Factors associated with pain and osteoarthritis at the hip and knee in Great Britain's Olympians: a cross-sectional study

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ABSTRACT

Background: Knowledge of epidemiology and potentially modifiable factors associated with musculoskeletal disease is an important first step in injury prevention among elite athletes.

Aim: This study investigated the prevalence and factors associated with pain and osteoarthritis (OA) at the hip and knee in Great Britain's (GB) Olympians aged 40 and older.

Methods: A cross-sectional study. A survey was distributed to 2742 GB Olympians living in 30 countries. Of the 714 (26.0%) who responded, 605 were eligible for the analysis (i.e. aged 40 and older).

Results: The prevalence of hip and knee pain was 22.4% and 26.1%, and hip and knee OA was 11.1% and 14.2%, respectively. Using a multivariable model, injury was associated with OA at the hip (adjusted odds ratio [aOR] 10.85; 95% CI 3.80-30.96), and knee (aOR 4.92; 95% CI 2.58-9.38), and pain at the hip (aOR 5.55; 95% CI 1.83-16.86), and knee (aOR 2.65; 95% CI 1.57-4.46). Widespread pain was associated with pain at the hip (aOR 7.63; 95% CI 1.84-31.72), and knee (aOR 4.77; 95% CI 1.58-14.41). Older age, obesity, knee malalignment, comorbidities, hypermobility, and weight-bearing exercise were associated with hip and knee OA and / or pain.

Conclusions: This study detected an association between several factors and hip and knee pain / OA in retired GB Olympic athletes. These associations require further substantiation in retired athletes from other National Olympic Committees, and through comparison with the general population. Longitudinal follow-up is needed to investigate the factors associated with the onset and progression of OA / pain, and to determine if modulation of such factors can reduce the prevalence of pain and OA in this population.

Keywords: Hip, Knee, Osteoarthritis, Health, Post-Olympic

BACKGROUND

A key priority of the International Olympic Committee (IOC) and its Medical Commission is to protect the health of the athlete in sport.[1] During recent years, the IOC has promoted research to prevent injuries and illnesses in sport by determining injury epidemiology, risk factors, injury mechanisms and interventions to protect the athletes' health. Yet the long-term musculoskeletal health of the athlete has received far less attention. Data from retired athletes is a valuable source of information for a number of reasons. First, it is important to understand the diseases affecting retired athletes in order to determine if there is a need for prevention. Second, data from retired athletes can help to determine if there are modifiable risk factors that can protect the long-term health of athletes.

Musculoskeletal diseases such as pain and osteoarthritis (OA) are likely to adversely impair a retired athlete's quality of life - morbidity associated with knee OA is high,[2] and years lived with disability for knee OA is substantial.[3] Previous studies have found that, compared to the general population, retired male elite athletes are at an increased risk of developing OA.[4-6] However, putative risk factors associated with pain and OA in non-sporting populations remain substantially unexplored in retired elite athletes. Therefore, in view of the responsibility to protect the long-term health of all athletes, it is essential to identify the risk factors that associate with musculoskeletal disease in later life. This study aimed to determine in Great Britain's (GB) Olympians, aged 40 years and older: (1) the prevalence of pain and OA at the hip and knee; and (2) the factors that are associated with pain and OA at the hip and knee.

METHODS
Study design

This study was cross-sectional and involved distributing a survey to collect information on factors potentially associated with pain and OA at the hip and knee as well as demographics, past medical history, drug history, general health and occupational history including participation in sport and physical activity. This study was approved by the Nottingham Research Ethics Committee (Reference No: K13022014). Implied consent to participate was obtained from all participants completing the study questionnaire.

Eligibility criteria and setting

Recruitment took place between May 2014 and April 2015. Initial contact was made by placing an advertisement for the study in the British Olympic Association (BOA) membership magazine. The BOA Athletes' Commission then distributed a letter by post, or email inviting GB Olympians listed on the BOA Olympian database the opportunity to complete and return a paper or web-based version of the questionnaire. One reminder was sent by post to those who did not respond within 4 weeks. Inclusion criteria for participants were male or female, aged 40 years and older and: (1) must have represented Great Britain (GB) at the Summer and / or the Winter Olympic Games; (2) were registered on the BOA Olympian database; and (3) were able to give informed consent.

