runners.
Common mental health issues among UER are eating disorders and exercise addiction.
Race distance within ultra-endurance running is not a risk factor for mental health issues.

Mental Health in Ultra-Endurance Runners: A Systematic Review

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Fig. 2 Main take-home messages of the systematic review. UER, ultra-endurance runners

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Review

Mental Health Disorders in Ultra Endurance Athletes per ICD-11 Classifications: A Review of an Overlooked Community in Sports Psychiatry

Jill Colangelo [1,*], Alexander Smith [1], Ana Buadze [2], Nicola Keay [3] and Michael Liebrenz [1]

Sports **2023**, *11*, 52. https://doi.org/10.3390/sports11030052

Abstract: Introduction: Although research suggests that exercise benefits mental health, psychiatric disorders have been acknowledged in the ultra-endurance-athlete population. At present, the mental-health consequences of high-volume training associated with ultra-endurance sports are not well understood. Methods: We conducted a narrative review summarizing primary observations about mental disorders per ICD-11 criteria in ultra-endurance athletes using a keyword search in Scopus and PubMed. Results: We identified 25 papers discussing ICD-11-classified psychiatric disorders such as depression, anxiety, eating disorders, attention-deficit/hyperactivity disorder, and schizophrenia in ultra-endurance athletes. Discussion: Although evidence is limited, available papers indicate that there is a sizable incidence of mental-health issues and composite psychopathological vulnerabilities in this community. We contend that ultra-endurance athletes may represent a different, though similar, demographic than elite and/or professional athletes, as they often engage in high-volume training with similarly high motivation. This can have regulatory implications, which we also highlight. Conclusion: Mental illness in ultra-endurance athletes is an underrepresented topic in sports medicine, though psychiatric disorders may be especially prevalent in this population. Further inquiry is necessary to inform athletes and healthcare practitioners about the possible mental-health implications associated with participation in ultra-endurance sports.

A Single Bout of Ultra-Endurance Exercise Reveals Early Signs of Muscle Aging in Master Athletes

International Journal of *Molecular Sciences*

2022

Cécile Coudy-Gandilhon [1], Marine Gueugneau [1], Christophe Chambon [2], Daniel Taillandier [1], Lydie Combaret [1], Cécile Polge [1], Guillaume Y. Millet [3], Léonard Féasson [3] and Daniel Béchet [1,*]

Abstract: Middle-aged and master endurance athletes exhibit similar physical performance and long-term muscle adaptation to aerobic exercise. Nevertheless, we hypothesized that the short-term plasticity of the skeletal muscle might be distinctly altered for master athletes when they are challenged by a single bout of prolonged moderate-intensity exercise. Six middle-aged (37Y) and five older (50Y) master highly-trained athletes performed a 24-h treadmill run (24TR). *Vastus lateralis* muscle biopsies were collected before and after the run and assessed for proteomics, fiber morphometry, intramyocellular lipid droplets (LD), mitochondrial oxidative activity, extracellular matrix (ECM), and micro-vascularisation. Before 24TR, muscle fiber type morphometry, intramyocellular LD, oxidative activity, ECM and micro-vascularisation were similar between master and middle-aged runners. For 37Y runners, 24TR was associated with ECM thickening, increased capillary-to-fiber interface, and an 89% depletion of LD in type-I fibers. In contrast, for 50Y runners, 24TR did not alter ECM and capillarization and poorly depleted LDs. Moreover, an impaired succinate dehydrogenase activity and functional class scoring of proteomes suggested reduced oxidative phosphorylation post-24TR exclusively in 50Y muscle. Collectively, our data support that middle-aged and master endurance athletes exhibit distinct transient plasticity in response to a single bout of ultra-endurance exercise, which may constitute early signs of muscle aging for master athletes.

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Topic 3 - Acute Effects Of Exercise On The Cardiovascular System

The Athlete's Heart

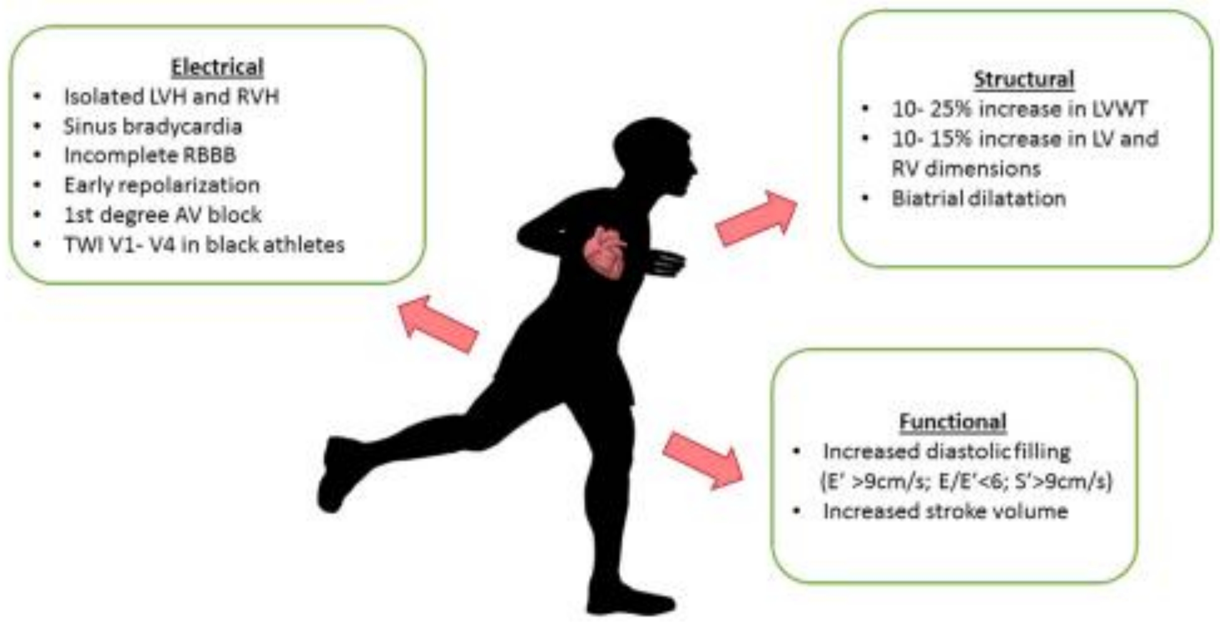
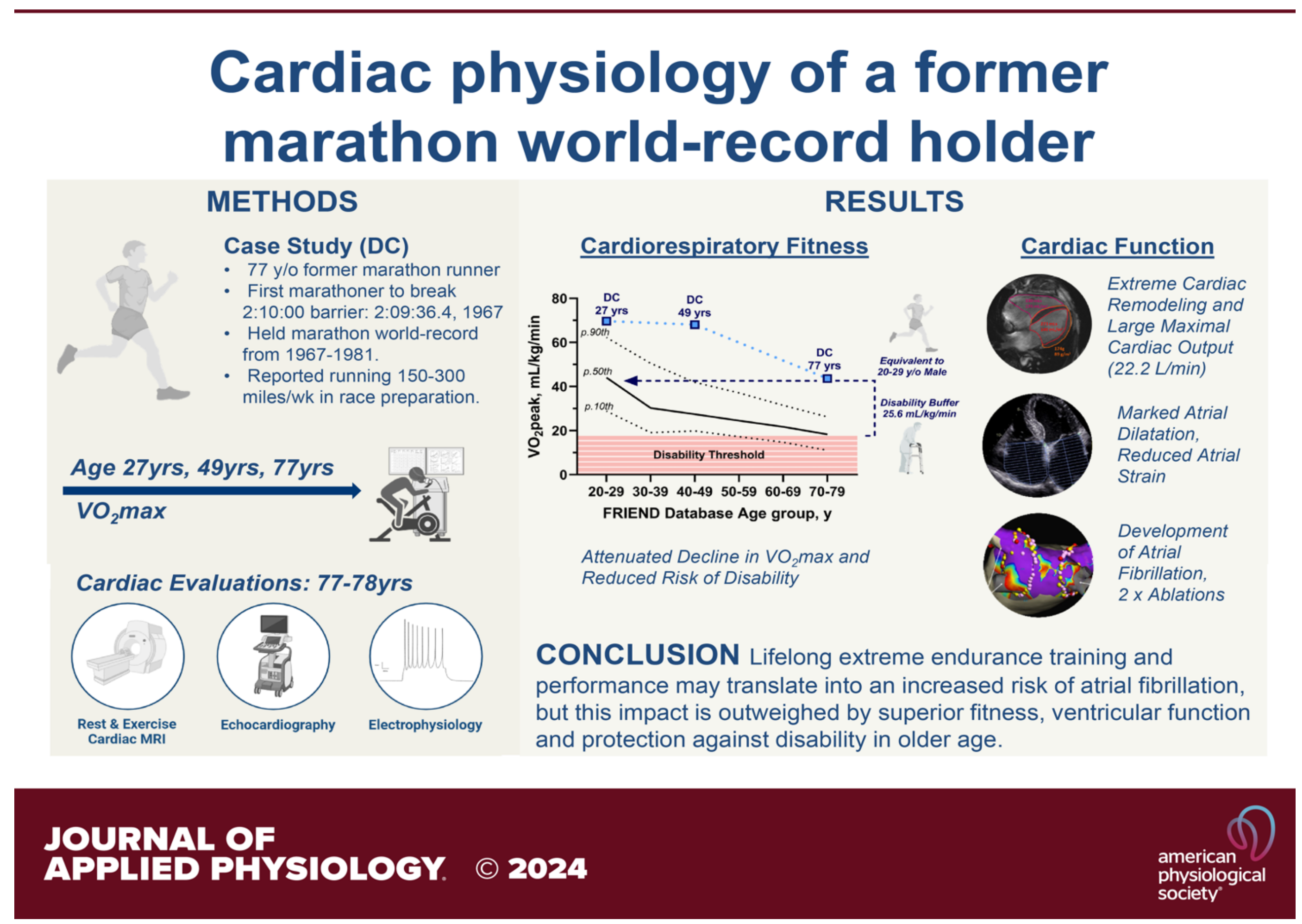


