# 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 residents (N = 6) and the Committee at the BOA Athletes' Commission (N = 14). The questionnaire was assessed as part of two pilot studies at the research institution (N = 12). All amendments were returned to the PPI members for verification.

The questionnaire was designed to collect detailed information including age (years), sex, ethnicity, body mass index (BMI, $kg/m^2$), and putative risk factors associated with pain and OA at the hip and knee. The questionnaire incorporated a validated screening question[7] that was also adapted for hip pain: "have you ever had knee pain for most days of the past one month?" A body manikin was used as a self-report screening instrument to record the location of hip and knee pain and pain in other body regions, using a method shown to be repeatable.[9] Chronic widespread pain was recorded if an individual had greater than or equal to 7 out of 19 regions on the Widespread Pain Index.[10] The presence of OA was determined by asking participants: "have you ever been diagnosed with osteoarthritis in any of your joints by a physician, and if so, please state which joint/s"? The presence of finger nodes and the index-ring finger ratio (2D: 4D) were determined using validated diagrams.[11-13] Finger nodes were classified as present in those self-reporting nodal changes on at least 2 rays of both hands. The visual classification of the index to ring finger ratio consisted of classifying each hand according to whether the index finger was visually longer (type 1), equal to (type 2), or shorter than the ring finger (type 3). Joint flexibility was determined by self-examination using line drawings of nine genetically determined sites from the 9-point Beighton score.[14] A cut-off threshold of equal to or greater than 4 out of 9 on the modified Beighton 9-point scoring system was used to denote generalised joint hypermobility (GJH), as recommended by the British Society of Rheumatology.[15] Knee alignment was assessed using a validated line drawing instrument.[16] Knee alignment grades were classified according to: A = severe varus, B = mild varus, C = straight legs, D = mild valgus, and E = severe valgus. Early-life (i.e. during 20s) and current measures of joint flexibility and knee alignment were recorded separately. The questionnaire captured information on comorbidities (i.e. diabetes, cancer, lung disease, stroke, heart disease), previous significant injuries and surgery. Comorbidities were graded into: 1) those who were not reported to be suffering from one or more comorbidities, 2) those suffering from a single comorbidity, and 3) those suffering from two or more. The presence of a significant injury was determined by asking participants: "have you ever sustained a significant injury that caused pain for most days during a one-month period and for which you consulted a medical professional or a health provider such as a general practitioner?" The sporting discipline in which participants competed in at the Olympic Games was categorised into impact sports and non-impact sports, and weight-bearing and non-weight-bearing sports based on published evidence.[4, 17] Where GB Olympians had competed in at least two disciplines at Olympic level, preference was given to the discipline in which the participant had spent the longest time competing.

**Statistical analysis**

Questionnaire data were entered into an Excel file. Data was then cleaned, coded and analysed using SPSS 22.0 (SPSS Inc., Chicago, IL, USA). The prevalence of the primary outcome variables of pain and OA were calculated using the most severe hip or knee joint. Crude odds ratios with 95% confidence intervals were computed using logistic regression to determine the univariate associations between each independent variable and the outcome variables. Age and BMI were non-linear and categorised according to previous research.[8] Significant injuries were included if they were reported to have proceeded the date of diagnosis of OA or episode of pain. All significant factors $p < 0.05$ were entered separately into a second model and adjusted for a priori confounders of age, sex and BMI.[8] A mutually adjusted model was then fitted of the a priori confounders plus any significant factors / variables. A final check was undertaken to refit, one at a time, the independent variables excluded from earlier models. Imputation was not undertaken for the occasional missing values.

**Study power**

A power calculation was based on the assumption of approximately 14% and 19% prevalence of hip and knee OA,[4] and 15% and 25% for hip and knee pain.[17, 18] With the assumptions of a 30% response rate from GB Olympians aged 40 years and older, assuming all exposures could at least be dichotomised into binary variables and assuming a ratio of exposed to unexposed individuals of 1:1 for any given factor, the study had power of at least 80% to detect odds ratios of 1.75 and 1.85 or greater for knee pain and knee OA, respectively, at 5% significance. Similarly this applies to hip pain and hip OA for odds ratio 2.0 or greater.

