Palmer, D., Cooper, D., Whittaker, J. L., Emery, C., Batt, M. E., Engebretsen, L., Schamasch, P., Shroff, M., Soligard, T., Steffen, K., Budgett, R. (2022). Prevalence of and factors associated with osteoarthritis and pain in retired Olympians, with comparison to the general population: part 1 - the lower limb. *British Journal of Sports Medicine, 56*(19), 1123-1131. http://dx.doi.org/10.1136/bjsports-2021-104762

Title: Prevalence of and factors associated with osteoarthritis and pain in retired Olympians, with comparison to the general population: part one – the lower limb.

Debbie Palmer,[1,2] Dale Cooper,[3] Jackie L Whittaker,[4,5] Carolyn Emery,[6] Mark Batt,[7,8] Lars Engebretsen,[9,10] Patrick Schamasch,[11] Malav Shroff,[11] Torbjørn Soligard,[10] Kathrin Steffen,[9] Richard Budgett[10]

Affiliations

1. Edinburgh Sports Medicine Research Network, Institute for Sport, PE and Health Sciences, University of Edinburgh, Edinburgh - United Kingdom

2. School of Medicine, University of Nottingham, Nottingham - United Kingdom

3. School of Allied Health Professions, Keele University, Keele - United Kingdom

4. Department of Physical Therapy, Faculty of Medicine, University of British Columbia, Vancouver – Canada

5. Arthritis Research Canada, Richmond – Canada

6. Sport Injury Prevention Research Centre, Faculty of Kinesiology and Departments of Paediatrics and Community Health Sciences, Cumming School of Medicine, University of Calgary, Calgary – Canada

7. Nottingham University Hospitals Trust, Nottingham - United Kingdom

8. Centre for Sport, Exercise and Osteoarthritis Versus Arthritis, Queen's Medical Centre, Nottingham - United Kingdom

9. Department of Sports Medicine, Oslo Sports Trauma Research Center, Norwegian School of Sport Sciences, Oslo - Norway

10. Medical & Scientific Department, International Olympic Committee, Lausanne - Switzerland

11. Medical Committee, World Olympians Association, Lausanne - Switzerland

Key words: pain, osteoarthritis, hip, knee, ankle, injury, retired, Olympians

Correspondence to: Dr Debbie Palmer, Institute for Sport, PE and Health Sciences, Moray House School of Education and Sport, University of Edinburgh, Edinburgh, EH4 1HE.

Contributors: All authors contributed to the study conception and design, data collection and interpretation. DP analysed the data and drafted the paper. All authors provided revisions and contributed to the final manuscript. DP is the guarantor.

Funding: The World Olympians Association funded the Retired Olympian Musculoskeletal Health Study (ROMHS) with a research grant from the International Olympic Committee (IOC).

Competing interests: TS works as Scientific Manager in the Medical and Scientific Department of the IOC. LE is Head of Scientific Activities in the Medical and Scientific Depart of the IOC. LE is Editor and KS co-editor of the *British Journal of Sports Medicine – Injury Prevention and Health Protection.* RB is Director of the Medical and Scientific Department of the IOC.

Ethical approval: Ethical approval for the study was obtained from Edinburgh Napier University (UK) ethics committee (SAS/00011)

Provenance and peer review: The study was commissioned by the World Olympians Association; externally peer reviewed

Acknowledgements: We acknowledge the contribution and support of the World Olympians Association administration team throughout the different stages of the study including study promotion and participant recruitment. We would also like to offer thanks to the study survey languages translation checkers, Francis Bougie, Gillian Cameron, Ayako Ito, Toshinobu Kawai, Juwon Kim, Natalia Salmina, Carlos Valiente Palazón, Ivory Wu and Valeriya Yanina. Finally, we would like to sincerely thank all of the Olympians and members of the general population who took the time and effort to complete the survey questions, without whose help this study would not have been possible.

ABSTRACT

Objectives

1) To determine the prevalence of lower limb osteoarthritis (OA) and pain in retired Olympians; 2) identify factors associated with their occurrence; and 3) compare with a sample of the general population.

Methods

3357 retired Olympians (median 44.7 yrs) and 1735 general population controls (40.5 yrs) completed a cross-sectional survey. The survey captured demographics, general health, self-reported physician-diagnosed OA, current joint/region pain and injury history (lasting >1 month). Adjusted odds ratio (aOR) compared retired Olympians with the general population.

Results

The prevalence of (any joint) OA in retired Olympians was 23.2% with the knee most affected (7.4%). Injury was associated with increased odds (aOR, 95% CI) of OA and pain in retired Olympians at the knee (OA = 9.40, 6.90 to 12.79; pain = 7.32, 5.77 to 9.28), hip (OA = 14.30, 8.25 to 24.79; pain = 9.76, 6.39 to 14.93) and ankle (OA = 9.90, 5.05 to 19.41; pain = 5.99, 3.84 to 9.34). Increasing age and obesity were also associated with knee OA and pain. While the odds of OA did not differ between Olympians and the general population, Olympians with prior knee and prior hip injury were more likely than controls with prior injury to experience knee (1.51, 1.03 to 2.21 (Olympians 22.0% vs controls 14.5%)) and hip OA (4.03, 1.10 to 14.85 (Olympians 19.1% vs Controls 11.5%,)), respectively.

Conclusions

One in four retired Olympians reported physician-diagnosed OA, with injury associated with knee, hip and ankle OA and pain. Although overall OA odds did not differ, after adjustment for recognised risk factors Olympians were more likely to have knee and hip OA after injury than the general population, suggesting injury is an occupational risk factor for retired Olympians.

What is already known on this topic

Elite sport participation can lead to an increased risk of injury, and there is emerging evidence from retired athlete studies of an association between injury, on-going pain and osteoarthritis.

What this study adds

One in four retired Olympians reported physician-diagnosed OA, and injury was associated with an increased risk of OA and pain at the knee, hip and ankle. The odds of knee and hip OA after prior injury were significantly greater for Olympians compared with the general population.

How this study might affect research, practice or policy

Primary injury prevention should be a continued focus for elite athlete medical and coaching teams with particular focus on the prevention of significant knee and hip injuries. Approaches to athlete injuries should ensure full and complete rehabilitation of injuries, with a biopsychosocial approach and discussion of long-term risks to inform athlete behaviours during and after injury.

INTRODUCTION

Elite sport participation can lead to an increased risk of injury, with injuries to the knee, lumbar spine, shoulder and ankle reported to be most frequent and also amongst the most severe in Olympic athletes.[1-4] Even after acute symptoms have resolved athletes frequently report ongoing pain and dysfunction for years after an initial injury.[4]

Significant joint injury is a risk factor for future osteoarthritis (OA), and there is an emerging body of evidence in retired athletes from football (soccer),[5-7] Rugby Union,[8] and from Olympic sports [9-11] reporting an association between joint injury and ongoing pain, and the development and progression of OA. In order to truly understand the magnitude of the problem it is important to understand if and how Olympians differ compared with the general population.[12] To date, few retired-athlete studies have included these comparisons, and where comparisons to a general population control are made, they are limited to a single sex, specific sport or geographical region.[5,7-10]

In addition, many studies focus on isolated body joints such as the hip or knee,[7,10,11] however the natural history of OA varies, with factors contributing to disease occurrence and progression appearing to be joint specific.[13-17] For example, around 8% of hip and 12% of knee OA are reported to be post-traumatic (due to injury),[13,15] compared with almost 80% for ankle OA.[18,19] Hip OA has been shown to progress more rapidly in men than in women but with no gender effect observed on progression of knee OA.[20,21] Hence, it is important that we understand the joint-specific response to different stimuli including injury, across multiple body sites. Therefore, we aimed to 1) determine the prevalence of lower limb self-reported physician-diagnosed OA and pain in retired Olympians, 2) identify factors associated with lower limb OA and pain in retired Olympians and 3) make comparisons with a sample of the general population. A similar detailed study describing the factors associated with spine and upper limb OA and pain are reported separately in part 2.