Fig. 3 – Electrical, structural, and functional changes observed in the athlete's heart. AV = atrioventricular, LV = left ventricle, LVH = left ventricular hypertrophy, LVWT = left ventricular wall thickness, RBBB = right bundle branch block, RV = right ventricular, TWI = T wave inversion.

Merghani A, Malhotra A, Sharma S. *Trends in Cardiovascular Medicine* 2016.



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Insult of Ultraendurance Events on Blood Pressure: A Systematic Review and Meta-Analysis

Steven B. Hammer [1] , Fred Strale Jr. [2] , Timothy B. Williams [3] , Shantele L. Kemp Van Ee [3] , James W. Agnew [1]

1. Anatomy and Physiology, Indian River State College, Fort Pierce, USA 2. Statistics, Wayne State University, Detroit, USA 3. Medicine, Dr. Kiran C. Patel College of Osteopathic Medicine, Nova Southeastern University, Fort Lauderdale, USA

Cureus

DOI: 10.7759/cureus.46801

Abstract

The rise of ultraendurance sports in the past two decades warrants evaluation of the impact on the heart and vessels of a growing number of athletes participating. Blood pressure is a simple, inexpensive method to evaluate one dimension of an athlete's cardiovascular health. No systematic review or meta-analysis to date has chronicled and delineated the effects of ultraendurance races, such as ultramarathons, marathons, half-marathons, and Ironman triathlon events, specifically on heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP), and mean arterial pressure (MAP) measurements in supine and standing positions before and after the event. This meta-analysis reviews the effects of ultraendurance events on positional and calculated hemodynamic values. Data were extracted from 38 studies and analyzed using a random effects model with a total of 1,645 total blood pressure measurements. Of these, 326 values were obtained from a standing position, and 1,319 blood pressures were taken supine. Pre-race and post-race measurements were evaluated for clinical significance using established standards of hypotension and orthostasis. HR and calculated BP features, such as PP and MAP, were evaluated. Across all included studies, the mean supine post-race HR increased by 21±8 beats per minute (bpm) compared to pre-race values. The mean standing post-race HR increased by 23±14 bpm when compared with pre-race HR. Overall, there was a mean SBP decrease of 19±9 mmHg and a DBP decrease of 9±5 mmHg post-race versus pre-race values. MAP variations reflected SBP and DBP changes. The mean supine and standing pre-race blood pressures across studies were systolic (126±7; 124±14) and diastolic (76±6; 75±12), suggesting that some athletes may enter races with existing hypertension. The post-race increase in the mean HR and decline in mean blood pressure across examined studies suggest that during long-term events, ultramarathon athletes perform with relatively asymptomatic hypotension.

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RESEARCH Open Access

Exploratory assessment of right ventricular structure and function during prolonged endurance cycling exercise

Lord *et al. Echo Research & Practice* (2023) 10:22
https://doi.org/10.1186/s44156-023-00035-8

Rachel N. Lord[1*], Zoe H. Adams[1], Keith George[2], John Somauroo[2,3], Helen Jones[2] and David Oxborough[2]

Abstract

Background A reduction in right ventricular (RV) function during recovery from prolonged endurance exercise has been documented alongside RV dilatation. A relative elevation in pulmonary artery pressure and therefore RV afterload during exercise has been implicated in this post-exercise dysfunction but has not yet been demonstrated. The current study aimed to assess RV structure and function and pulmonary artery pressure before, during and after a 6-h cycling exercise bout.

Methods Eight ultra-endurance athletes were recruited for this study. Participants were assessed prior to exercise supine and seated, during exercise at 2, 4 and 6 h whilst cycling seated at 75% maximum heart rate, and post-exercise in the supine position. Standard 2D, Doppler and speckle tracking echocardiography were used to determine indices of RV size, systolic and diastolic function.

Results Heart rate and RV functional parameters increased from baseline during exercise, however RV structural parameters and indices of RV systolic and diastolic function were unchanged between in-exercise assessment points. Neither pulmonary artery pressures (26 ± 9 mmHg vs 17 ± 10 mmHg, $P > 0.05$) nor RV wall stress (7.1 ± 3.0 vs 6.2 ± 2.4, $P > 0.05$) were significantly elevated during exercise. Despite this, post-exercise measurements revealed RV dilation (increased RVD1 and 3), and reduced RV global strain (– 21.2 ± 3.5 vs – 23.8 ± 2.3, $P = 0.0168$) and diastolic tissue velocity (13.8 ± 2.5 vs 17.1 ± 3.4, $P = 0.019$) vs pre-exercise values.

Conclusion A 6 h cycling exercise bout at 75% maximum heart rate did not alter RV structure, systolic or diastolic function assessments during exercise. Pulmonary artery pressures are not elevated beyond normal limits and therefore RV afterload is unchanged throughout exercise. Despite this, there is some evidence of RV dilation and altered function in post-exercise measurements.

Keywords Endurance, Exercise, Ultrasound, Right ventricular function

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Impact of an Ultra-Endurance Marathon on Cardiac Function in Association with Cardiovascular Biomarkers

Achim Leo Burger[1,2*†], Claudia Wegberger[1†], Maximilian Tscharre[1], Christoph C. Kaufmann[1,2], Marie Muthspiel[1], Edita Pogran[1], Matthias K. Freynhofer[1], Alexander Szalay[1], Kurt Huber[1,2] and Bernhard Jäger[1,2]

Burger et al. Sports Medicine - Open (2024) 10:67
https://doi.org/10.1186/s40798-024-00737-1

Sports Medicine - Open

Abstract

Background Participation in ultra-endurance races may lead to a transient decline in cardiac function and increased cardiovascular biomarkers. This study aims to assess alterations in biventricular function immediately and five days after the competition in relation to elevation of high-sensitivity cardiac Troponin I (hs-cTnI) and N-terminal-pro-brain-natriuretic-peptide (NT-proBNP).