Data collection and management

The design of the questionnaire was based on two previously published questionnaires[7, 8] and was available in two formats: 1) a paper-based version, and 2) a web-based version hosted by Bristol University Survey. The content and clarity of the questionnaire was reviewed in a Patient Public Involvement (PPI) focus group interview with local

154 residents (N = 6) and the Committee at the BOA Athletes' Commission (N = 14). The
155 questionnaire was assessed as part of two pilot studies at the research institution (N =
156 12). All amendments were returned to the PPI members for verification.
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158 The questionnaire was designed to collect detailed information including age (years),
159 sex, ethnicity, body mass index (BMI, kg/m^2), and putative risk factors associated with
160 pain and OA at the hip and knee. The questionnaire incorporated a validated screening
161 question[7] that was also adapted for hip pain: "have you ever had knee pain for most
162 days of the past one month?" A body manikin was used as a self-report screening
163 instrument to record the location of hip and knee pain and pain in other body regions,
164 using a method shown to be repeatable.[9] Chronic widespread pain was recorded if an
165 individual had greater than or equal to 7 out of 19 regions on the Widespread Pain
166 Index.[10] The presence of OA was determined by asking participants: "have you ever
167 been diagnosed with osteoarthritis in any of your joints by a physician, and if so, please
168 state which joint/s"? The presence of finger nodes and the index-ring finger ratio (2D:
169 4D) were determined using validated diagrams.[11-13] Finger nodes were classified as
170 present in those self-reporting nodal changes on at least 2 rays of both hands. The
171 visual classification of the index to ring finger ratio consisted of classifying each hand
172 according to whether the index finger was visually longer (type 1), equal to (type 2), or
173 shorter than the ring finger (type 3). Joint flexibility was determined by self-examination
174 using line drawings of nine genetically determined sites from the 9-point Beighton
175 score.[14] A cut-off threshold of equal to or greater than 4 out of 9 on the modified
176 Beighton 9-point scoring system was used to denote generalised joint hypermobility
177 (GJH), as recommended by the British Society of Rheumatology.[15] Knee alignment was
178 assessed using a validated line drawing instrument.[16] Knee alignment grades were
179 classified according to: A = severe varus, B = mild varus, C = straight legs, D = mild
180 valgus, and E = severe valgus. Early-life (i.e. during 20s) and current measures of joint
181 flexibility and knee alignment were recorded separately. The questionnaire captured
182 information on comorbidities (i.e. diabetes, cancer, lung disease, stroke, heart disease),
183 previous significant injuries and surgery. Comorbidities were graded into: 1) those who
184 were not reported to be suffering from one or more comorbidities, 2) those suffering from
185 a single comorbidity, and 3) those suffering from two or more. The presence of a
186 significant injury was determined by asking participants: "have you ever sustained a
187 significant injury that caused pain for most days during a one-month period and for
188 which you consulted a medical professional or a health provider such as a general
189 practitioner?" The sporting discipline in which participants competed in at the Olympic
190 Games was categorised into impact sports and non-impact sports, and weight-bearing
191 and non-weight-bearing sports based on published evidence.[4, 17] Where GB Olympians
192 had competed in at least two disciplines at Olympic level, preference was given to the
193 discipline in which the participant had spent the longest time competing.
194
195 **Statistical analysis**
196 Questionnaire data were entered into an Excel file. Data was then cleaned, coded and
197 analysed using SPSS 22.0 (SPSS Inc., Chicago, IL, USA). The prevalence of the
198 primary outcome variables of pain and OA were calculated using the most severe hip or
199 knee joint. Crude odds ratios with 95% confidence intervals were computed using
200 logistic regression to determine the univariate associations between each independent
201 variable and the outcome variables. Age and BMI were non-linear and categorised
202 according to previous research.[8] Significant injuries were included if they were reported
203 to have proceeded the date of diagnosis of OA or episode of pain. All significant factors
204 $p < 0.05$ were entered separately into a second model and adjusted for a priori

205 confounders of age, sex and BMI.[8] A mutually adjusted model was then fitted of the a
206 priori confounders plus any significant factors / variables. A final check was undertaken
207 to refit, one at a time, the independent variables excluded from earlier models.
208 Imputation was not undertaken for the occasional missing values.
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210 **Study power**
211 A power calculation was based on the assumption of approximately 14% and 19%
212 prevalence of hip and knee OA,[4] and 15% and 25% for hip and knee pain.[17, 18] With the
213 assumptions of a 30% response rate from GB Olympians aged 40 years and older,
214 assuming all exposures could at least be dichotomised into binary variables and
215 assuming a ratio of exposed to unexposed individuals of 1:1 for any given factor, the
216 study had power of at least 80% to detect odds ratios of 1.75 and 1.85 or greater for
217 knee pain and knee OA, respectively, at 5% significance. Similarly this applies to hip
218 pain and hip OA for odds ratio 2.0 or greater.
219

220 **RESULTS**
221 **Characteristics of the participants**
222 The overall response rate to the questionnaire was 26.0% (714/2742). Of those who
223 replied to the questionnaire, 605 were equal to or greater than 40 years and had data for
224 the analysis. This represents 32.1% (605/1887) of the cohort on the BOA Olympian
225 database who were aged 40 and older in 2015 (see Figure 1). Of those included in the
226 analysis, the mean age was 63.6 $\pm$ 13.3 years, 59.7% were male (361/605), and 40.3%
227 were female (244/605) (See Table 1). Of the 605 respondents, 60 had competed in 11
228 sports at the Winter Olympic Games: alpine skiing (12), bobsleigh (12), figure skating
229 (10), cross-country skiing (9), luge (4), biathlon (4), short track speed skating (4), speed
230 skating (2), ice hockey (1), skeleton (1), and freestyle skiing (1); and 545 had competed
231 in 25 sporting disciplines at the Summer Olympic Games: athletics (144), rowing (87),
232 swimming (65), hockey (51), canoe (27), cycling (25), fencing (22), gymnastics (20),
233 sailing (18), archery (11), equestrian (11), shooting (10), diving (10), judo (8), boxing (7),
234 weightlifting (7), football (5), wrestling (3), basketball (3), water polo (3), tennis (2),
235 badminton (2), synchronised swimming (2), table tennis (1), and windsurfing (1).
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Table 1: Anthropometry, Lifestyle and Health Factors