METHODS

This cross-sectional study collected self-report data from retired Olympians and general population controls using an online questionnaire available in eight languages (English, French, German, Spanish, Russian, Chinese, Japanese and Korean). Data collection was conducted between April 2018 and June 2019. Retired Olympians were those who had competed in at least one summer and/or winter Olympic Games, who were aged 16 years of age or older, and considered themselves retired from Olympic level training and competition. General population controls in the present study were any individuals who had not competed at a summer and/or winter Olympic Games, who were 16 years of age or older.

Recruitment

The survey was promoted to retired Olympians Globally through World Olympians Association (WOA) and International Olympic Committee (IOC) communication platforms. Those wishing to participate were asked to register with the WOA OLY database. A survey link was then emailed to all Olympians on the database. Additionally, the WOA engaged with

National Olympians Associations (NOA) who direct emailed the survey to their countries Olympians.[4] The researchers are unaware how many Olympians NOA promotions reached, it is also unknown how many of the 14,300 Olympians on the OLY database were active and how many were retired, hence it is not possible to calculate a retired Olympian response rate. The general population control group recruitment was conducted in three phases: 1) through study promotion globally through WOA and IOC communication platforms; 2) by members of the research group through their own academic and industry organisations and their local regional public leisure, medical and community centres (the latter via posters), and 3) using Olympian 'buddies' where at the end of their survey Olympians were asked to recruit a non-Olympian friend.

Detailed study information, including information on data handling and confidentiality, was provided at the start of the survey. We explicitly outlined that by completing and submitting the questionnaire, participants were consenting to their information being used anonymously for the study.

Questionnaire survey

The questionnaire was an online web-based survey hosted by SurveyMonkey. The Olympian survey was password protected while the general population survey open.[4] The survey contained four main sections: (1) baseline demographics, (2) sport participation and self-reported injury history details, (3) self-reported current musculoskeletal health, and (4) current general health, and quality of life.

Baseline questions requested demographics including age (years), sex, country of residence, and current height (cm) and weight (kg) which were used to calculate body mass index (BMI kg/m^2). Injury history questions asked participants to recall all significant injuries (lasting $\geq$1 month) occurring at any time during sport, exercise, or other activities, including the injury anatomical location, mechanism (e.g. recurrence) and treatment. Significant 'injury' was defined as 'any injury causing significant pain and/or dysfunction for a period of 1 month (or more)'.[4]

The questionnaire captured information on participants current musculoskeletal health. The presence of joint pain was established using a validated question 'Do you currently experience pain, for most days of the last month, in this joint',[22] which was also modified to record joint stiffness. Self-reported physician-diagnosed osteoarthritis (OA) was ascertained by asking 'Have you ever been diagnosed with OA in any of your joints by a medical professional. If yes, please complete details by joint'.[11] History of joint surgery including type of surgery e.g. joint replacement, was also recorded. Constitutional (in their 20s – if aged over 30) and current knee alignment were assessed using a validated drawing,[22] and classified as either normal, varus or valgus (mild and severe combined). The presence of nodal OA was determined using a validated diagram.[23] Nodal OA was present if finger nodes were reported in at least 2 rays of both hands. Additional questions on general health asked about the presence of co-morbidities e.g. heart disease or diabetes.

Patient and public involvement

A patient advisory group of nine retired Olympians provided input in the face validation of the questionnaire content and design, focusing on question understanding and clarity and overall questionnaire length and acceptability. Comments from the patient advisory group were incorporated into the final version of the survey.

Ethics and confidentiality

Ethical approval for the study was obtained from the Edinburgh Napier University ethics committee (SAS/00011). No identifying parameters were recorded, and individuals were not identifiable at any stage of the research. All data were treated confidentially, ensuring participant anonymity at all times.

Statistical analysis

Descriptive statistics were presented as frequencies (proportion) for categorical variable, and mean and SD for continuous variables. Prevalence was calculated dividing the number of participants with the outcome of interest by the total number of participants and presented as percentage (%) with 95% CIs. To determine if distributions of variables were statistically different between Olympians and the general population continuous variables were analysed by independent t-tests, or Mann-Whitney, and categorical variables by the $\chi 2$ test as appropriate. Significance was accepted at $p<0.05$. The prevalence of the primary outcome variables OA and pain were calculated for each lower limb joint (hip, knee, ankle). If bilateral, the most severe joint was selected as the index joint for analysis. Logistic regression was used to estimate odd ratios (with 95% CI) of each primary outcome for each independent variable, adjusted (aOR) in a multivariable model for a priori age, BMI, sex and injury, for Olympians. A separate model was used to assess putative risk factors for each primary outcome comparing Olympians versus general population controls followed by stage adjustment for age, BMI, sex; and age, BMI, sex and injury. Independent variables with fewer than 5 events per variable were excluded.[25,26] Age and BMI were non-linear and so were categorised according to previous research.[7,11,22] Significant injuries were matched according to the index joint and included if they preceded OA diagnosis or episode of pain in that joint. Where there was co-linearity (e.g. adjusted ORs for OA associated with injury) variables were removed. Imputation was not undertaken for occasional missing values. Analysis was conducted using Stata IC v16.

A power calculation was conducted based on an estimated prevalence of 7% knee OA in a similar aged general population (median 45 yrs).[27] With a 2:1 ratio of exposed (Olympians) and unexposed (general population), this study had at least 80% power at 0.05 to detect an odds ratio of 1.32 or greater based on a total sample of 5062 (calculation conducted using GPower v3.1.9.7).[7,11]

RESULTS

Descriptive characteristics

At the close of the survey there were 4,745 Olympian and 2,462 general population entries. 1,388 Olympian and 727 general population ineligible (i.e., blank, incomplete, duplicate) entries were removed leaving 3,357 Olympian (from 131 countries) and 1,735 general population (73 countries) completed questionnaires for data analysis.

The median age of Olympians was 44.7 yrs (range 16 to 97) with 45% female (and 55% male) while the comparison general population controls were aged 40.5 yrs (range 16 to 88) with 58% female (and 42% male) (Table 1). Retired Olympians reported a higher prevalence of injury (68.5% *vs* 60.5%), recurrent injury (41.5% *vs* 30.7%), and OA (in any joint) (23.2% *vs* 15.7%) and pain (41.3% *vs* 37.8%) compared with the general population.

Table 1. Anthropometric, injury, joint health and constitutional factors for Olympians and general population controls.