Methods and Results Fifteen participants of an ultramarathon (UM) with a running distance of 130 km were included. Transthoracic echocardiography and quantification of biomarkers was performed before, immediately after and five days after the race. A significant reduction in right ventricular fractional area change (FAC) was observed after the race (48.0 ± 4.6% vs. 46.7 ± 3.8%, $p = 0.011$) that persisted five days later (48.0 ± 4.6% vs. 46.3 ± 3.9%, $p = 0.027$). No difference in left ventricular ejection fraction (LVEF) was found ($p = 0.510$). Upon stratification according to biomarkers, participants with NT-proBNP above the median had a significantly reduced LVEF directly (60.8 ± 3.6% vs. 56.9 ± 4.8%, $p = 0.030$) and five days after the race (60.8 ± 3.6% vs. 55.3 ± 4.5%, $p = 0.007$) compared to baseline values. FAC was significantly reduced five days after the race (48.4 ± 5.1 vs. 44.3 ± 3.9, $p = 0.044$). Athletes with hs-cTnI above the median had a significantly reduced FAC directly after the race (48.1 ± 4.6 vs. 46.5 ± 4.4, $p = 0.038$), while no difference in LVEF was observed. No alteration in cardiac function was observed if hs-cTnI or NT-proBNP was below the median.

Conclusion A slight decline in cardiac function after prolonged strenuous exercise was observed in athletes with an elevation of hs-cTnI and NT-proBNP above the median but not below.

Key Findings

- Participation in an ultra-endurance marathon with a running distance of 130 km is associated with a transient decline in cardiac function in those athletes with markedly increased N-terminal pro-brain natriuretic peptide and high-sensitivity cardiac troponin I after the race.
- This alteration in cardiac function is not found in athletes with only a minor elevation of these biomarkers.

Keywords Ultramarathon, Cardiac function, Echocardiography, Cardiovascular biomarkers

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The Acute Impact of Endurance Exercise on Right Ventricular Structure and Function

A Systematic Review and Meta-analysis

Tristan Ramcharan, MD[a,b], Jamie Edwards, MSc[c], Jamie O'Driscoll, PhD[c,*], Michael Papadakis, MD[d]

Card Electrophysiol Clin 16 (2024) 25–34
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KEY POINTS

- Endurance exercise is associated with acute RV dilatation and reduction in systolic function.
- There is a dose–response relationship because acute RV effects seem to be amplified following ultraendurance events.
- Those training more hours per week demonstrate a larger acute reduction of RVFAC following endurance events.
- RV systolic impairment resolves within a week following acute exercise, suggesting a reversible, short-term impact.

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Table 1
Details of studies looking at acute endurance exercise effects

Study, Year	Country	Number of Participants	Male/Female Ratio	Mean Age, Years (SD)	Event
[a]Douglas et al,[22] 1990	United States	41	22:19	38 (10)	Ironman triathlon
[a]Carrio et al,[23] 1990	Spain	10	Unk	Unk	Ultramarathon
[a]Davila-Roman et al,[14] 1997	United States	14	Unk	Unk	High-altitude ultramarathon
Neilan et al,[24]2006	United States	20	10:10	34 (10)	Marathon
Neilan et al,[25] 2006	United States	60	41:19	41 (11)	Marathon
Neilan et al,[26] 2006	United States	17	12:5	37	Rowers
Oxborough et al,[27] 2006	United Kingdom	35	29:6	30 (8)	Marathon
[a]La Gerche et al,[28] 2008	Australia	26	Unk	32	Ironman triathlon
Mousavi et al,[20] 2009	Canada	14	8:6	33 (6)	Marathon
Trivax et al,[29] 2010	United States	25	13:12	39 (9)	Marathon
O'Hanlon et al,[30] 2010	United Kingdom	17	17:0	34 (7)	Marathon
[a]Oxborough et al,[31] 2011	United Kingdom	16	12:4	42 (8)	Ultramarathon
Oomah et al,[32] 2011	Canada	15	7:8	32 (6)	Half-marathon
Karlstedt et al,[33] 2012	Canada	25	21:4	55 (4)	Marathon
Schattke et al,[34] 2012	Germany	21	21:0	46 (15)	Marathon
[a]La Gerche et al,[8] 2012	Australia	40	36:4	37 (8)	Ultratriathlon
Claessen et al,[35] 2014	Belgium	14	14:0	36 (6)	Cycling
[a]Lord et al,[36] 2015	United States	15	14:1	40 (8)	Ultramarathon
[a]Sanz de la Garza et al,[19] 2016	Spain	55	55:0	37 (7)	High-altitude ultramarathon
[a]Maufrais et al,[37] 2016	France	15	15:0	46 (13)	Ultramarathon
Stewart et al,[38] 2017	Australia	23	23:0	28 (8)	Cycling
Gajda et al,[39] 2019	Poland	12	7:5	Unk	Swimmers
Martinez et al,[40] 2019	Spain	33	26:7	41 (7)	Swimmers
[a]Christou et al,[41] 2020	Greece	25	19:8	45 (7)	Ultramarathon
[a]Coates et al,[42] 2020	Canada	8	6:2	45 (10)	Ultramarathon
Chen et al,[43] 2021	Germany	50	40:10	45 (10)	Triathlon

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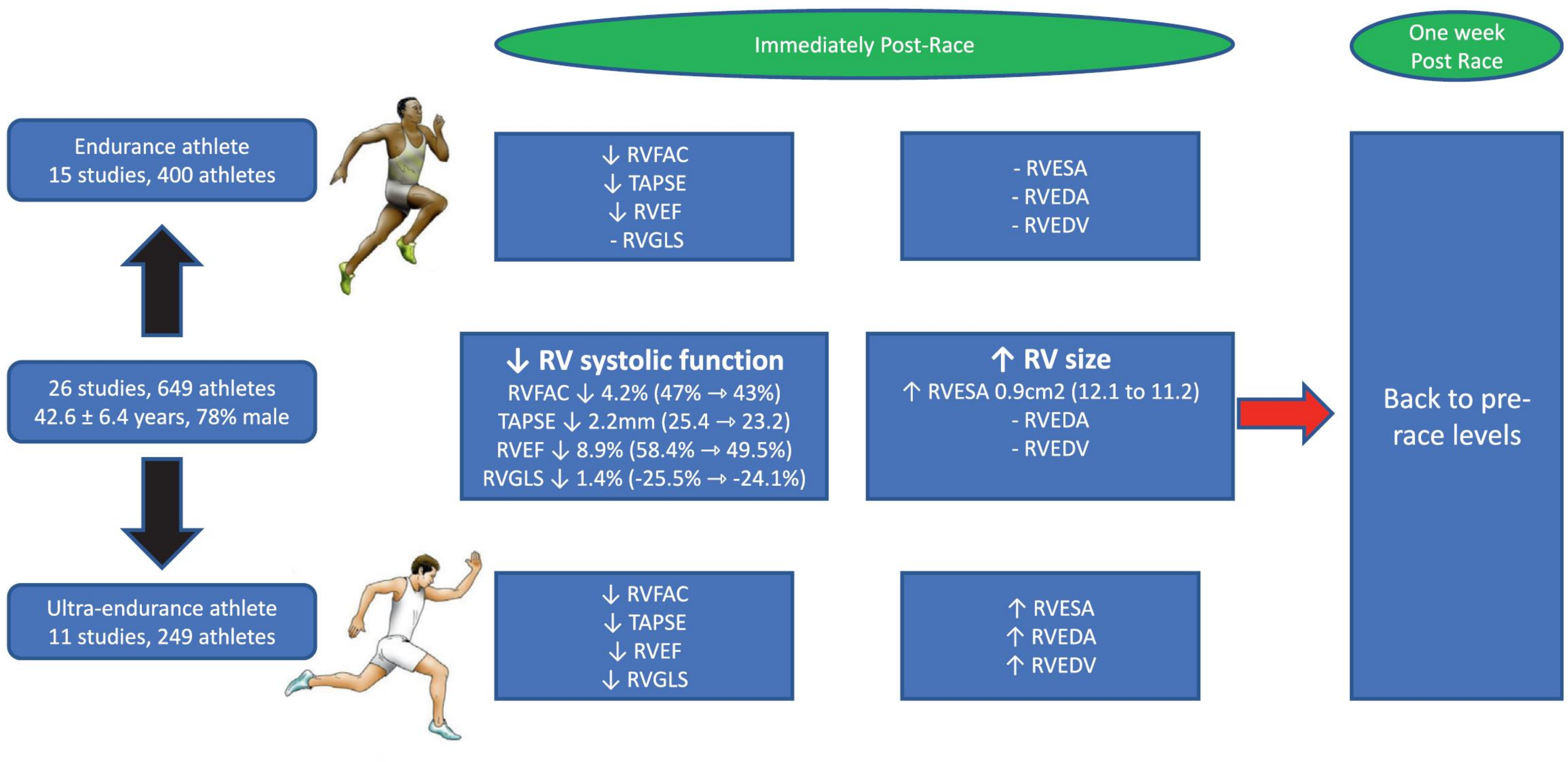

Fig. 1. Graphical abstract. RVEDA, right ventricular end-diastolic area; RVEDV, right ventricular end-diastolic volume; RVEF, right ventricular ejection fraction; RVESA, right ventricular end-systolic area; RVFAC, right ventricular fractional area change; RVGLS, right ventricular global longitudinal strain; TAPSE, tricuspid annular plane systolic excursion.