	All (n = 605)		Female (n = 244)		Male (n = 361)		
	Mean	SD	Mean	SD	Mean	SD	*P* Value
Anthropometrics:							
Age, years	63.6	13.3	59.0	12.2	66.7	13.1	**<.001**
Height, cm	175.0	10.2	175.5	10.4	175.4	10.2	.91
Weight, kg	75.9	15.3	77.0	16.8	75.1	14.1	.14
Body mass index, kg/m^2	24.8	3.7	23.8	4.0	25.4	3.4	**<.001**
Body mass index in 20s, kg/m^2	22.7	2.9	21.6	2.5	23.4	3.0	**<.001**
Lifestyle factors:							
Age when starting to compete[a], years	19.3	4.2	18.5	4.8	19.7	3.7	**.006**
Age when ceasing to compete[a], years	28.2	6.4	27.5	7.3	28.6	5.8	.08
Duration of competition career[a], years	9.2	5.3	9.2	5.4	9.2	5.2	.96
Duration of retirement period, years	35.2	14.2	31.9	14.1	37.4	13.9	**<.001**
Retired from sport due to injury, %	19.0%	-	23.4%	-	16.1%	-	**.03**
Any current disease, %	65.1%	-	59.8%	-	68.7%	-	**.03**
Any current medication, %	46.3%	-	43.4%	-	48.3%	-	.26
Health factors:							
Physician-diagnosed OA at any joint, %	27.4%	-	25.7%	-	28.6%	-	.50
Pain at any joint (most days of last month), %	65.8%	-	68.9%	-	64.0%	-	.25
Hip arthroplasty, %	7.0%	-	3.8%	-	9.2%	-	**.02**
Knee arthroplasty, %	5.9%	-	3.8%	-	7.3%	-	.11

259 [a] National / International: Data are presented as means with 95% confidence intervals (95% CIs) or as
260 proportions (%). The P values represent comparison between male and female retired athletes, using
261 unpaired t-test or chi-square analysis. Statistically significant differences are highlighted in bold.

Prevalence of pain and osteoarthritis

The prevalence of hip and knee pain was 22.4% (126/563) and 26.1% (147/564), and hip and knee OA was 11.1% (66/597) and 14.2% (85/597), respectively. The results of the multivariable regression models are presented in Tables 2-5.

Factors associated with knee pain and knee osteoarthritis

Knee pain was associated with widespread pain (aOR 4.77; 95% CI 1.58-14.41, p=0.006), obesity (kg/m^2) (aOR 4.34; 95% CI 2.30-8.19, p<0.001), knee injury (aOR 2.65; 95% CI 1.57-4.46, p<0.001), and older age (aOR 1.61; 95% CI 1.02-2.53, p=0.04). There was some evidence that participation in weight-bearing sport (aOR 1.61; 95% CI 1.06-2.44, p=0.027) was associated with knee pain only if adjusted for age, sex and BMI (see Table 2). Knee OA was associated with knee injury (aOR 4.92; 95% CI 2.58-9.38, p<0.001), older age (aOR 3.49; 95% CI 1.71-7.11, p=0.001), early-life (i.e. during 20s) varus knee malalignment (aOR 2.97; 95% CI 1.11-7.94, p=0.03), early-life joint hypermobility (aOR 2.64; 95% CI 1.21-5.78, p=0.015), comorbidities (2 or more) (aOR 2.61; 95% CI 1.23-5.52, p=0.012), and obesity (kg/m^2) (aOR 2.35; 95% CI 1.03-5.38, p=0.042) (see Table 3).

Factors associated with hip pain and hip osteoarthritis

Hip pain was associated with prior injury (aOR 5.55; 95% CI 1.83-16.86, p=0.002), widespread pain (aOR 7.63; 95% CI 1.84-31.72, p = 0.005), participation in weight-bearing sport (aOR 1.66; 95% CI 1.05, 2.63, p=0.032), and comorbidities (aOR 1.84; 95% CI 1.05-3.22, p=0.033) (see Table 4). Hip OA was also associated with prior hip injury (aOR 10.85; 95% CI 3.80-30.96, p<0.001), older age (aOR 2.93; 95% CI 1.48-5.82, p=0.002), and comorbidities (aOR 2.46; 95% CI 1.19-5.06, p=0.015) (see Table 5).