	Olympians n=3357	Controls n=1735	p value
Anthropometrics			
Female/male, n (%)	1488/1840 (45%/55%)	998/723 (58/42%)	<0.001
Age (years), median (range)	44.7 (16 to 97)	40.5 (16-88)	<0.001
Height (cm), mean (SD)	174.1 (11.9)	171.4 (11.1)	<0.001
Weight (kgs), mean (SD)	78.2 (18.0)	75.1 (16.8)	<0.001
BMI (kg/m2), mean (SD)	25.7 (5.4)	25.7 (6.3)	0.937
Right hand dominance, n (%)	2933 (87.6)	1499 (86.5)	0.272
Right lower limb dominance, n (%)	494 (75.2)	1320 (76.6)	0.272
Injury (any injury)			
Injury prevalence, n (%)	2300 (68.5)	1050 (60.5)	<0.001
Total injuries , n (per individual)	4761 (1.42)	2041 (1.18)	<0.001
Recurrent injury, n (%)	1393 (41.5)	533 (30.7)	<0.001
Joint injection, n (%)	752/2875 (26.1)	175/1547 (11.3)	<0.001
Joint health			
Physician-diagnosed OA (at any joint), n (%)	599/2587 (23.2)	217/1380 (15.7)	<0.001
Current pain (any joint) $\geq$1 month, n (%)	1422 (41.3)	655 (37.8)	0.002
Current stiffness (any joint) $\geq$1month, n (%)	1720 (51.2)	777 (44.8)	<0.001
Current painkiller use, n (%)	521 (15.5)	223 (12.8)	0.011
Joint surgery, n (%)	764/2844 (26.9)	284/1484 (19.1)	<0.001
Knee arthroplasty, n (%)	48 (1.43)	8 (0.46)	0.002
Hip arthroplasty, n (%)	54 (1.61)	25 (1.44)	0.646
Constitutional			
Constitutional knee malalignment, n (%)	333/2537 (13.1)	128/1187 (10.8)	0.019
Current knee malalignment, n (%)	404/2749 (14.7)	174/1446 (12.0)	<0.001
Finger nodes, n (%)	198 (5.9)	59 (3.4)	<0.001
Comorbidities, n (%)	978 (29.1)	472 (27.2)	0.352
Family history of OA, n (%)	417 (12.4)	335 (19.3)	<0.001

(BMI = body mass index. Joint injection included any injection into an injured body joint as treatment for the injury e.g. steroid, painkiller. Pain or stiffness (any joint) reported for most days of the last month. Knee malalignment = varus and valgus combined)

Prevalence of OA by body joint/region

The prevalence of self-reported physician-diagnosed OA was highest for the knee (Olympians 7.4% vs controls 5.5%; p=0.011), followed by the lumbar spine (5.7% vs 3.8%; p=0.004), hip (3.3% vs 2.1%; p=0.011), shoulder (2.4% vs 1.3%; p=0.008) and cervical spine (2.3% vs 1.4%; p=0.04) but similar for the ankle (1.1% vs 1.1%; p=0.982) (Figure 1). Among the most common sites for OA data from this point forwards are presented for the lower limb.

insert figure 1

Lower limb OA in Olympians

Table 2 presents the prevalence and adjusted odds for factors associated with self-reported knee, hip and ankle OA in Olympians. The odds of OA were associated with increasing age at the knee (40-59 yrs aOR 2.44 (95% CI 1.66 to 3.60) and ≥60 yrs aOR 5.67 (95% CI 3.66 to 8.79) and hip (40-59 yrs aOR 2.41 (95% CI 1.35 to 4.32) and ≥60 yrs aOR 6.75 (95% CI 3.64 to 12.53)). Female sex (aOR 1.88 (95% CI 1.37 to 2.58)) and obesity (aOR 1.67 (95% CI 1.05 to 2.63)) were also associated with greater odds of knee OA. Prior knee injury was significantly associated with greater odds of knee OA (aOR 9.40 (95% CI 6.90 to 12.79)), and the same was observed for prior hip injury and hip OA, and for the ankle. Recurrent knee injury was also associated with knee OA (aOR 2.40 (95% CI 1.63 to 3.53)). Factors associated with knee, hip and ankle OA in the general population are presented in online supplementary appendix 1, 2 and 3, respectively.

Table 2. Factors associated with lower limb OA in Olympians.

	Knee OA		Hip OA		Ankle OA	
	Prevalence n (%)	aOR (95% CI) adjusted a, s, b, i	Prevalence n (%)	aOR (95% CI) adjusted a, s, b, i	Prevalence n (%)	aOR (95% CI) adjusted a, s, b, i
Age						
20-39	40/1194 (3.35)	1.00 (reference)	19/1194 (1.59)	1.00 (reference)	11/1194 (0.92)	1.00 (reference)
40-59	114/1359 (8.39)	**2.44 (1.66 to 3.60)**	42/1359 (3.09)	**2.41 (1.35 to 4.32)**	16/1359 (1.18)	1.32 (0.60 to 2.91)
≥60	78/580 (13.45)	**5.67 (3.66 to 8.79)**	42/580 (7.24)	**6.75 (3.64 to 12.53)**	9/580 (1.55)	2.18 (0.86 to 5.50)
Sex						
male	113/1840 (6.14)	1.00 (reference)	62/1840 (3.37)	1.00 (reference)	19/1840 (1.03)	1.00 (reference)
female	133/1488 (8.94)	**1.88 (1.37 to 2.58)**	49/1488 (3.29)	0.78 (0.50 to 1.24)	18/1488 (1.21)	1.34 (0.66 to 2.72)
BMI						
normal	112/1774 (6.31)	1.00 (reference)	51/1774 (2.87)	1.00 (reference)	16/1774 (0.90)	1.00 (reference)
overweight	84/1063 (7.90)	1.23 (0.87 to 1.73)	41/1063 (3.86)	1.33 (0.83 to 2.13)	15/1063 (1.41)	1.99 (0.91 to 4.34)
obese	36/342 (10.53)	**1.67 (1.05 to 2.63)**	14/342 (4.09)	1.34 (0.69 to 2.60)	4/342 (1.17)	-
Injury						
no	83/2613 (3.18)	1.00 (reference)	86/3221 (2.67)	1.00 (reference)	20/3070 (0.65)	1.00 (reference)
yes	164/744 (22.04)	**9.40 (6.90 to 12.79)**	26/136 (19.12)	**14.30 (8.25 to 24.79)**	17/287 (5.92)	**9.90 (5.05 to 19.41)**
Recurrent injury	80/236 (33.90)	**2.40 (1.63 to 3.53)**	19/72 (26.39)	1.14 (0.44 to 2.95)	12/119 (10.08)	2.24 (0.80 to 6.26)
Finger nodes	35/198 (17.68)	**1.83 (1.13 to 2.95)**	9/198 (4.55)	1.02 (0.43 to 2.42)	3/198 (1.51)	-
Comorbidities						
none	120/2379 (5.04)	1.00 (reference)	43/2379 (1.81)	1.00 (reference)	15/2379 (0.63)	1.00 (reference)
1	75/696 (10.78)	1.79 (1.27 to 2.51)	39/696 (5.60)	2.87 (1.75 to 4.70)	15/696 (2.16)	**2.93 (1.40 to 6.17)**
2 or more	52/282 (18.44)	**2.71 (1.75 to 4.19)**	30/282 (10.64)	**5.18 (2.96 to 9.09)**	7/282 (2.48)	2.71 (0.97 to 7.52)
Knee alignment						
normal	184/2345 (7.85)	1.00 (reference)				
valgus	24/131 (18.32)	**2.65 (1.51 to 4.64)**				
varus	31/273 (11.36)	1.30 (0.82 to 2.08)				

(Values are presented as count (n) and prevalence (%). aOR adjusted a, s, b, I = odds ratio adjusted for covariates age, sex, BMI and injury. BMI = body mass index. Bold denotes statistical significance. – analysis not performed due to small number of events (<5))

Lower limb pain in Olympians

Table 3 presents the prevalence of and adjusted odd ratios for factors associated with self-reported pain at the knee, hip and ankle in Olympians. Pain was associated with increasing age for the knee (>60 yrs aOR 1.99 (95% CI 1.41 to 2.80)) and hip (aOR 1.78 (95% CI 1.13 to 2.82)). For the ankle the odds of pain did not change by age. Overweight (aOR 1.48 (95% CI 1.12 to 1.95)) and obesity (aOR 2.34 (95% CI 1.63 to 3.37)) were associated with increased odds of pain at the knee. Prior knee injury was significantly associated with knee pain (aOR 7.32 (95% CI 5.77 to 9.28)), and the same was observed for the hip and ankle. Recurrent knee injury and recurrent ankle injury were also associated with greater odds of pain at the knee (2.33 aOR (95% CI 1.67 to 3.26)) and ankle (3.88 aOR (95% CI 1.75 to 8.61)). The prevalence and odds for factors associated with knee, hip and ankle pain in the general population are presented in online supplementary appendix 4, 5 and 6, respectively.