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The acute effects of an ultramarathon on biventricular function in master athletes: everything in moderation or not?

ESC
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Efstathios D. Pagourelias [1,2], Georgios A. Christou[1], and Evangelia J. Kouidi[1]*

In a recent paper, Cavigli *et al.*[2] have followed 68 healthy master athletes who have successfully crossed the finish line of the Siena Ultramarathon running race (50 km, 600 m of elevation gain). After comparing traditional and deformation-based echocardiographic parameters, before and after the race, the authors concluded that in master endurance athletes running an ultramarathon, exercise-induced ventricular dysfunction was not detected. They finally supported that their results refuted the hypothesis of a detrimental acute effect of strenuous exercise on the heart.[2]

Ultramarathon races have become a significant part of sportsmen' life, who continuously reach their limits by conquering longer distances in shorter times. Considering that our study group and other researchers in the field have shown that alterations imposed by UE exercise could be seen in the context of myocardial adaptations rather than that of myocardial necrosis or progression to cardiomyopathy, accepting that ultra-strenuous exercise has no acute effects on the heart, may be considered a 'dangerous' oversimplification. After all, the basic principle of ancient Greek philosophy 'everything in moderation' should also apply in exercise.

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Topic 4 – Cardiovascular (Mal)adaptation To Chronic Exercise

Echocardiographic Assessment of Left Ventricular Function 10 Years after the Ultra-Endurance Running Event Eco-Trail de Paris® 2011

International Journal of *Environmental Research and Public Health*

2022

Romain Jouffroy [1,2,3,4,*], Oussama Benaceur [1], Jean-François Toussaint [2,4,5] and Juliana Antero [2]

Abstract: *Background:* Regular and moderate physical activity is beneficial for physical and mental health, resulting in an increase in life expectancy for both sexes. From a cardiovascular point of view, although the benefits of regular moderate physical exercise have been established, the long-term effects of repeated ultra-endurance running events are still unknown. *Hypothesis:* The aim of our study is to evaluate the 10-year evolution of the parameters of the left ventricular systolic and diastolic functions of amateur subjects regularly practising ultra-endurance running events using resting echocardiography. *Study design:* Cross-sectional study. *Level of evidence:* Level 3—non-randomized controlled cohort/follow-up study. *Methods:* The 66 participants who participated in the 2011 edition of the Eco-Trail de Paris® were contacted by e-mail. Demographic data, sports practice, and the results of an echocardiography scan carried out during the year 2021 evaluating left ventricular systolic and diastolic function variables were collected. Echographic variables from 2011 and 2021 were compared using the paired Student's *t*-test. *Results:* Forty-six (70%) participants responded positively. Twenty (30%) participants could not be reached and were not analysed. Of the 46 respondents, 42 (91%) provided data from a trans-thoracic cardiac ultrasound performed in 2021. Over the past 10 years, the participants reported having completed an average of 4 ± 2 ultra-trails per year. No significant differences were observed between left ventricular diastolic and systolic echocardiographic parameters between the years 2011 and 2021. *Conclusions:* Among amateur participants, long-distance running is not associated with an alteration in the echocardiographic parameters of resting left ventricular systolic and diastolic function after 10 years of practice. *Clinical relevance:* Long-term long-distance running practice is not associated with left ventricular cardiac function alteration. These results suggest a potential adaptation role of the cardiovascular system to regular and moderate long-distance running practice.

Echocardiographic Assessment of Left Ventricular Function 10 Years after the Ultra-Endurance Running Event Eco-Trail de Paris® 2011

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2022

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Table 1. Characteristics of the 46 amateur participants. Data are expressed as mean ± standard deviation (SD) and range (min–max value).

	Year 2011		Year 2021	
Variable	**Mean ± SD**	**Range (Min–Max Value)**	**Mean ± SD**	**Range (Min–Max Value)**
Age (years)	43 ± 7	25–61	53 ± 7	42–71
Height (cm)	176 ± 7	167–188	177 ± 6	165–188
Weight (kg)	74 ± 8	61–82	69 ± 6	60–80
Body mass index (kg/m^2)	22.4 ± 1.1	18.9–25.2	22.1 ± 1.6	18.9–25.2
Training (hours/week)	5 ± 4	1–16	6 ± 3	2–14
Training (km/week)	45 ± 18	20–80	48 ± 19	15–80

Table 2. Echocardiographic and Doppler measurements in 2011 and 2021. Data are expressed in mean ± standard deviation.

Variable	Year 2011	Year 2021	*p*-Value
Heart rate (beats/min)	63 ± 10	66 ± 15	0.282
End-diastolic measurements:			
Interventricular septum (mm)	9.6 ± 1.4	10.2 ± 1.8	0.670
Posterior wall (mm)	8.4 ± 1.4	9.3 ± 1.9	0.512
Left ventricular diameter (mm)	51.5 ± 5.4	52.0 ± 6.6	0.435
Aortic diameter (mm)	31.8 ± 4.4	33.4 ± 5.6	0.660
End-systolic measurements:			
Left ventricular diameter (mm)	35.0 ± 5.4	34.5 ± 6.2	0.368
Left atrial diameter (mm)	35.6 ± 4.5	37.0 ± 9.6	0.386
Left ventricular ejection fraction (%)	65.3 ± 10.6	67.5 ± 6.7	0.777

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Relationship Between Lifelong Exercise Volume and Coronary Atherosclerosis in Athletes

Circulation. 2017;136:138–148.

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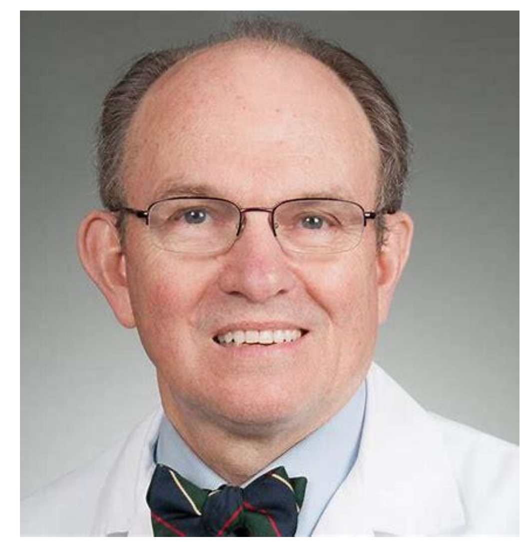
BACKGROUND: Higher levels of physical activity are associated with a lower risk of cardiovascular events. Nevertheless, there is debate on the dose-response relationship of exercise and cardiovascular disease outcomes and whether high volumes of exercise may accelerate coronary atherosclerosis. We aimed to determine the relationship between lifelong exercise volumes and coronary atherosclerosis.

METHODS: Middle-aged men engaged in competitive or recreational leisure sports underwent a noncontrast and contrast-enhanced computed tomography scan to assess coronary artery calcification (CAC) and plaque characteristics. Participants reported lifelong exercise history patterns. Exercise volumes were multiplied by metabolic equivalent of task (MET) scores to calculate MET-minutes per week. Participants' activity was categorized as <1000, 1000 to 2000, or >2000 MET-min/wk.