## RESULTS

### Characteristics of the participants

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

Figure 1: insert

**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 |

[a] National / International: Data are presented as means with 95% confidence intervals (95% CIs) or as proportions (%). The P values represent comparison between male and female retired athletes, using 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 (%) | OR (95% Confidence Interval, CI) | | |
|---|---|---|---|---|
| | | Crude | Adjusted 1 | Adjusted 2 |
| 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

**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

**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) | |

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

## 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 a subgroup of the general population who reported long-term sports activity.[17] The present study found an association between participation in weight-bearing sport and hip pain, and knee pain, but only if adjusted for age, sex and BMI. It remains unclear if participation in weight-bearing sports is associated with future hip and knee pain or OA. Furthermore, participation in impact (i.e. contact) sport was not detected to be associated with hip and knee pain or OA. A previous study[4] reported that retired male athletes who participated in impact sports at an elite level had an increased prevalence of self-report, physician-diagnosed knee OA following adjustment for age, BMI, and occupational load. However, this increased risk from participating in impact sports was within a population consisting largely of ex-professional football players, and was driven by an increased risk of joint injury. The present study population included retired athletes from a wide range of sporting disciplines.

Knee malalignment is thought to contribute to cartilage degeneration through an alteration in the load distribution acting across the articular surfaces of the tibiofemoral joint.[37] A case-control study in 1901 patients found early-life knee malalignment (especially varus) was associated with the later development of knee OA.[40] The same self-reported instrument was also used in a cohort study in 2156 healthy controls and found that early-life self-reported knee varus or valgus malalignment was also a cause of knee pain.[8] Used in this study, the same self-reported instrument confirmed that early-life varus knee malalignment is associated with knee OA in retired elite athletes. This study found no association between knee varus malalignment and knee pain; nor did this study detect an association between valgus malalignment and knee pain or knee OA. These findings are consistent with previous studies that tend to show more positive associations between varus knee malalignment and the development of knee OA in the general population.[40, 41]

Hypermobile joints are thought to exert greater biomechanical stresses on articular cartilage, and this may increase the risk of OA and pain. Although a correlation between joint hypermobility and OA appears to be possible in community populations,[42-45] there is a lack of evidence to conclude whether joint hypermobility acts as a risk factor or as a protector from the development of pain and OA. In the present cohort, there was no association detected between self-report joint hypermobility in early-life with the various outcomes other than knee OA. Those suffering from two or more comorbidities (i.e. diabetes, cancer, lung disease, stroke, heart disease) were more likely to report hip and knee OA, as well as hip pain. This study did not detect an association between the index: ring finger length (2D: 4D) ratio and knee OA. This was in contrast to a previous study[13] that demonstrated that individuals in the general population with male patterning (i.e. type III – index: finger shorter than ring finger) were at greater risk of knee OA than those with a different finger patterning. This lack of association is possibly due to the present study using a self-report instrument compared to a radiographic measurement used in the previous study to determine the index: ring finger ratio.

In community populations, bodily pain at other sites (i.e. widespread pain) was associated with knee pain in knee OA.[31, 46] The present study found hip and knee pain to be more prevalent than hip and knee OA, respectively, and that an association existed between widespread pain and pain at the hip and knee. The findings of this study suggest that a subset of GB Olympians may have a chronic widespread pain disorder, and that persistent hip and knee pain in those aged 40 and older is not a surrogate of self-reported physician diagnosed hip and knee OA.

**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.

| What are the new findings? |
| --- |
| • Significant joint injury was strongly associated with self-reported hip and knee OA, and hip and knee pain.<br>• Bodily pain at other sites (i.e. widespread pain) was strongly associated with self-reported hip and knee pain.<br>• Participation in impact (i.e. contact) sport was not associated with hip and knee pain or OA.<br>• It remains unclear if participation in weight-bearing sports is associated with future hip and knee pain or OA. |

| 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.<br>• Further research should focus on the factors for joint injury in different sports.<br>• This information may help to develop interventions to protect the long-term health of the athlete.<br>• 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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## Authors' contributions

DC conceived and designed the study, distributed the survey, collected, analysed and interpreted the data, and drafted the manuscript. BES assisted with the conception of the study and design. BES critically revised the manuscript, and gave final approval of the version to be published. MEB assisted with the conception of the study, and with accessing the study participants. MEB critically revised the manuscript, and gave final approval of the version to be published. DP assisted with the conception of the study and with distribution of the survey. DP critically revised the manuscript, and gave final approval of the version to be published. All authors read and approved the final manuscript.

## Data sharing

An anonymised summary of the dataset generated and analysed during the current study may be available from the corresponding author on reasonable request.

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**Legend**

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