Table 3. Factors associated with lower limb pain in Olympians.

	Knee pain		Hip pain		Ankle pain	
	Prevalence n (%)	aOR (95% CI) adjusted a, s, b, i	Prevalence n (%)	aOR (95% CI) adjusted a, s, b, i	Prevalence n (%)	aOR (95% CI) adjusted a, s, b, i
Age						
20-39	101/1194 (8.46)	1.00 (reference)	63/1194 (5.28)	1.00 (reference)	41/1194 (3.43)	1.00 (reference)
40-59	185/1359 (13.61)	**1.52 (1.15 to 2.00)**	80/1359 (5.89)	1.36 (0.04 to 1.96)	45/1359 (3.31)	0.90 (0.57 to 1.41)
≥60	85/580 (14.66)	**1.99 (1.41 to 2.80)**	37/580 (6.38)	**1.78 (1.13 to 2.82)**	14/580 (2.41)	0.72 (0.38 to 1.39)
Sex						
male	208/1840 (11.30)	1.00 (reference)	84/1840 (4.57)	1.00 (reference)	57/1840 (3.10)	1.00 (reference)
female	184/1488 (12.37)	1.18 (0.92 to 1.51)	102/1488 (6.85)	**1.65 (1.18 to 2.31)**	47/1488 (3.16)	0.88 (0.57 to 1.36)
BMI						
normal	163/1774 (9.19)	1.00 (reference)	94/1774 (5.3)	1.00 (reference)	50/1774 (2.82)	1.00 (reference)
overweight	142/1063 (13.36)	**1.48 (1.12 to 1.95)**	65/1063 (6.11)	1.34 (0.93 to 1.93)	36/1063 (3.39)	1.28 (0.79 to 2.06)
obese	66/342 (19.30)	**2.34 (1.63 to 3.37)**	19/342 (5.56)	1.26 (0.74 to 2.16)	11/342 (3.22)	1.14 (0.55 to 2.34)
Injury						
no	157/2613 (6.01)	1.00 (reference)	145/3221 (4.50)	1.00 (reference)	69/3070 (2.25)	1.00 (reference)
yes	236/744 (31.72)	**7.32 (5.77 to 9.28)**	42/136 (30.88)	**9.76 (6.39 to 14.93)**	35/287 (12.20)	**5.99 (3.84 to 9.34)**
Recurrent injury	141/343 (41.11)	**2.33 (1.67 to 3.26)**	27/72 (37.5)	1.98 (0.90 to 4.38)	25/119 (21.01)	**3.88 (1.75 to 8.61)**
Finger nodes	43/198 (21.71)	1.38 (0.91 to 2.11)	20/198 (10.10)	**2.30 (1.37 to 3.84)**	12/198 (6.06)	
Comorbidities						
none	227/2379 (9.54)	1.00 (reference)	109/2379 (4.58)	1.00 (reference)	63/2379 (2.65)	1.00 (reference)
1	105/696 (15.09)	**1.35 (1.02 to 1.79)**	55/696 (7.9)	**1.49 (1.03 to 2.15)**	32/696 (4.60)	**1.71 (1.07 to 2.74)**
2 or more	61/282 (21.63)	**1.97 (1.35 to 2.87)**	23/282 (8.16)	**1.71 (1.02 to 2.88)**	9/282 (3.19)	1.28 (0.58 to 2.81)
Knee alignment						
normal	305/2345 (13.00)	1.00 (reference)				
valgus	27/131 (20.61)	1.54 (0.02 to 2.55)				
varus	54/273 (19.78)	1.40 (0.96 to 2.03)				

(Values are presented as count (n) and prevalence (%). aOR adjusted a, s, b, I = odds ratio adjusted for covariates age, sex, BMI and injury. BMI = body mass index. Bold denotes statistical significance.)

Lower limb OA in Olympians versus Controls

Overall, after adjusting for covariates the odds of knee OA (aOR 1.17 (95% CI 0.88 to 1.54) and hip OA (aOR 1.43 (95% CI 0.93 to 2.20) were not significantly different in retired Olympians compared with general population controls (Table 4). However the odds of experiencing knee OA were greater for Olympians compared with the general population after prior knee injury (prevalence 22.0% *vs* 14.5%, aOR 1.51 (95% CI 1.03 to 2.21)) and after recurrent knee injury (30.6% *vs* 17.4%, aOR 1.86 (95% CI 1.06 to 3.26)). The odds of self-reported hip OA after hip injury were also greater for Olympians compared with the general population controls (prevalence 19.1% *vs* 11.5%, aOR 4.03 (95% CI 1.10 to 14.85)). There were no differences observed between Olympians and the general population for ankle OA (online supplementary appendix 7).

Table 4. Odds of lower limb OA for Olympians versus a general population control.

	Knee OA		Olympians *versus* Controls			Hip OA		Olympians *versus* Controls		
	Olympians n (%)	Controls n (%)	OR (95% CI) crude	aOR (95% CI) adjusted a, s, b	aOR (95% CI) adjusted a, s, b, i	Olympians n (%)	Controls n (%)	OR (95% CI) crude	aOR (95% CI) adjusted a, s, b	aOR (95% CI) adjusted a, s, b, i
OA	247 (7.36)	95 (5.48)	**1.37 (1.07 to 1.75)**	**1.33 (1.02 to 1.73)**	1.17 (0.88 to 1.54)	112 (3.34)	36 (2.07)	**1.63 (1.11 to 2.38)**	1.46 (0.96 to 2.23)	1.43 (0.93 to 2.20)
Age										
20-39	40 (3.35)	17 (2.19)	1.38 (0.98 to 2.40)	1.60 (0.90 to 2.86)	1.32 (0.71 to 2.42)	19 (1.59)	3 (0.39)	-	-	-
40-59	114 (8.39)	48 (7.43)	1.14 (0.80 to 1.62)	1.29 (0.89 to 1.87)	1.09 (0.74 to 1.60)	42 (3.09)	11 (1.70)	1.84 (0.94 to 3.60)	**1.97 (1.00 to 3.91)**	1.88 (0.93 to 3.78)
>60	78 (13.45)	26 (12.26)	1.11 (0.69 to 1.79)	1.42 (0.83 to 2.40)	1.29 (0.74 to 2.23)	42 (7.24)	19 (8.96)	0.79 (0.45 to 1.40)	0.77 (0.42 to 1.41)	0.80 (0.43 to 1.48)
Sex										
male	113 (6.14)	33 (4.56)	1.37 (0.92 to 2.04)	1.14 (0.75 to 1.74)	1.11 (0.72 to 1.72)	62 (3.37)	15 (2.07)	1.65 (0.93 to 2.91)	1.37 (0.73 to 2.54)	1.42 (0.75 to 2.69)
female	133 (8.94)	61 (6.11)	**1.51 (1.10 to 2.06)**	**1.56 (1.10 to 2.20)**	1.29 (0.90 to 1.86)	49 (3.29)	20 (2.00)	1.66 (0.98 to 2.82)	1.61 (0.90 to 2.86)	1.55 (0.86 to 2.82)
BMI										
normal	112 (6.31)	38 (3.87)	**1.67 (1.15 to 2.44)**	**1.59 (1.07 to 2.36)**	1.42 (0.95 to 2.15)	51 (2.87)	11 (1.12)	**2.61 (1.35 to 5.03)**	**2.83 (1.32 to 6.06)**	**2.73 (1.26 to 5.88)**
overweight	84 (7.90)	28 (6.13)	1.31 (0.84 to 2.05)	1.37 (0.85 to 2.20)	1.24 (0.75 to 2.03)	41 (3.86)	14 (3.06)	1.27 (0.69 to 2.35)	1.11 (0.58 to 2.12)	0.97 (0.50 to 1.86)
obese	36 (10.53)	22 (11.58)	0.90 (0.51 to 1.58)	0.75 (0.40 to 1.39)	0.59 (0.31 to 1.13)	14 (4.09)	9 (4.74)	0.86 (0.36 to 2.02)	0.64 (0.23 to 1.78)	0.88 (0.29 to 2.71)
Injury	164 (22.04)	50 (14.53)	**1.66 (1.17 to 2.35)**	**1.51 (1.03 to 2.21)**		26 (19.12)	7 (11.48)	1.82 (0.74 to 4.47)	**4.03 (1.10 to 14.85)**	
Recurrent injury	105 (30.61)	21 (17.36)	**2.10 (1.25 to 3.55)**	**1.86 (1.06 to 3.26)**		19 (26.39)	3 (15.00)	-	-	