Table 2: Constitutional / biomechanical factors and prevalence of knee pain (n = 564)

Factors	Prevalence (%)	Crude	Adjusted 1	Adjusted 2
		OR (95% Confidence Interval, CI)		
Age (Years)				
40-59	52/237 (21.9)	1	1	1
≥ 60	95/327 (29.1)	1.46 (0.99, 2.15)	1.46 (0.96, 2.23)	**1.61 (1.02, 2.53) ***
BMI (Kg/m^2)				
Normal (<25)	75/336 (22.3)	1	1	1
Overweight (25-<30)	39/169 (23.1)	1.04 (0.67, 1.62)	1.11 (0.70, 1.74)	1.06 (0.65, 1.72)
Obese (≥30)	30/53 (56.6)	**4.54 (2.49, 8.28) ‡**	**4.50 (2.45, 8.25) ‡**	**4.34 (2.30, 8.19) ‡**
Sex				
Male	86/340 (25.3)	1	1	1
Female	61/224 (27.2)	1.11 (0.75, 1.62)	1.27 (0.83, 1.95)	1.38 (0.87, 2.19)
Knee injury				
No	103/456 (22.6)	1	1	1
Yes	34/83 (41.0)	**2.38 (1.46, 3.88) †**	**2.63 (1.58, 4.38) ‡**	**2.65 (1.57, 4.46) ‡**
Knee alignment 20s				
Normal	124/492 (25.2)	1	1	
Varus	15/43 (34.9)	1.59 (0.82, 3.07)	1.63 (0.80, 3.29)	
Valgus	2/12 (16.7)	0.59 (0.13, 2.75)	0.63 (0.13, 3.14)	
Sport: weight-bearing				
No	44/221 (19.9)	1	1	1
Yes	103/343 (30.0)	**1.73 (1.15, 2.58) †**	**1.61 (1.06, 2.44) ***	1.43 (0.92, 2.22)
Hypermobility 20s				
≤ 3/9 Beighton	93/407 (22.9)	1	1	
≥ 4/9 Beighton	22/67 (32.8)	1.65 (0.94, 2.89)	1.71 (0.94, 3.12)	
Comorbidities				
No	42/197 (21.3)	1	1	
1	48/197 (24.4)	1.19 (0.74, 1.91)	1.13 (0.70, 1.85)	
2 or more	57/170 (33.5)	**1.86 (1.17, 2.97) †**	1.54 (0.93, 2.56)	
Index: ring finger ratio				
Index = Ring	33/142 (23.2)	**1**	1	
Index > Ring	15/54 (27.8)	1.27 (0.62, 2.59)	1.60 (0.76, 3.34)	
Index < Ring	93/344 (27.0)	1.22 (0.78, 1.93)	1.23 (0.76, 2.01)	
Finger nodes				
No	136/515 (26.4)	1	1	
Yes	6/37 (16.2)	0.54 (0.22, 1.32)	0.43 (0.17, 1.12)	
Sport: impact				
No	124/461 (26.9)	1	1	
Yes	23/103 (22.3)	0.78 (0.47, 1.30)	0.78 (0.46, 1.34)	
Widespread pain				
No	136/547 (24.9)	1	1	1
Yes	11/17 (64.7)	**5.54 (2.01, 15.26) †**	**4.89 (1.70, 14.03) †**	**4.77 (1.58, 14.41) †**

Adjusted 1: OR was adjusted for a priori confounders of age, sex and BMI; *p<0.05, †p<0.01, ‡p<0.001.
Adjusted 2: A mutually adjusted model was fitted of the a priori confounders plus any significant factors / variables

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Table 3: Constitutional / biomechanical factors and prevalence of knee osteoarthritis (n = 597)