RESULTS: A total of 284 men (age, 55±7 years) were included. CAC was present in 150 of 284 participants (53%) with a median CAC score of 35.8 (interquartile range, 9.3–145.8). Athletes with a lifelong exercise volume >2000 MET-min/wk (n=75) had a significantly higher CAC score (9.4 [interquartile range, 0–60.9] versus 0 [interquartile range, 0–43.5]; *P*=0.02) and prevalence of CAC (68%; adjusted odds ratio [$OR_{adjusted}$]=3.2; 95% confidence interval [CI], 1.6–6.6) and plaque (77%; $OR_{adjusted}$=3.3; 95% CI, 1.6–7.1) compared with <1000 MET-min/wk (n=88; 43% and 56%, respectively). Very vigorous intensity exercise (≥9 MET) was associated with CAC ($OR_{adjusted}$=1.47; 95% CI, 1.14–1.91) and plaque ($OR_{adjusted}$=1.56; 95% CI, 1.17–2.08). Among participants with CAC>0, there was no difference in CAC score (*P*=0.20), area (*P*=0.21), density (*P*=0.25), and regions of interest (*P*=0.20) across exercise volume groups. Among participants with plaque, the most active group (>2000 MET-min/wk) had a lower prevalence of mixed plaques (48% versus 69%; $OR_{adjusted}$=0.35; 95% CI, 0.15–0.85) and more often had only calcified plaques (38% versus 16%; $OR_{adjusted}$=3.57; 95% CI, 1.28–9.97) compared with the least active group (<1000 MET-min/wk).

CONCLUSIONS: Participants in the >2000 MET-min/wk group had a higher prevalence of CAC and atherosclerotic plaques. The most active group, however, had a more benign composition of plaques, with fewer mixed plaques and more often only calcified plaques. These observations may explain the increased longevity typical of endurance athletes despite the presence of more coronary atherosclerotic plaque in the most active participants.



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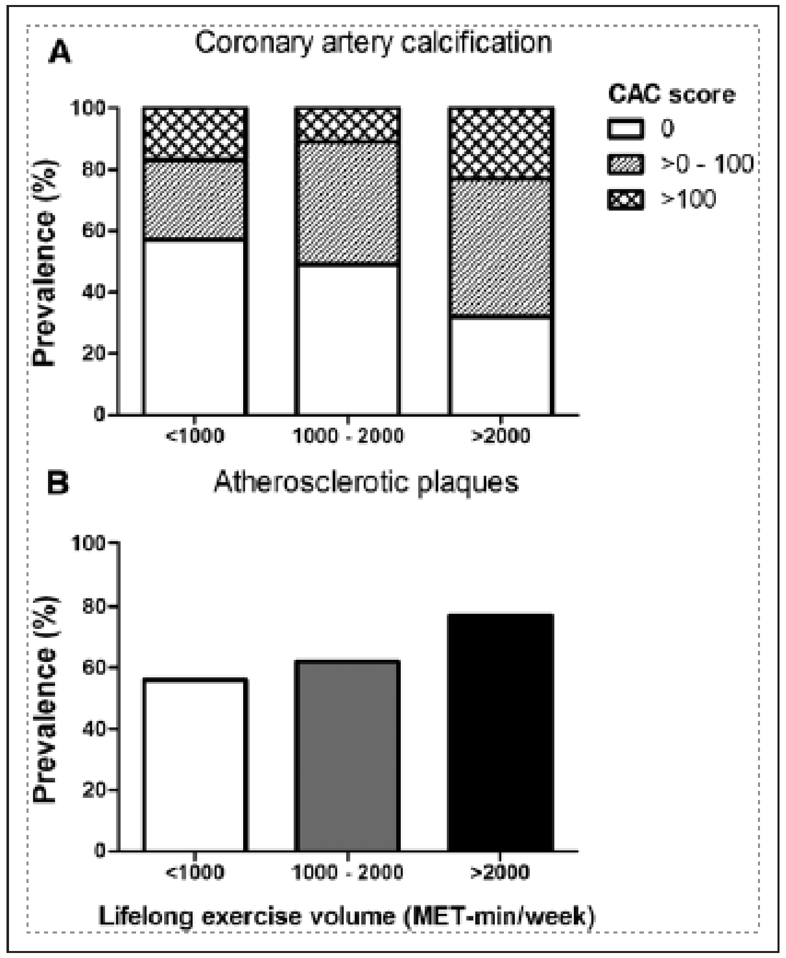

Figure 2. Prevalence of coronary artery calcification (CAC) and atherosclerotic plaques across lifelong exercise volume groups.
Data were derived from computed tomography (CT) and CT coronary angiography scans for assessment of CAC and atherosclerotic plaques (n=284). **A**, Comparison of CAC score categories across exercise volume groups. A significant difference in CAC score categories (*P*=0.006) was found across exercise volume groups, with higher CAC scores in the >2000 MET-min/wk group. The >2000 MET-min/wk group had an adjusted odds ratio of 3.2 (95% confidence interval [CI], 1.6–6.6) for CAC scores >0 compared with the <1000 MET-min/wk group. **B**, Significant increase of atherosclerotic plaque prevalence across exercise volume groups (*P*=0.013) with an adjusted odds ratio of 3.3 (95% CI, 1.6–7.1) for the presence of plaque for the >2000– compared with the <1000 MET-min/wk group. MET indicates metabolic equivalent of task.

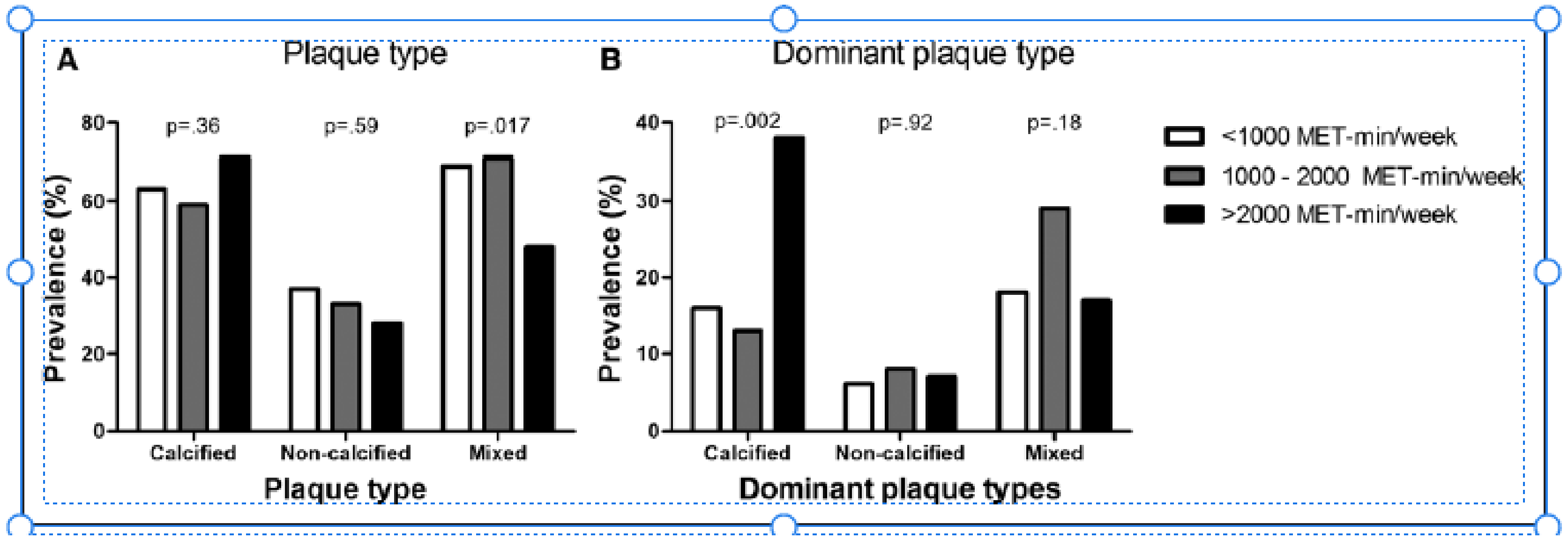

Figure 3. Plaque characteristics across the lifelong exercise volume groups in participants with computed tomography coronary angiography evidence of coronary atherosclerosis (n=182).
The >2000 MET-min/wk group had fewer mixed plaques (**A**) and more often only calcified plaques (**B**). These data suggest that plaque morphology is different across exercise volume groups, which may translate to a lower risk for major adverse cardiac events for the most active exercisers, despite their higher prevalence of coronary atherosclerosis. MET indicates metabolic equivalent of task.

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Relationship Between Lifelong Exercise Volume and Coronary Atherosclerosis in Athletes

Circulation. 2017;136:138–148.