(Values are presented as count (n) and prevalence (%), with comparisons made between Olympians and controls. Controls are the reference value (1.00). OR adjusted a, s, b = odds ratios adjusted for covariates age, sex and BMI. OR adjusted a, s, b, I = odds ratios are adjusted for age, sex, BMI and injury. Bold denotes statistical significance. – analysis not performed due to small number of events (<5). Comparison between Olympians and controls for the ankle presented in Appendix 7 due to the small number of events in control data)

Lower limb pain in Olympians versus Controls

The odds of knee and hip pain when adjusting for covariates (age, sex and BMI and injury), were not significantly different in retired Olympians in comparison to the general population controls (Table 5). While the prevalence of knee and hip pain associated with injury was higher for Olympians compared with the general population (31.7% vs 24.4% and 30.9% vs 19.7%, respectively) the odds were not significant (Knee aOR 1.34 (95% CI 0.98 to 1.83); Hip aOR 1.63 (95% CI 0.77 to 3.49)). There were no differences observed between Olympians and the general population for ankle pain (online supplementary appendix 8).

Table 5. Odds of lower limb pain for Olympians versus a general population control.

	Knee pain		Olympians *versus* Controls			Hip pain		Olympians *versus* Controls		
	Olympians n (%)	Controls n (%)	OR (95% CI) crude	aOR (95% CI) adjusted a, s, b	aOR (95% CI) adjusted a, s, b, i	Olympians n (%)	Controls n (%)	OR (95% CI) crude	aOR (95% CI) adjusted a, s, b	aOR (95% CI) adjusted a, s, b, i
Pain	393 (11.7)	160 (9.22)	**1.31 (1.08 to 1.58)**	**1.26 (1.02 to 1.55)**	1.17 (0.94 to 1.45)	187 (5.57)	79 (4.55)	1.24 (0.94 to 1.62)	**1.36 (1.02 to 1.81)**	1.28 (0.96 to 1.71)
Age										
20-39	101 (8.46)	63 (8.12)	1.05 (0.75 to 1.45)	1.06 (0.76 to 1.49)	1.06 (0.75 to 1.50)	63 (5.28)	30 (3.87)	1.39 (0.89 to 2.16)	1.50 (0.95 to 2.36)	1.36 (0.85 to 2.16)
40-59	185 (13.61)	66 (10.22)	**1.38 (1.03 to 1.87)**	**1.45 (1.06 to 1.97)**	1.29 (0.93 to 1.78)	80 (5.89)	32 (4.95)	1.20 (0.79 to 1.83)	1.47 (0.94 to 2.29)	1.39 (0.88 to 2.20)
>60	85 (14.66)	25 (11.79)	1.28 (0.80 to 2.07)	1.37 (0.82 to 2.30)	1.25 (0.73 to 2.15)	37 (6.38)	15 (7.08)	0.89 (0.48 to 1.67)	0.97 (0.49 to 1.91)	1.02 (0.51 to 2.04)
Sex										
male	208 (11.30)	72 (9.96)	1.15 (0.77 to 1.36)	1.10 (0.81 to 1.47)	1.10 (0.81 to 1.51)	84 (4.57)	26 (3.6)	1.28 (0.82 to 2.01)	1.30 (0.80 to 2.10)	1.35 (0.83 to 2.21)
female	184 (12.37)	88 (8.82)	**1.46 (1.27 to 2.15)**	**1.45 (1.10 to 1.93)**	1.27 (0.94 to 1.71)	102 (6.85)	52 (5.21)	1.34 (0.95 to 1.89)	1.40 (0.98 to 2.00)	1.27 (0.88 to 1.83)
BMI										
normal	163 (9.19)	70 (7.14)	1.31 (0.98 to 1.76)	1.29 (0.96 to 1.74)	1.22 (0.90 to 1.67)	94 (5.3)	36 (3.67)	1.47 (0.99 to 2.17)	1.47 (0.98 to 2.19)	1.37 (0.91 to 2.06)
overweight	142 (13.36)	56 (12.25)	1.10 (0.79 to 1.54)	1.13 (0.80 to 1.59)	1.04 (0.72 to 1.51)	65 (6.11)	24 (5.25)	1.18 (0.73 to 1.90)	1.25 (0.76 to 2.07)	1.15 (0.70 to 1.91)
obese	66 (19.30)	26 (13.68)	1.51 (0.92 to 2.47)	1.27 (0.75 to 2.15)	1.15 (0.66 to 1.99)	19 (5.56)	11 (5.79)	0.96 (0.45 to 2.06)	1.36 (0.60 to 3.06)	1.46 (0.64 to 3.35)
Injury	236 (31.72)	84 (24.42)	**1.44 (1.08 to 1.92)**	1.34 (0.98 to 1.83)		42 (30.88)	12 (19.67)	1.82 (0.88 to 3.78)	1.63 (0.77 to 3.49)	
Recurrent injury	141 (41.11)	38 (31.4)	1.52 (0.98 to 2.37)	1.41 (0.89 to 2.24)		27 (37.5)	4 (20)	-	-	

(Values are presented as count (n) and prevalence (%), with comparisons made between Olympians and controls. Controls are the reference value (1.00). OR adjusted a, s, b = odds ratios adjusted for covariates age, sex and BMI. OR adjusted a, s, b, I = odds ratios are adjusted for age, sex, BMI and injury. Bold denotes statistical significance. – analysis not performed due to small number of events (<5). Comparison between Olympians and controls for the ankle presented in Appendix 8 due to the small number of events in control data)

DISCUSSION

This is the first worldwide study comparing the factors associated with self-reported lower limb OA and pain in retired Olympians, with comparison to the general population. The main findings were: (1) one in four retired Olympians reported having physician-diagnosed OA in any joint, with the knee, hip, and ankle among the most common sites for OA; (2) injury was associated with increased odds of self-reported OA and pain in the knee, hip, and ankle in Olympians; (3) the odds of lower limb OA and pain did not differ between Olympians and controls; (4) however after significant injury the odds of knee and hip OA were higher for Olympians compared with the general population.