Factors	Prevalence (%)	OR (95% Confidence Interval, CI)		
		Crude	Adjusted 1	Adjusted 2
Age (Years)				
40-59	18/256 (7.0)	1	1	1
≥ 60	67/341 (19.6)	**3.23 (1.87, 5.60) ‡**	**3.08 (1.74, 5.44) ‡**	**3.49 (1.71, 7.11) †**
BMI (Kg/m^2)				
Normal (<25)	46/359 (12.8)	1	1	1
Overweight (25-<30)	22/180 (12.2)	0.95 (0.55, 1.63)	0.96 (0.55, 1.69)	0.90 (0.44, 1.82)
Obese (≥30)	15/53 (28.3)	**2.69 (1.37, 5.27) †**	**2.49 (1.25, 4.95) ***	**2.35 (1.03, 5.38) ***
Sex				
Male	54/356 (15.2)	1	1	1
Female	31/241 (12.9)	0.83 (0.51, 1.33)	1.08 (0.64, 1.81)	1.26 (0.65, 2.44)
Knee injury				
No	53/483 (11.0)	1	1	1
Yes	26/88 (29.5)	**3.40 (1.98, 5.84) ‡**	**4.40 (2.45,7.88) ‡**	**4.92 (2.58, 9.38) ‡**
Knee alignment 20s				
Normal	64/525 (12.2)	1	1	1
Varus	13/43 (30.2)	**3.12 (1.55, 6.29) †**	**3.45 (1.61, 7.36) †**	**2.97 (1.11, 7.94) ***
Valgus	2/12 (16.7)	1.44 (0.31, 6.72)	2.05 (0.40, 10.45)	2.08 (0.39, 11.17)
Sport: weight-bearing				
No	30/232 (12.9)	1	1	
Yes	55/365 (15.1)	1.20 (0.74, 1.93)	1.04 (0.63, 1.72)	
Hypermobility 20s				
≤ 3/9 Beighton	52/435 (12.0)	1	1	1
≥ 4/9 Beighton	15/69 (21.7)	**2.05 (1.08, 3.89) ***	**2.73 (1.36, 5.48) †**	**2.64 (1.21, 5.78) ***
Comorbidities				
No	18/207 (8.7)	1	1	1
1	24/215 (11.2)	1.32 (0.69, 2.51)	1.25 (0.64, 2.43)	1.09 (0.51, 2.35)
2 or more	43/175 (24.6)	**3.42 (1.89, 6.19) ‡**	**2.53 (1.34, 4.78) †**	**2.61 (1.23, 5.52) ***
Index: ring finger ratio				
Index = Ring	21/157 (13.4)	**1**	1	
Index > Ring	7/57 (12.3)	0.91 (0.36, 2.26)	1.22 (0.47, 3.16)	
Index < Ring	51/362 (14.1)	1.06 (0.62, 1.84)	0.92 (0.52, 1.64)	
Finger nodes				
No	73/549 (13.3)	1	1	
Yes	9/39 (23.1)	1.96 (0.89, 4.29)	1.79 (0.78,4.11)	
Sport: impact				
No	64/487 (13.1)	1	1	
Yes	21/110 (19.1)	1.56 (0.91, 2.69)	1.56 (0.87, 2.77)	
Widespread pain				
No	79/549 (14.4)	1	1	
Yes	5/18 (27.8)	2.29 (0.79, 6.60)	2.04 (0.67, 6.21)	

Adjusted 1: OR was adjusted for a priori confounders of age, sex and BMI; *p<0.05, †p<0.01, ‡p<0.001.
Adjusted 2: A mutually adjusted model was fitted of the a priori confounders plus any significant factors / variables

Table 4: Constitutional / biomechanical factors and prevalence of hip pain (n = 563)

Factors	Prevalence (%)	OR (95% Confidence Interval, CI)		
		Crude	Adjusted 1	Adjusted 2
Age (Years)				
40-59	45/237 (19.0)	1	1	1
≥ 60	81/326 (24.8)	1.41 (0.94, 2.13)	1.42 (0.92, 2.18)	1.18 (0.73, 1.90)
BMI (Kg/m^2)				
Normal (<25)	74/335 (22.1)	1	1	1
Overweight (25-<30)	36/169 (21.3)	0.96 (0.61, 1.50)	0.96 (0.61, 1.53)	1.11 (0.68, 1.83)
Obese (≥30)	16/53 (30.2)	1.53 (0.80, 2.90)	1.47 (0.77, 2.80)	1.33 (0.66, 2.68)
Sex				
Male	77/339 (22.7)	1	1	1
Female	49/224 (21.9)	0.95 (0.64, 1.43)	1.06 (0.68, 1.64)	1.10 (0.68, 1.77)
Hip injury				
No	108/523 (20.7)	1	1	1
Yes	9/15 (60.0)	**5.76 (2.01 16.55) †**	**5.65 (1.95, 16.43) †**	**5.55 (1.83, 16.86) †**
Knee alignment 20s				
Normal	108/487 (22.2)	1	1	
Varus	10/43 (23.3)	1.06 (0.51, 2.23)	1.02 (0.48, 2.16)	
Valgus	5/17 (29.4)	1.46 (0.50, 4.24)	1.46 (0.50, 4.27)	
Sport: weight-bearing				
No	37/220 (16.8)	1	1	1
Yes	89/343 (25.9)	**1.73 (1.13, 2.66) ***	**1.71 (1.11, 2.64) ***	**1.66 (1.05, 2.63) ***
Hypermobility 20s				
≤ 3/9 Beighton	96/406 (23.6)	1	1	
≥ 4/9 Beighton	14/67 (20.9)	0.85 (0.45, 1.61)	0.93 (0.48, 1.78)	
Comorbidities				
No	33/197 (16.8)	1	1	1
1	43/196 (21.9)	1.40 (0.84, 2.31)	1.38 (0.83, 2.29)	1.36 (0.79, 2.34)
2 or more	50/170 (29.4)	**2.07 (1.26, 3.41) †**	**1.94 (1.15, 3.28) ***	**1.84 (1.05, 3.22) ***
Index: ring finger ratio				
Index = Ring	27/142 (19.0)	1	1	
Index > Ring	15/54 (27.8)	1.64 (0.79, 3.39)	1.86 (0.88, 3.91)	
Index < Ring	76/343 (22.2)	1.21 (0.74, 1.98)	1.17 (0.71, 1.94)	
Finger nodes				
No	115/514 (22.4)	0.81 (0.35, 1.89)	0.73 (0.31, 1.76)	
Yes	7/37 (18.9)			
Sport: impact				
No	107/460 (23.3)	1	1	
Yes	19/103 (18.4)	0.75 (0.43, 1.28)	0.71 (0.41, 1.25)	
Widespread pain				
No	119/552 (21.6)	1	1	
Yes	7/11 (63.6)	**6.37 (1.83, 22.12) †**	**6.03 (1.71, 21.29) †**	**7.63 (1.84, 31.72) †**