Conclusions

In this study of middle-aged men engaged in competitive or recreational leisure sports, participants in the >2000–MET-min/wk group had a higher prevalence of CAC and atherosclerotic plaques. The most active group, however, had a more benign composition of plaques, with fewer mixed plaques and more often only calcified plaques. These observations may explain the increased longevity typical of endurance athletes despite the presence of more coronary atherosclerosis in the most active participants.

Clinical Perspective

What Is New?

- This study improves our understanding of coronary atherosclerosis in middle-aged athletes by analyzing coronary artery calcification and atherosclerotic plaque characteristics with contrast-enhanced computed tomography in relation to the amount of lifelong exercise.
- Athletes with a high lifelong exercise volume are more likely to have coronary atherosclerosis, but the most active athletes have a more benign composition of atherosclerotic plaques, that is, less mixed and more often only calcified plaques.

What Are the Clinical Implications?

- Physically active individuals may have substantial, asymptomatic coronary atherosclerosis.
- We showed substantial coronary artery calcification and plaque in very active athletes, which is associated with an increased risk of cardiac events.
- Because the atherosclerotic plaque types had a more benign composition in the most active athletes, long-term follow-up of athletes needs to show whether atherosclerotic burden in athletes confers a risk similar to that in the general population.
- Future studies unraveling the mechanisms leading to higher coronary artery calcification and plaque prevalence in very active athletes are warranted.

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Coronary Artery Calcification Among Endurance Athletes

"Hearts of Stone"

Aaron L. Baggish, MD,
and Benjamin D. Levine, MD

- Dose-response relationship between exercise and health outcomes incompletely understood
- Highly fit athletes have reduced risk of SCD and development of heart failure with little evidence of plateau at high levels of fitness (Al-Mallah MH et al 2016)
- Long-term, high-volume endurance exercise may accelerate rather than **reduce** coronary atherosclerosis (Mohlenkamp S et al 2008)
- Merghani et al – 152 competitive cyclists and runners and age-matched control cohort without known risk factors
- CT angiography – 60% of athletes and 63% control participants no demonstrable CAC
- Male athletes higher prevalence of plaque with luminal irregularity (44% vs 22% in controls)
- "Although the majority of aging endurance athletes demonstrate no appreciable CAC, athletic men are more likely than normally active men to have calcific coronary plaques despite absence of traditional risk factors"

Circulation
Volume 136, Issue 2, 11 July 2017; Pages 149-151
https://doi.org/10.1161/CIRCULATIONAHA.117.028750

Lifelong endurance exercise and its relation with coronary atherosclerosis

Ruben De Bosscher [1,2], Christophe Dausin [3], Piet Claus [1], Jan Bogaert [4], Steven Dymarkowski [4], Kaatje Goetschalckx [2], Olivier Ghekiere [5,6], Caroline M. Van De Heyning [7,8], Paul Van Herck [7,8], Bernard Paelinck [7,8], Haroun El Addouli [7,8], André La Gerche [9], Lieven Herbots [6,10], Rik Willems [1,2†], Hein Heidbuchel [7,8†], and Guido Claessen [1,6,9,10*†]; on behalf of Master@Heart Consortium

European Heart Journal (2023) **44**, 2388–2399
https://doi.org/10.1093/eurheartj/ehad152

Abstract

Aims The impact of long-term endurance sport participation (on top of a healthy lifestyle) on coronary atherosclerosis and acute cardiac events remains controversial.

Methods and results The Master@Heart study is a well-balanced prospective observational cohort study. Overall, 191 lifelong master endurance athletes, 191 late-onset athletes (endurance sports initiation after 30 years of age), and 176 healthy non-athletes, all male with a low cardiovascular risk profile, were included. Peak oxygen uptake quantified fitness. The primary endpoint was the prevalence of coronary plaques (calcified, mixed, and non-calcified) on computed tomography coronary angiography. Analyses were corrected for multiple cardiovascular risk factors. The median age was 55 (50–60) years in all groups. Lifelong and late-onset athletes had higher peak oxygen uptake than non-athletes [159 (143–177) vs. 155 (138–169) vs. 122 (108–138) % predicted]. Lifelong endurance sports was associated with having ≥1 coronary plaque [odds ratio (OR) 1.86, 95% confidence interval (CI) 1.17–2.94], ≥ 1 proximal plaque (OR 1.96, 95% CI 1.24–3.11), ≥ 1 calcified plaques (OR 1.58, 95% CI 1.01–2.49), ≥ 1 calcified proximal plaque (OR 2.07, 95% CI 1.28–3.35), ≥ 1 non-calcified plaque (OR 1.95, 95% CI 1.12–3.40), ≥ 1 non-calcified proximal plaque (OR 2.80, 95% CI 1.39–5.65), and ≥1 mixed plaque (OR 1.78, 95% CI 1.06–2.99) as compared to a healthy non-athletic lifestyle.

Conclusion Lifelong endurance sport participation is not associated with a more favourable coronary plaque composition compared to a healthy lifestyle. Lifelong endurance athletes had more coronary plaques, including more non-calcified plaques in proximal segments, than fit and healthy individuals with a similarly low cardiovascular risk profile. Longitudinal research is needed to reconcile these findings with the risk of cardiovascular events at the higher end of the endurance exercise spectrum.

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Lifelong endurance exercise and its relation with coronary atherosclerosis

Ruben De Bosscher[1,2], Christophe Dausin[3], Piet Claus[1], Jan Bogaert[4], Steven Dymarkowski[4], Kaatje Goetschalckx[2], Olivier Ghekiere[5,6], Caroline M. Van De Heyning[7,8], Paul Van Herck[7,8], Bernard Paelinck[7,8], Haroun El Addouli[7,8], André La Gerche[9], Lieven Herbots[6,10], Rik Willems[1,2†], Hein Heidbuchel[7,8†], and Guido Claessen[1,6,9,10*†]; on behalf of Master@Heart Consortium

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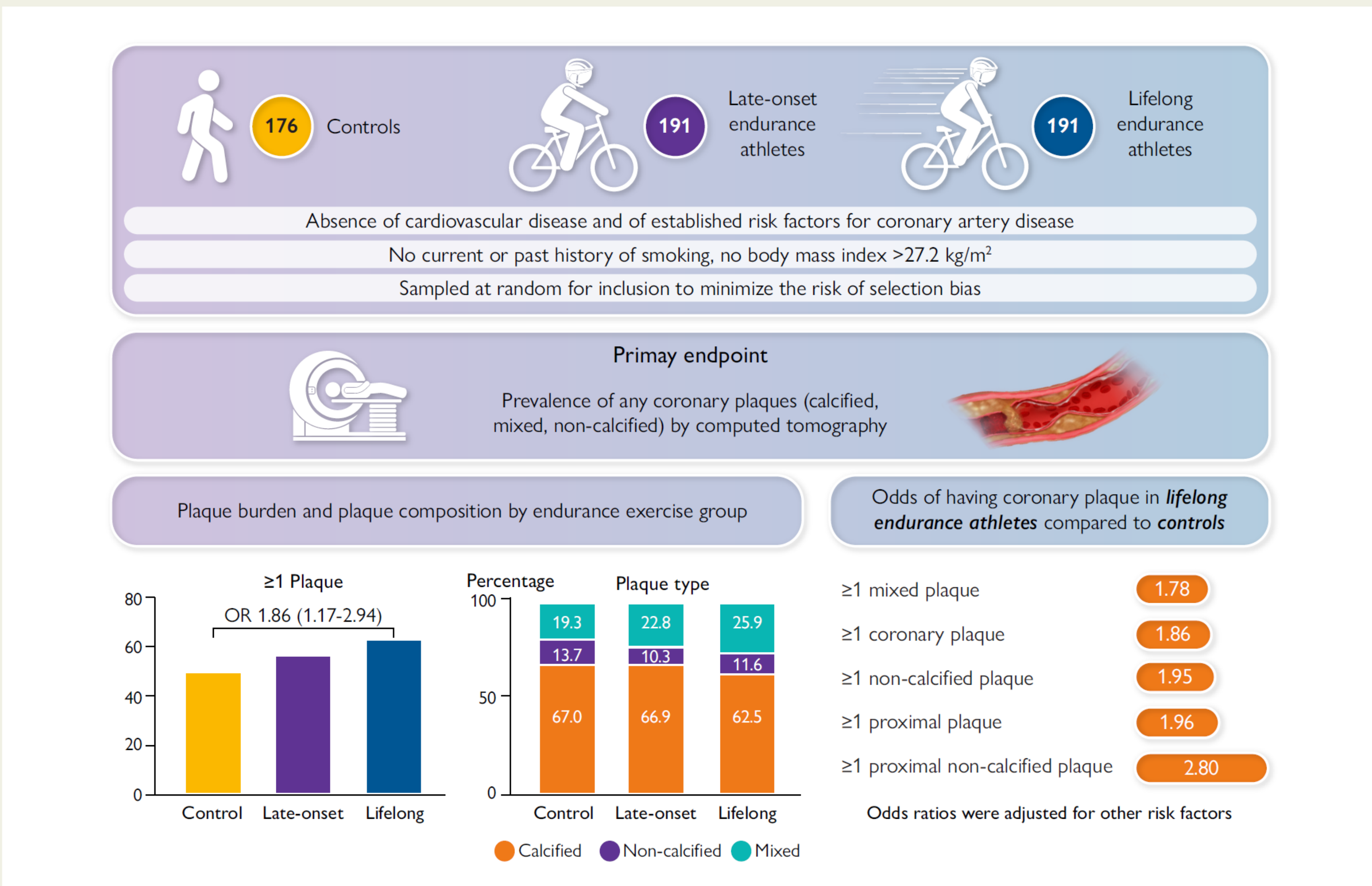