OA and pain

The prevalence of knee OA (7.5%) among our global cohort of retired Olympians was lower compared with previous retired athlete studies in footballers (28%), cricketers (22%) and GB Olympians (14%). The prevalence of hip OA (cricketers 8%, GB Olympians 11%) and ankle OA (cricketers 4.0%) were also lower.[7,11,28] A similar pattern was observed for lower limb pain where knee, hip and ankle pain were lower compared with previous reported rates.[7,11,28] Some of the differences observed are likely influenced by the multisport nature of the current cohort and inclusion of a large proportion of athletes from sports characterised by few contact events and acute traumatic injuries - known risk factors for OA - such as swimming, rowing, sailing and shooting.[4,29] In addition the current cohort was younger (45 yrs) compared to other retired athlete studies (59-64 yrs),[7,11,28] and increasing age is known to be associated with higher rates of pain and OA,[27] a finding also present in our study. OA rates may also be influenced by the instrument of measurement, for example, rates of radiographic established knee OA such as that used by Fernandes et al [7] may be higher than self-reported physician-diagnosed OA due to the discordance between radiographic findings and symptomatic disease.[30]

When comparing Olympians with the general population in the present study the prevalence of OA and pain at the hip and knee were higher, similar to previous retired athlete study findings.[5,7,9,29] However, when adjusting for covariates between the groups there was no difference in the odds of experiencing OA and pain. This is in contrast to findings reported previously in retired footballers who found higher odds of knee pain and OA when compared with the general population.[5,7] For the ankle there was no difference in pain and OA between Olympians and controls in agreement with findings observed for ankle pain and OA in former Greek footballers (versus controls).[31]

Factors associated with lower limb OA

Across the lower limb the odds of self-reported OA in retired Olympians were higher after significant joint injury (lasting one month or more). For example 22% of Olympians in the present study who reported having a significant prior knee injury reported knee OA compared to just 3.1% reporting knee OA with no prior knee injury (aOR 9.40). A similar pattern was also observed for the hip and ankle. Previous retired athlete studies have shown injury is a risk factor for osteoarthritis at the hip, knee [6,7,11,32,33] and ankle [6] and the present study adds weight to this association. Overall, the risk of injury-related OA in the present study is greater than previously reported in retired elite German female footballers (knee aOR 1.32; ankle 1.13),[6] English male professional footballers (knee aOR 2.88),[33] and Great

Britain Olympians (knee aOR 4.40 and hip 1.61).[11] The reasons for the differences observed are unclear, but may be due to geographical and/or sport (type, and single vs multi) related factors,[11,33] and level and intensity of sport participation.[12,34,35] Of concern, the present study cohort were younger than the English footballer and Great Britain Olympian cohorts, and so the magnitude of this injury-related risk may increase further as this population ages.[36,37] Recurrent injury was also associated with greater odds of knee OA in retired Olympians, which supports findings by Parekh et al [33] who identified an injury dose response for radiographic knee OA in ex professional footballers whereby subsequent injuries after the index injury increased the odds of knee OA.[33)

The association between injury and OA in retired Olympians in the present study may be unsurprising given previous injury is also a known risk factor for OA at the knee,[38-40] hip [13,38] and ankle [16,18] in the general population. While the overall odds of lower limb OA did not differ when comparing retired Olympians with the general population in the present study, Olympians were one and a half times more likely to have knee OA after knee injury, and two times more likely to have knee OA after recurrent knee injury. They were also four times more likely to have hip OA after hip injury. Meaning knee and hip injuries, and recurrent knee injuries, in Olympians may have greater consequences with respect to the onset of self-reported OA in those joints, compared with similar injuries occurring in the general population. Few retired athlete studies reporting knee and hip OA have used comparisons with a general population control [7,9,29,34] and none have directly compared the influence of injury on OA between these groups. Fernandes et al [7] reported higher prevalence and odds of knee OA in male retired footballers compared with men in the general population with the authors stating that knee injury was the main attributable risk factor.[7,33]

The nature and intensity of sport participation may influence the frequency and severity of injuries in elite athletes, when compared with the general population, and in the present study the prevalence of significant injury (lasting 30 days or more) was higher for retired Olympians. The type of injury may also be a contributing factor. For example, injuries that directly damage articular cartilage or lead to instability (e.g. ACL injuries) are known to precipitate OA onset and injuries of greater severity known to accelerate the onset and progression of OA;[19,41-44] Knee lesion of meniscus/cartilage and knee ligament rupture injuries were among the most common injuries reported by Olympians in the present study.[4] In addition, athlete behaviours and treatments during injury where there is pressure to return quickly from injury may be influencing outcomes. For example, three quarters of Olympians in the present study indicated that they put pressure on themselves to return to sport, with a quarter continuing all training/competition activities, when experiencing injury.[4] Continuing to compete while injured likely delays recovery,[45] and the higher prevalence of recurrent injury in Olympians compared with the general population, and the greater odds of OA after recurrent injury, may be indicators of poor or incomplete rehabilitation and may also add weight to early findings of an injury-dose response for OA.[33]

Factors associated with lower limb pain

Similar to previous retired athlete studies, the odds of knee (aOR 7.72), hip (aOR9.76) and ankle (aOR 5.99) pain were significantly higher after prior injury in retired Olympians. This also confirms anecdotal findings from the present study where Olympians attributed ongoing pain and functional limitation to sport-related injuries they had sustained.[4] In a comparable study in retired GB Olympians the odds of joint pain were also reported to be higher after joint injury at the knee and hip.[11] Injury was also the strongest risk factor reported for knee pain in retired professional footballers.[7,33] Recurrent knee and ankle injuries in the present study were associated with a 2 and 4 fold increase in knee and ankle pain, respectively, in retired Olympians. Similar to OA, pointing to a potential injury-dose pain response previously reported in retired footballers.[33]

When comparing retired Olympians with the general population in the present study, overall there were no differences observed between the groups for knee, hip or ankle pain. This was similar to findings for lower limb OA in the present study and again in contrast to previous retired athlete studies who report higher rates of lower limb pain in retired athletes versus controls.[5,7,29] While these findings are positive, interpretation should be made with caution. With the comparative young age of the present cohort, it will be important to understand if the magnitude of any current differences between retired Olympians and the controls changes over time.

Clinical implications

To be able to prevent long-term health complaints such as pain and OA in retired athlete populations, it is important to understand the different factors associated with joint specific responses. While some findings within the present study are not significant it does not mean that they are not clinically meaningful. Results from this study indicate that current athlete injury management should allow wherever possible full and complete rehabilitation from significant index injuries athletes sustained during their careers, in particular injuries to the knee and hip. A multidisciplinary approach should include addressing athlete behaviours and treatments during injury, e.g. pressure to return, depression, pain killer use and joint injections.[4] Post-retirement, targeted tertiary prevention strategies should also be employed. Female sex, and overweight and obesity are risk factors for OA; they have been linked to higher rates of knee OA and knee pain in the general population, and knee (and hip) disability in former athletes,[29] and were factors associated with knee pain and OA for Olympians in the present study. Body weight is a potential modifiable risk factor, and numerous studies have shown reductions in BMI attenuate knee pain in patients with obesity and those with both obesity and knee OA.[46,47] Greater weight loss can also precipitate greater reductions in pain.[48] In the present cohort BMI increased significantly from the time Olympians competed to post athletic career.[4] Hence, targeted weight management advice and interventions for those with a prior history of significant knee and/or hip injury, may have the potential to reduce both symptomatic OA and pain in later life.[47]

Strengths and limitations

Previous retired athlete studies have focussed on single sport, joint and sex, with few including comparisons to the general population.[5,7-10] For the first time, the current study presents factors associated with OA and pain across multiple joints of the lower limb in both male and female retired athletes globally, with comparison to the general population. While the present study includes Olympian data across 42 summer and 15 winter Olympic sports as one homogenous group, there is limited understanding of the influence individual Olympic sports may have on these risks.