Adjusted 1: OR was adjusted for a priori confounders of age, sex and BMI; *p<0.05, †p<0.01, ‡p<0.001.
Adjusted 2: A mutually adjusted model was fitted of the a priori confounders plus any significant factors / variables

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Table 5: Constitutional / biomechanical factors and prevalence of hip osteoarthritis (n = 597)

Factors	Prevalence (%)	OR (95% Confidence Interval, CI)		
		Crude	Adjusted 1	Adjusted 2
Age (Years)				
40-59	13/256 (5.1)	1	1	1
≥ 60	53/341 (15.5)	**3.44 (1.83, 6.46) ‡**	**3.44 (1.80, 6.57) ‡**	**2.93 (1.48, 5.82) †**
BMI (Kg/m^2)				
Normal (<25)	39/359 (10.9)	1	1	1
Overweight (25-<30)	23/180 (12.8)	1.20 (0.69, 2.08)	1.18 (0.67, 2.09)	1.19 (0.66, 2.17)
Obese (≥30)	4/53 (7.5)	0.67 (0.23, 1.96)	0.58 (0.20, 1.72)	0.48 (0.16, 1.45)
Sex				
Male	45/356 (12.6)	1	1	1
Female	21/241 (8.7)	0.66 (0.38, 1.14)	0.90 (0.51, 1.61)	0.90 (0.49, 1.65)
Hip injury				
No	56/553 (10.1)	1	1	1
Yes	9/18 (50.0)	**8.88 (3.38, 23.28) ‡**	**10.01 (3.61, 27.75) ‡**	**10.85 (3.80, 30.96) ‡**
Knee alignment 20s				
Normal	59/519 (11.4)	1	1	
Varus	4/43 (9.3)	0.80 (0.28, 2.32)	0.74 (0.25, 2.17)	
Valgus	3/17 (17.6)	1.67 (0.47, 5.99)	1.64 (0.45, 6.04)	
Sport: weight-bearing				
No	19/232 (8.2)	1	1	
Yes	47/365 (12.9)	1.66 (0.95, 2.90)	1.61 (0.91, 2.85)	
Hypermobility 20s				
≤ 3/9 Beighton	47/435 (10.8)	1	1	
≥ 4/9 Beighton	6/69 (8.7)	0.79 (0.32, 1.92)	1.01 (0.40, 2.53)	
Comorbidities				
No	15/207 (7.2)	1	1	1
1	19/215 (8.8)	1.24 (0.61, 2.51)	1.11 (0.54, 2.27)	1.37 (0.65, 2.90)
2 or more	32/175 (18.3)	**2.86 (1.50, 5.49) †**	**2.18 (1.10, 4.31) ***	**2.46 (1.19, 5.06) ***
Index: ring finger ratio				
Index = Ring	18/157 (11.5)	1	1	
Index > Ring	6/57 (10.5)	0.91 (0.34, 2.42)	1.14 (0.41, 3.13)	
Index < Ring	38/362 (10.5)	0.91 (0.50, 1.64)	0.70 (0.38, 1.31)	
Finger nodes				
No	61/549 (11.1)	1	1	
Yes	4/39 (10.3)	0.91 (0.31, 2.66)	0.84 (0.28, 2.54)	
Sport: impact				
No	53/487 (10.9)	1	1	
Yes	13/110 (11.8)	1.10 (0.58, 2.09)	1.00 (0.51, 1.95)	
Widespread pain				
No	58/555 (10.5)	1	1	
Yes	2/12 (16.7)	1.71 (0.37, 8.01)	1.80 (0.36, 8.99)	

337   Adjusted 1: OR was adjusted for a priori confounders of age, sex and BMI; *p<0.05, †p<0.01, ‡p<0.001.
338   Adjusted 2: A mutually adjusted model was fitted of the a priori confounders plus any significant factors /
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DISCUSSION

This study investigated the prevalence and factors associated with pain and osteoarthritis (OA) at the hip and knee in Great Britain's (GB) Olympians aged 40 and older. The present study found that: (i) pain at the hip (22.4%; 126/563) and knee (26.1%; 147/564), as well as OA at the hip (11.1%; 66/597) and knee (14.2%; 85/597) are prevalent disorders in GB Olympians aged 40 and older; that (ii) significant injury was associated with hip and knee OA, and pain at the hip and knee; that (iii) bodily pain at other sites (i.e. widespread pain) was associated with hip and knee pain; that (iv) early-life knee malalignment and joint hypermobility (self-report Beighton ≥ 4/9) were not associated with pain and OA, with the exception of knee OA; that (v) retired athletes with two or more comorbidities were more likely to report hip pain, and hip and knee OA; and that (vi) participation in impact (i.e. contact) sport was not associated with pain and OA. It remains unclear if participation in weight-bearing sports is associated with future hip and knee pain or OA.