- Lifelong middle-aged athletes had more coronary plaques, including more calcified and mixed and plaques in proximal segments with significant luminal stenosis, than fit and healthy individuals with a similarly low CV risk profile

Key Question
Does lifelong exercise result in less and/or a more favourable plaque composition (i.e. a lower prevalence of non-calcified and mixed plaques) to explain the presumably lower risk of cardiovascular events in individuals with high cardiorespiratory fitness?

Key Finding
Lifelong athletes had more coronary plaques, including more risk-prone non-calcified plaques in proximal segments, than fit and healthy individuals with a similarly low cardiovascular risk profile.

Take Home Message
Lifelong endurance sport participation is not associated with a more favourable coronary plaque composition compared to a healthy lifestyle.

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Understanding the cardiac effects of ultra-endurance sports: the benefit of the doubt

European Heart Journal - Cardiovascular Imaging (2022) **23**, e304–e305
https://doi.org/10.1093/ehjci/jeac093

Luna Cavigli[1], Alessandro Zorzi [2], and Flavio D'Ascenzi [1]*

In our study,[1] we analyzed the acute effects of an ultra-marathon on the electrical and mechanical function of the heart in master athletes. We found that a 50 km ultramarathon did not significantly impact biventricular function, and no ventricular arrhythmias were elicited in this population, suggesting that not all the ultra-endurance competitions had acute adverse effects on cardiac function. We agree with Pagourelias *et al.*[2] that, in this ultra-marathon, the magnitude of exercise-induced cardiac stress was likely insufficient to produce relevant changes that may alter myocardial strain, including dehydration.[3] Accordingly, in interpreting our findings, we contextualized the discussion to non-professional competitive athletes running a 50 km ultramarathon race, a real-life population of master athletes. We demonstrated the absence of detrimental effects on cardiac function and arrhythmias in this population. Therefore, we firmly believe that our findings cannot be generalized to different ultra-endurance races or populations. Different and longer types of races may have a different impact on cardiac adaptation, causing a transient increase in the electrical instability of the ventricular myocardium, secondary to myocardial fatigue and electrolytic imbalance, as we demonstrated in athletes running a high-altitude ultra-trail.[4] However, on the contrary, the results obtained in professional athletes running long-distance races in different environments cannot be applied to the entire population of ultra-endurance athletes, and the hypothesis of detrimental effects on these disciplines should be interpreted with caution. Notably, most of the studies currently published demonstrated a transient reduction of strain parameters often interpreted in the context of a physiological adaptation. While irreversible dysfunction of the right ventricle has been hypothesized, studies showing long-term consequences of ultra-endurance disciplines on biventricular function have not yet been published.

Understanding the cardiac effects of ultra-endurance sports: the benefit of the doubt

European Heart Journal - Cardiovascular Imaging (2022) **23**, e304–e305
https://doi.org/10.1093/ehjci/jeac093

Luna Cavigli[1], Alessandro Zorzi [2], and Flavio D'Ascenzi [1]*

In conclusion, applying the basic principle of 'moderation' is important for exercise prescription in cardiac patients[6] but seems unjustified in healthy individuals practising endurance or ultra-endurance disciplines without solid evidence. The benefit of the doubt is essential, and we need more data on the long-term consequences of ultra-endurance sports as a cause of biventricular dysfunction. Until then, the risk of overdiagnosis and misinterpretation of physiological remodelling should be avoided, and the principle of 'easy does it' should be applied.

Lifelong physiology of a former marathon world-record holder: the pros and cons of extreme cardiac remodeling

Stephen J. Foulkes,[1,2] Mark J. Haykowsky,[2] Peter M. Kistler,[3] Glenn K. McConell,[4] Scott Trappe,[5] Mark Hargreaves,[6] David L. Costill,[5] and Andre La Gerche[1,7]

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Abstract

In a 77-year-old former world-record-holding male marathoner (2:08:33.6), this study sought to investigate the impact of lifelong intensive endurance exercise on cardiac structure, function, and the trajectory of functional capacity (determined by maximal oxygen consumption, $\dot{V}O_{2max}$) throughout the adult lifespan. As a competitive runner, our athlete (DC) reported performing up to 150–300 miles/wk of moderate-to-vigorous exercise and sustained 10–15 h/wk of endurance exercise after retirement from competition. DC underwent maximal cardiopulmonary exercise testing in 1970 (aged 27 yr), 1991 (aged 49 yr), and 2020 (aged 77 yr) to determine $\dot{V}O_{2max}$. At his evaluation in 2020, DC also underwent comprehensive cardiac assessments including resting echocardiography, and resting and exercise cardiac magnetic resonance to quantify cardiac structure and function at rest and during peak supine exercise. DC's $\dot{V}O_{2max}$ showed minimal change from 27 yr (69.7 mL/kg/min) to 49 yr (68.1 mL/kg/min), although it eventually declined by 36% by the age of 77 yr (43.6 mL/kg/min). DC's $\dot{V}O_{2max}$ at 77 yr, was equivalent to the 50th percentile for healthy 20- to 29-yr-old males and 2.4 times the requirement for maintaining functional independence. This was partly due to marked ventricular dilatation (left-ventricular end-diastolic volume: 273 mL), which facilitates a large peak supine exercise stroke volume (200 mL) and cardiac output (22.2 L/min). However, at the age of 78 yr, DC developed palpitations and fatigue and was found to be in atrial fibrillation requiring ablation procedures to revert his heart to sinus rhythm. Overall, this life study of a world champion marathon runner exemplifies the substantial benefits and potential side effects of many decades of intense endurance exercise.

NEW & NOTEWORTHY This life study of a 77-yr-old former world champion marathon runner exemplifies the impact of lifelong high-volume endurance exercise on functional capacity ($\dot{V}O_{2max}$ equivalent to a 20- to 29-yr-old), partly due to extreme ventricular remodeling that facilitates a large cardiac output during exercise despite reduced maximal heart rate. Although it is possible that this extreme remodeling may contribute to developing atrial fibrillation, the net benefits of extreme exercise throughout this athlete's lifespan favor increased health span and expected longevity.