However, with pain and OA clearly associated with prior injury, and the wealth of previous research reporting the aetiology of injury for different sports,[2-4] it can be anticipated that athletes participating in those sports with known higher prevalence of significant injuries to the knee, hip and ankle, including recurrent injuries, may be at increased risk.

There are several limitations to this study. It is recognised that this cross-sectional study may be limited by recall bias, given the range of ages. To mitigate some recall bias a significant, one month, injury definition was used.[4] Results presented in some categories may be affected by sparse data bias.[49] While the authors were able to include known risk factors for OA and pain there may be unmeasured or unknown confounders influencing these outcomes, hence causal inferences should be made with caution. We cannot provide an accurate survey response rate as it was not possible to know how many retired Olympians study promotion reached.[4] There are an estimated 100000 Olympians worldwide today and around 20000 current Olympians.[2,3,4] Therefore the present sample represents around 4% of the total retired Olympian population and our conclusions are limited to this sample. Finally, it is not clear if the control sample in this study are truly representative of the general population. Given that the control cohort were recruited from WOA and IOC social media, and via 'Olympian buddies' it is not unlikely that this general population group were more interested in sport and consequently more active in sport and exercise than other comparison general population controls. If the current control cohort were more active in sport they may also have reported higher rates of injury, which may explain some of the lack of difference observed between our two groups, when compared to significant differences found in other retired athlete studies.

CONCLUSIONS

In summary, injury was associated with an increased risk of OA and pain in the knee, hip and ankle in retired Olympians. Overall, the odds of OA and pain did not differ between Olympians and controls, however the odds of knee and hip OA after prior injury were significantly higher for Olympians. These findings may be used to inform prevention strategies to reduce the risk of knee, hip and ankle OA and pain in Olympians after retirement from sport.

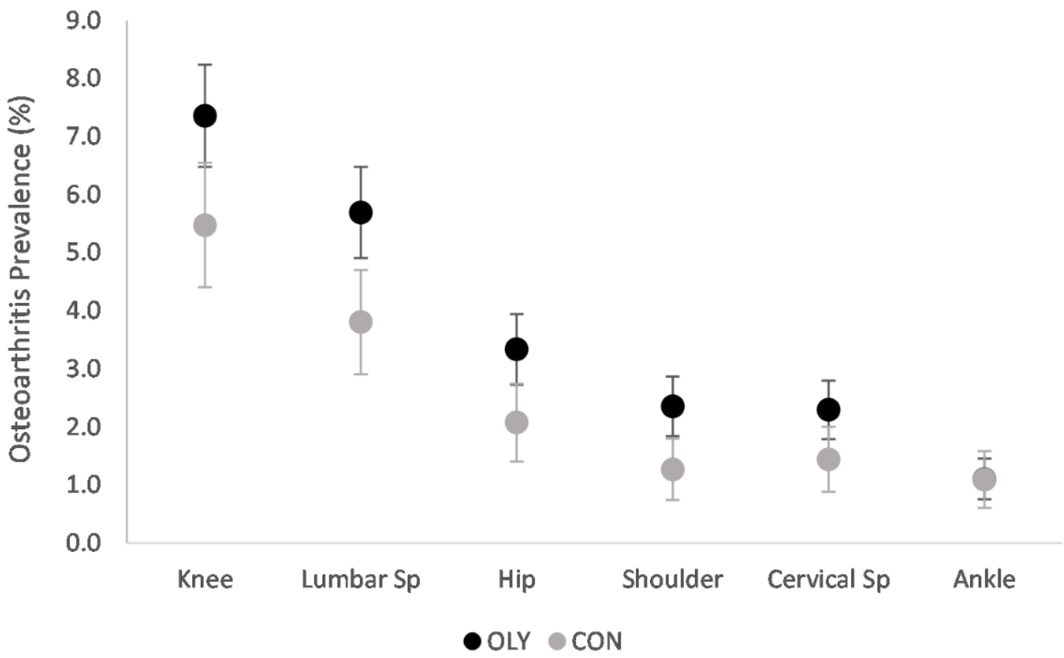

Figure 1. OA prevalence (with 95% CI) by body joint/region for Olympians and general population controls

REFERENCES

[1] Palmer-Green D, Elliott N. Sports Injury and Illness Epidemiology: Great Britain Olympic Team (TeamGB) surveillance during the Sochi 2014 Winter Olympic Games. *Br J Sports Med* 2015;49:25-9.

[2] Soligard T, Steffen K, Palmer D, *et al*. Sports injury and illness incidence in the Rio de Janeiro 2016 Olympic Summer Games: A prospective study of 11274 athletes from 207 countries. *Br J Sports Med* 2017;51(17):1265-71.

[3] Soligard T, Palmer D, Steffen K, *et al*. Sports injury and illness incidence in the PyeongChang 2018 Olympic Winter Games: A prospective study of 2914 athletes from 92 countries. *Br J Sports Med* 2019 2019;53:1085-92.

[4] Palmer D, Cooper DJ, Emery C, *et al* Self-reported sports injuries and later-life health status in 3357 retired Olympians from 131 countries: a cross-sectional survey among those competing in the games between London 1948 and PyeongChang 2018. *Br J Sports Med* 2021;55:46-53.

[5] Arliani GG, Astur DC, Yamada RKF, *et al*. Early osteoarthritis and reduced quality of life after retirement in former professional soccer players. *Clinics* 2014;69(9):589-94.

[6] Prien A, Prinz B, Dvořák J, *et al*. Health problems in former elite female football players: Prevalence and risk factors. *Scand J Med Sci Sports* 2017;27(11):1404-10.

[7] Fernandes GS, Parekh SM, Moses J, *et al*. Prevalence of knee pain, radiographic osteoarthritis and arthroplasty in retired professional footballers compared with men in the general population: A cross-sectional study. *Br J Sports Med* 2018;52(10):678-83.

[8] Brauge D, Delpierre C, Adam P, *et al*. Clinical and radiological cervical spine evaluation in retired professional rugby players. *J Neurosurg-Spine* 2015;23(5):551-7.

[9] Kujala UM, Kaprio J, Sarno S. Osteoarthritis of weight bearing joints of lower limbs in former elite male athletes. *BMJ* 1994; 308 :231 doi:10.1136/bmj.308.6923.231

[10] Tveit M, Rosengren BE, Nilsson J-Å, *et al*. Former Male Elite Athletes Have a Higher Prevalence of Osteoarthritis and Arthroplasty in the Hip and Knee Than Expected. *Am J Sports Med* 2012;40(3):527-33.

[11] Cooper DJ, Scammell BE, Batt ME, *et al*. Factors associated with pain and osteoarthritis at the hip and knee in Great Britain's Olympians: A cross-sectional study. *Br J Sports Med* 2018;52(17):1101-8.

[12] Cooper C, Inskip H, Croft P, *et al*. Individual Risk factors for Hip Osteoarthritis: Obesity, Hip Injury and Physical Activity, *Am Journal Epidemiol* 1998;147(6):516–22.