Comparisons with other studies

The paucity of existing data limits the number of comparisons that can be made with other sporting populations. The present study found the prevalence of knee pain of 26.1% is similar, though slightly higher, than that previously found in non-sporting community populations[19, 21] but lower compared to that found in retired male international athletes who had competed in fewer Olympic sporting disciplines.[5] The present study found a higher prevalence of hip and knee OA of 11.1% and 14.2%, compared to previous observations in community populations.[22, 23] Yet the prevalence of OA at the hip and knee was lower than that found in 709 former internationally or nationally ranked Swedish athletes,[4] and 991 male former athletes who had represented Finland in international competitions,[5] using an identical self-report, physician-diagnosed definition of OA. Direct comparisons with other cohort studies including the general population are problematic, mainly due to different age distribution of the study participants, different case definitions, and variations between studies in how prevalence is calculated.

The present study found a higher prevalence of knee OA, and pain at the hip and knee in GB Olympians aged 60 and older compared to those aged 40-59. Previous studies in the general population confirm that older age is a constitutional risk factor for OA at the hip,[24] and knee,[20, 25-27] as well as knee pain.[28] There was also a significant association between obesity and pain / OA at the knee. This is consistent with findings from previous cohort studies of knee OA,[29, 30] and knee pain.[8, 31] Obesity is commonly believed to affect joints through biomechanical loading, although more recent studies provide evidence of a metabolic inflammatory pathway between BMI and knee OA.[32, 33]

Previous observations in the general population posit injury as a major risk factor for the development of knee OA,[34, 35] and knee pain.[8, 28, 36] The present study confirmed a significant association between injury and hip and knee OA / pain. Meniscal injuries, dislocations, fractures,[37] and anterior cruciate ligament tears[38,39] have all been shown to increase the risk of knee OA. Direct trauma to tissue may disrupt normal joint kinematics and cause altered load distribution within the joint, and this is thought to contribute to the initiation of OA.[37] For the present study, all the knee cartilage injuries sustained in competition or training among GB Olympians occurred during weight-bearing activities.

Long-term weight-bearing sports activity was associated with a twofold-to-threefold increase in the risk of radiographic hip and knee OA in middle-aged ex-elite athletes and

404 a subgroup of the general population who reported long-term sports activity.[17] The
405 present study found an association between participation in weight-bearing sport and hip
406 pain, and knee pain, but only if adjusted for age, sex and BMI. It remains unclear if
407 participation in weight-bearing sports is associated with future hip and knee pain or OA.
408 Furthermore, participation in impact (i.e. contact) sport was not detected to be
409 associated with hip and knee pain or OA. A previous study[4] reported that retired male
410 athletes who participated in impact sports at an elite level had an increased prevalence
411 of self-report, physician-diagnosed knee OA following adjustment for age, BMI, and
412 occupational load. However, this increased risk from participating in impact sports was
413 within a population consisting largely of ex-professional football players, and was driven
414 by an increased risk of joint injury. The present study population included retired athletes
415 from a wide range of sporting disciplines.
416
417 Knee malalignment is thought to contribute to cartilage degeneration through an
418 alteration in the load distribution acting across the articular surfaces of the tibiofemoral
419 joint.[37] A case-control study in 1901 patients found early-life knee malalignment
420 (especially varus) was associated with the later development of knee OA.[40] The same
421 self-reported instrument was also used in a cohort study in 2156 healthy controls and
422 found that early-life self-reported knee varus or valgus malalignment was also a cause of
423 knee pain.[8] Used in this study, the same self-reported instrument confirmed that early-
424 life varus knee malalignment is associated with knee OA in retired elite athletes. This
425 study found no association between knee varus malalignment and knee pain; nor did
426 this study detect an association between valgus malalignment and knee pain or knee
427 OA. These findings are consistent with previous studies that tend to show more positive
428 associations between varus knee malalignment and the development of knee OA in the
429 general population.[40, 41]
430
431 Hypermobile joints are thought to exert greater biomechanical stresses on articular
432 cartilage, and this may increase the risk of OA and pain. Although a correlation between
433 joint hypermobility and OA appears to be possible in community populations,[42-45] there is
434 a lack of evidence to conclude whether joint hypermobility acts as a risk factor or as a
435 protector from the development of pain and OA. In the present cohort, there was no
436 association detected between self-report joint hypermobility in early-life with the various
437 outcomes other than knee OA. Those suffering from two or more comorbidities (i.e.
438 diabetes, cancer, lung disease, stroke, heart disease) were more likely to report hip and
439 knee OA, as well as hip pain. This study did not detect an association between the
440 index: ring finger length (2D: 4D) ratio and knee OA. This was in contrast to a previous
441 study[13] that demonstrated that individuals in the general population with male patterning
442 (i.e. type III – index: finger shorter than ring finger) were at greater risk of knee OA than
443 those with a different finger patterning. This lack of association is possibly due to the
444 present study using a self-report instrument compared to a radiographic measurement
445 used in the previous study to determine the index: ring finger ratio.
446
447 In community populations, bodily pain at other sites (i.e. widespread pain) was
448 associated with knee pain in knee OA.[31, 46] The present study found hip and knee pain to
449 be more prevalent than hip and knee OA, respectively, and that an association existed
450 between widespread pain and pain at the hip and knee. The findings of this study
451 suggest that a subset of GB Olympians may have a chronic widespread pain disorder,
452 and that persistent hip and knee pain in those aged 40 and older is not a surrogate of
453 self-reported physician diagnosed hip and knee OA.
454