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Lifelong physiology of a former marathon world-record holder: the pros and cons of extreme cardiac remodeling

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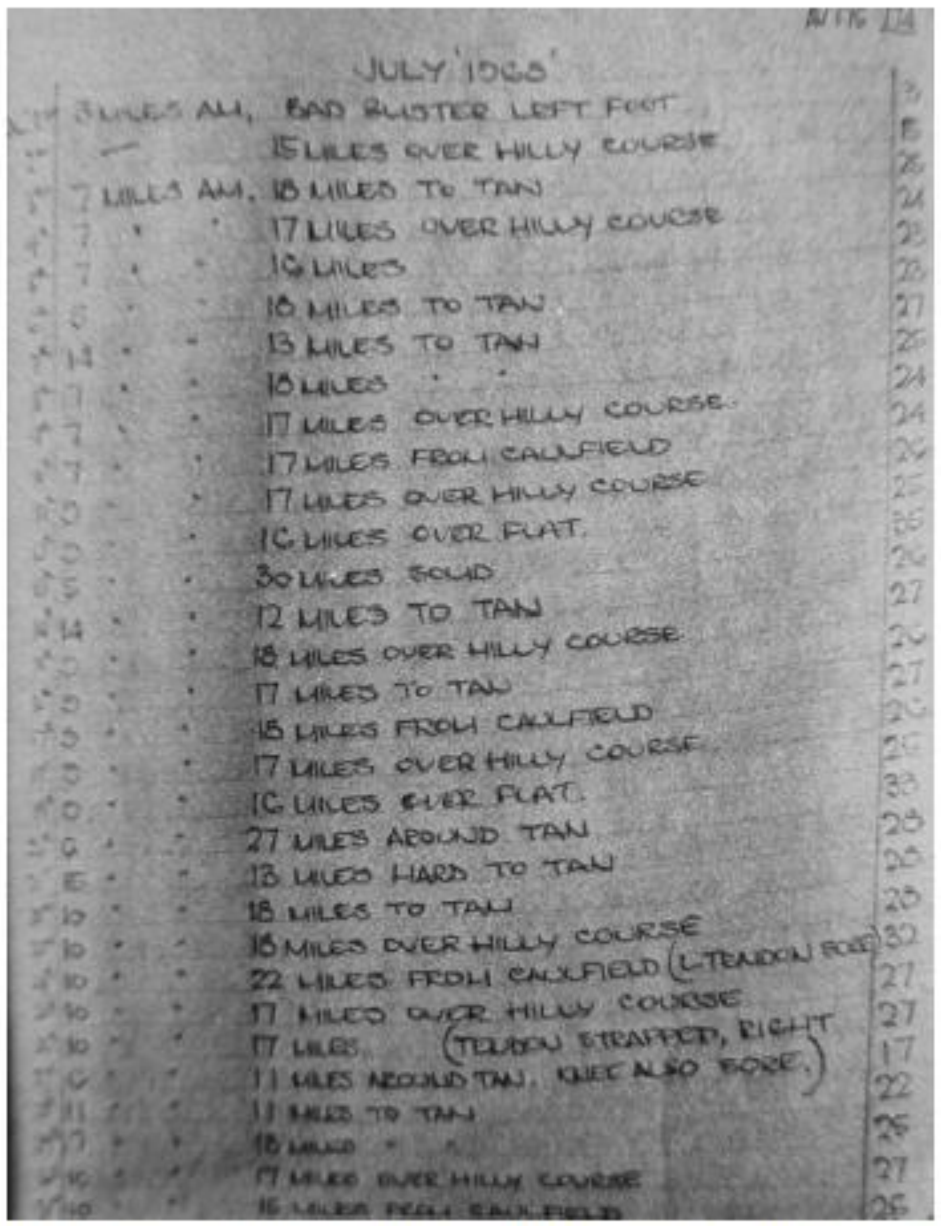

Figure 1. Example of the training diary of DC from 1965. The *left* column describes a daily morning run between 3 and 14 miles, the *central* column describes the nature and distance of the main training session for the day while the column on the *right* summarizes the total daily mileage (up to 35 miles, 57 km, in a single day).

This life study of a world champion marathon runner exemplifies the substantial benefits and potential side effects of many decades of intense endurance exercise. At an advanced age, functional capacity can be preserved to approximate that of a young adult but, on the other hand, more extreme cardiac remodeling may predispose to some cardiac arrhythmias. The "pros and cons" of endurance exercise are encapsulated in an extraordinary life and a holistic conclusion would note the resultant net benefits in disability, quality of life, and expected longevity.

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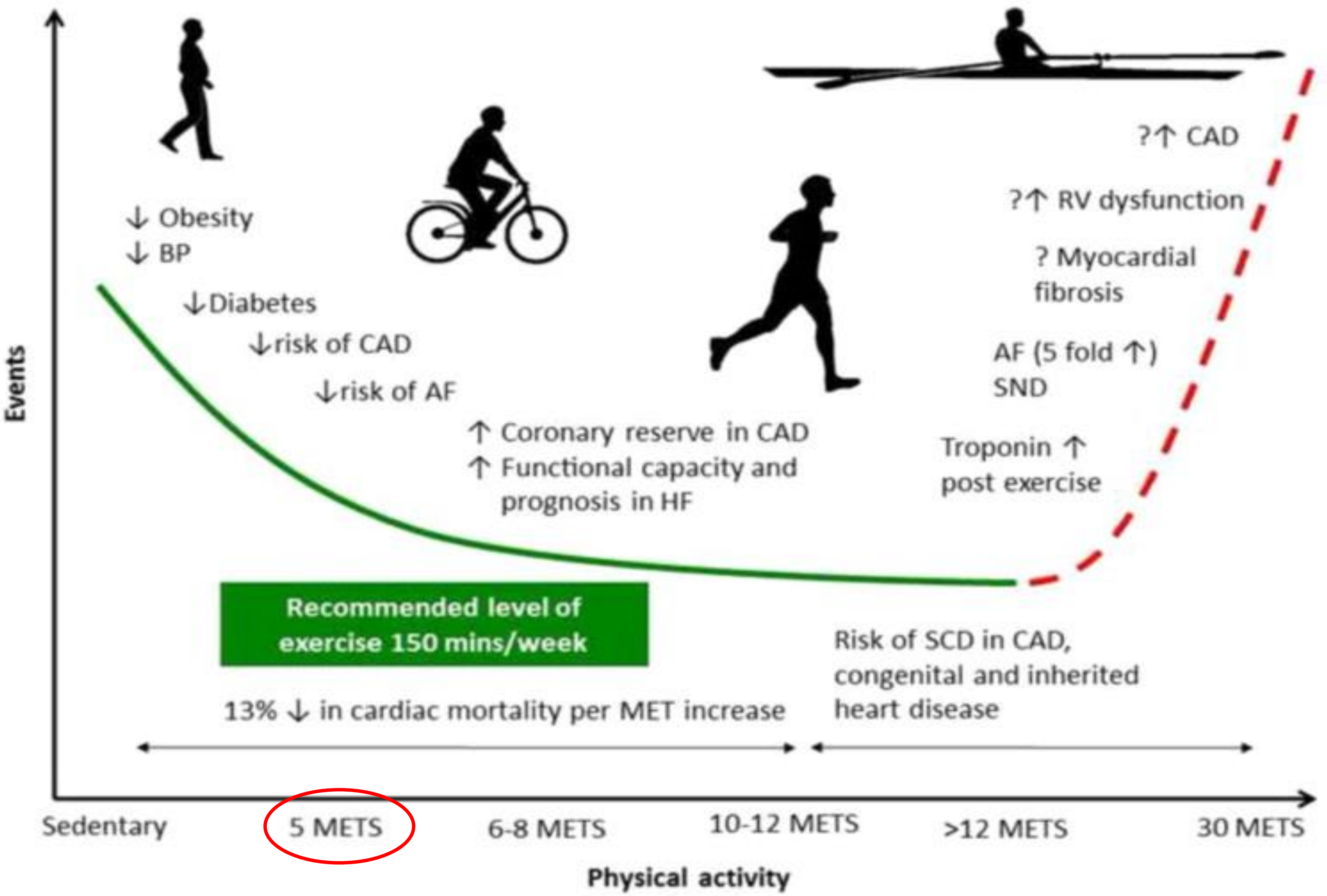
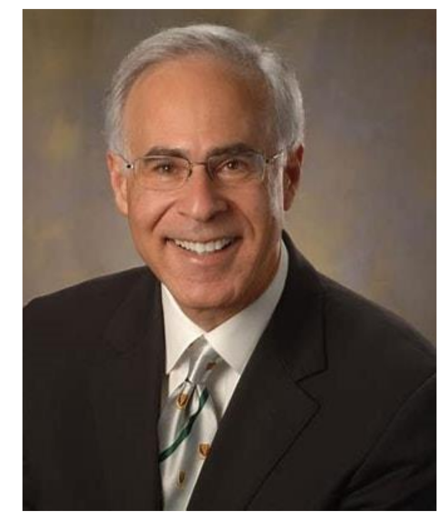
Is There A Recommended Dose Of Exercise For Optimal Health?





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