[13] Tran G, Smith TO, Grice A*, et al.* Does sports participation (including level of performance and previous injury) increase risk of osteoarthritis? A systematic review and meta-analysis. *Br J Sports Med* 2016;50:1459-66.

[14] Arden N, Nevitt MC. Osteoarthritis: epidemiology. Best Practice & Research. *Clin Rheumatol* 2006;20(1):3–25.

[15] Lohmander LS, Englund PM, Dahl LL, *et al*. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med* 2007;35(10):1756-69.

[16] Valderrabano V, Horisberger M, Russell I, *et al*. Etiology of ankle osteoarthritis. *Clin J Orthop Relat Res* 2009;467:1800e6.

[17] Palmer-Green DS, Batt ME, Scammell BE. Simple advice for a simple ankle sprain? The not so benign ankle injury. *Osteoarthr Cartil* 2016;1(6)947-8.

[18] Saltzman CL, Salamon ML, Blanchard GM *et al*. Epidemiology of ankle arthritis: report of a consecutive series of 639 patients from a tertiary orthopaedic center. *Iowa Orthop J* 2005;25:44.

[19] Novakofski KD, Berg LC, Bronzini I, *et al*. Joint-dependent response to impact and implications for post-traumatic osteoarthritis. *Osteoarthr Cartil* 2015;23:1130e7.

[20] Felson DT, Zhang Y, Hannan MT, *et al*. The incidence and natural history of knee osteoarthritis in the elderly, the Framingham osteoarthritis study. *Arthritis Rheum* 1995;38:1500e5.

[21] Dougados M, Gueguen A, Nguyen M, et al. Radiological progression of hip osteoarthritis: definition, risk factors and correlations with clinical status. *Ann Rheumatic* Dis 1996;55:356e62.

[22] Ingham SL, Zhang W, Doherty SA, *et al*. Incident knee pain in the Nottingham community: a 12-year retrospective cohort study. *Osteoarthr Cartil* 2011;19:847–52.

[23] Rees F, Doherty S, Hui M, *et al.* Distribution of finger nodes and their association with underlying radiographic features of osteoarthritis. *Arthritis Care Res* 2012;64:533–8.

[24] Schmidt CO, Kohlmann T. When to use the odds ratio or the relative risk? *Int J Public Health* 2008;53:165-67.

[25] Peduzzi, P. Concato J, Kemper E, *et al*. A simulation study of the number of events per variable in logistic regression analysis. *J Clin Epidemiol* 1996;49(12):1373–9.

[26] van Smeden M, de Groot JA, Moons KG, *et al*. No rationale for 1 variable per 10 events criterion for binary logistic regression analysis. *BMC Med Res Methodol* 2016;16:163.

[27] Grotle M, Hagen KB, Natvig B, *et al*. Prevalence and burden of osteoarthritis: results from a population survey in Norway. *J Rheumatol* 2008;35:677–84.

[28] Cai H, Bullock GS, Sanchez-Santos MT, et al. Joint pain and osteoarthritis in former recreational and elite cricketers. *BMC Musculoskelet Disord* 2019;20:596.

[29] Kettunen JA, Kujala UM, Kaprio J, *et al*. Lower-limb function among former elite male athletes. *Am J Sports Med* 2001;29:2–8.

[30] Bedson J, Croft PR. The discordance between clinical and radiographic knee osteoarthritis: a systematic search and summary of the literature. *BMC Musculoskelet Disord* 2008;9:116.

[31] Armenis E, Pefanis N, Tsiganos G, *et al* Osteoarthritis of the ankle and foot complex in former Greek soccer players. *Foot Ankle Spec* 2011;4:338-43.

[32] Kujala UM, Kettunen J, Paananen H, *et al*. Knee osteoarthritis in former runners, soccer players, weight lifters, and shooters. *Arthritis Rheum* 1995;38:539–46.

[33] Parekh SM, Fernandes GS, Moses JP, *et al*. Risk Factors for Knee Osteoarthritis in Retired Professional Footballers: A Cross-Sectional Study. *Clin J Sport Med* 2021;31(3):281-8.

[34] Spector TD, Harris PA, Hart DJ, *et al*. Risk of osteoarthritis associated with long-term weight-bearing sports: a radiologic survey of the hips and knees in female ex-athletes and population controls. *Arthritis Rheum* 1996;39:988–95.

[35] Lane NE, Oehlert JW, Bloch DA, *et al.* The relationship of running to osteoarthritis of the knee and hip and bone mineral density of the lumbar spine: a 9 year longitudinal study. *J Rheumatol* 1998;25:334–41.

[36] Dagenais S, Garbedian S, Wai EK. Systematic review of the prevalence of radiographic primary hip osteoarthritis. *Clin Orthop Relat Res* 2009;467:623–37.

[37] Blagojevic M, Jinks C, Jeffery A, *et al*. Risk factors for onset of osteoarthritis of the knee in older adults: a systematic review and meta-analysis. *Osteoarthr Cartil* 2010;18:24–33.

[38] Gelber AC, Hochberg MC, Mead LA, *et al*. Joint injury in young adults and risk for subsequent knee and hip osteoarthritis. *Ann Intern Med* 2000;133:321e8.

[39] Yoshimura N, Nishioka S, Kinoshita H, *et al*. Risk factors for knee osteoarthritis in Japanese women: heavy weight, previous joint injuries, and occupational activities. *J Rheumatol* 2004;31:157e62.

[40] Poulsen E, Goncalves GH, Bricca A*, et al.* Knee osteoarthritis risk is increased 4-6 fold after knee injury – a systematic review and meta-analysis. *Br J Sports Med* 2019;53:1454-63.

[41] Englund M, Roos EM, Lohmander LS. Impact of type of meniscal tear on radiographic and symptomatic knee osteoarthritis: a sixteen-year followup of meniscectomy with matched controls. *Arthritis Rheum* 2003;48:2178e87.

[42] Horisberger M, Hintermann B, Valderrabano V. Alterations of plantar pressure distribution in posttraumatic end-stage ankle osteoarthritis. *Clin Biomech* 2009;24:303e7.

[43] Schenker ML, Mauck RL, Ahn J, *et al*. Pathogenesis and prevention of posttraumatic osteoarthritis after intra-articular fracture. *J Am Acad Orthop Surg* 2014;22(1):20–8.

[44] Englund M, Lohmander LS. Risk factors for symptomatic knee osteoarthritis fifteen to twenty-two years after meniscectomy. *Arthritis Rheum* 2004;50:2811e9.

[45] Kujala U, Orava S, Parkkari J, *et al*. Sports career-related musculoskeletal injuries: longterm health effects on former athletes. *Sports Med* 2003;33:869–75.

[46] Vincent HK, Ben-David K, Conrad BP, *et al*. Rapid changes in gait, musculoskeletal pain, and quality of life after bariatric surgery. *Surg Obes Relat Dis.* 2012;8(3):346-54.

[47] Messier SP, Mihalko SL, Legault C, *et al*. Effects of intensive diet and exercise on knee joint loads, inflammation, and clinical outcomes among overweight and obese adults with knee osteoarthritis: the IDEA randomized clinical trial. *JAMA* 2013;310(12):1263-73.

[48] Li JS, Tsai TY, Clancy MM, *et al*. Weight loss changed gait kinematics in individuals with obesity and knee pain. *Gait & Posture* 2019;68:461-65.

[49] Greenland S, Mansournia MA, Altman DG. Sparse data bias: a problem hiding in plain sight. BMJ 2016;352:i1981.