Strengths and limitations of this study

The strengths of the present study include a large population sample with a wide age range from both sexes. The analysis represents approximately a third of all GB Olympians aged 40 years and older in 2015. This study used validated patient-reported outcome measures. The findings of the present study concur with previous studies in cohorts of non-sporting elite athletes: studies indicating that age, obesity, and previous joint injury are associated with pain and OA. This study also detected that age, comorbidities, widespread pain, weight-bearing sports, early-life knee malalignment and joint hypermobility were associated with the prevalence of pain and / or OA in retired elite athletes. However, this study did not find any association with participation in an impact sport, length of the index: ring finger ratio, finger nodes, and sex. Thus, this study extends previous findings and contributes to the knowledge of factors associated with pain and OA in retired elite athletes.

This study was not without its limitations. First, the results of this study (e.g. history of injury / OA / joint hypermobility) are subject to potential recall bias. Second, the use of BMI was potentially misleading; triceps-skinfold thickness (peripheral fat) in men and the waist-hip ratio (central fat) in women are demonstrated to be more strongly associated with knee OA than BMI.[47] Furthermore, BMI is unable to discriminate between muscle and adipose tissue, which may be particularly pertinent in a retired elite sporting population, and it cannot directly assess regional adiposity.[48] Third, one should apply caution when assuming that there is a direct causality between factors and the outcome, as other explanations may exist, and this study cannot exclude the possibility of residual confounding. The cross-sectional design is subject to limitations of temporality and future cohort studies can better demonstrate that causes preceded the outcome. Fourth, internal validity was increased through the use of internal controls although this reduced the generalisability of the findings to the general population and retired athletes from other National Olympic Committee as the sports included reflect those Olympic events most pursued by Great Britain. Fifth, despite the strenuous efforts to achieve a high response rate - all GB Olympians on the BOA Olympian database were invited to participate in this study - there is a possibility of recruitment bias. Sixth, the crude odds ratio for hip injury and OA is large and mildly inflated in multivariable analyses and this may reflect sparse-data bias as a result of the small number of cases of hip injury and OA.[49, 50] Penalization was not undertaken as the events per covariate were above five.[49]

Conclusions

This study reports early important work on the long-term musculoskeletal health of retired Olympic athletes. This study detected an association between several factors and hip and knee pain and / or OA in retired GB Olympians. These associations require further substantiation in retired athletes from other National Olympic Committees, and through comparison with the general population. Longitudinal follow-up is needed to investigate the onset and progression of OA / pain, and to determine if modulation of such factors can reduce the prevalence of pain and OA in this population. Strategies to treat one of the mechanisms of pain for all retired athletes may have low efficacy, should the pain in some retired athletes be mediated by other mechanisms. Further research is required to identify the factors associated with different pain mechanisms in non-sporting and sporting populations including retired athletes from other National Olympic Committees.

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What are the new findings?

- Significant joint injury was strongly associated with self-reported hip and knee OA, and hip and knee pain.

- Bodily pain at other sites (i.e. widespread pain) was strongly associated with self-reported hip and knee pain.

- Participation in impact (i.e. contact) sport was not associated with hip and knee pain or OA.

- It remains unclear if participation in weight-bearing sports is associated with future hip and knee pain or OA.

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

- The evidence demonstrates an association between significant joint injury and pain / OA at the hip and knee in retired GB Olympic athletes.

- Further research should focus on the factors for joint injury in different sports.

- This information may help to develop interventions to protect the long-term health of the athlete.

- Medical staff, athletes, coaches, and key stakeholders should seek to integrate injury prevention programmes in daily training to minimise the long-term health risks associated with joint injury.

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744   **Legend**
745   Figure 1. Flowchart describing the number of retired Olympic athletes included in this
746   study from the British Olympic Association database in 2015. Describing those that
747   could not be contacted, the number of surveys distributed, the number of surveys
748   returned, and the number of surveys included in the analysis meeting the inclusion
749   criteria.